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Fine Water Spray system - extinguishing tests in medium and full scale turbine hood

SINTEF NBL - Norwegian Fire Research Laboratory
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REPORT

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TITLE

Fine Water Spray system - extinguishing tests in medium and full scale turbine hood

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ABSTRACT

This report is based on the results from two test series, called Phase I and Phase II of the project "Halon Replacement by Fine Water Spray Technology - Turbine Hood application". Detailed results are presented in technical reports from Phase I and Phase II.

The tests were carried out in two different scales, one 30 m^3 test enclosure formerly used to characterize different water spray nozzles, and a full scale 70 m^3 model of a turbine hood. The scope of work in Phase I was to identify the extinguishing characteristics of various nozzles developed by BP Sunbury Research Centre, UK, and to verify the efficiency of a total fire suppression system developed by Ginge-Kerr Offshore. The fire suppression system uses a twin-fluid nozzles using air and water at pressures about 5 bar. The nozzles produce a water spray with small droplets and high velocity.

The scope of work of Phase II was to verify the efficiency of the Fine Water Spray nozzles fighting a variety of fire scenarios which may occur in a real turbine hood. A full scale test enclosure containing a mock-up of a turbine heated internally to simulate hot metal surfaces, with insulation mats and piping as in a real turbine hood was constructed in the large test hall of SINTEF NBL. The turbine hood model was built by elements of a Multipurpose Fire Test Rig. Realistic fires with Diesel pool- and spray fires, fires in insulation mats soaked with Diesel oil under different ventilation conditions were ignited in the turbine hood model. Number of Fine Water Spray nozzles, nozzle position and spraying sequences were varied.

A base for design of a Fine Water Spray system for a turbine hood is developed, and several unique features of the performance of a Fine Water Spray fire suppression system have been documented.

KEYWORDS	ENGLISH	NORWEGIAN
GROUP 1	FIRE	BRANN
GROUP 2	EXTINGUISHING	SLOKKING
SELECTED BY AUTHOR(S)	WATER	VANN
	DROPLET SIZE	DRÅPESTØRRELSE

SINTEF

1 INTRODUCTION

SINTEF NBL has carried out three series of tests of a Fine Water Spray fire suppression system intended to be used as a replacement for Halon systems in turbine hoods on offshore platforms operated by British Petroleum Norway.

Phase I of the project was carried out in a 30 m^3 fire test compartment, formerly used to characterize the effect of different water spray nozzles in suppression of gas fires. The scope of work in Phase I was to identify the key characteristics of various nozzles designed, produced and tested by BP Research Centre, Sunbury, UK, and to study the performance of the Fine Water Spray suppressing different fire scenarios. The most suitable nozzle design in addition to water and air requirement for the nozzle, were identified through the tests. Gas fires, liquid spray fires, pool fires and fires of liquid soaked into an insulating mat were produced, and the spray performance was measured by a well instrumented fire compartment. Both well ventilated and poorly ventilated fire situations were tested. The main results of Phase I were a choice of a nozzle type suitable for the turbine hood scenario in Phase II and identification of the most challenging fire scenarios.

Phase II of the project was carried out in a full scale model representing a turbine hood of the Ula platform in the North Sea, with a mock-up of a gas turbine installed. The turbine hood was constructed with realistic geometry including obstacles and a realistic ventilation system. In the tests the turbine mock-up was heated internally up to typical operation temperatures. The total volume of the turbine hood was about 70 m^3. The scope of work in Phase II was to verify the efficiency of fire suppression in realistic fire scenarios using a Fine Water Spray system, and to find an optimum procedure for water application in a fire situation.

A special challenge for the water based fire suppression system used in a turbine hood, is the possibility of damaging the turbine by cooling hot metal parts too rapid. Personnel from the producer of the turbine, ABB-Stal, Finspong, Sweden, performed a special study of the behaviour of the material of the turbine mock-up, and were also providing key data on the operation of the turbine.

Phase III of the project was carried out in a model twice as large as the turbine hood, representing a room for an emergency generator. As a typical obstruction the turbine mock-up was located centrally in the room, and a mock-up of a diesel tank was located on the west end wall. The total volume of the generator room was about 140 m^3. Diesel pool- and spray fires of various sizes were burnt at different positions, and the number and type of Fine Water Spray Nozzles were varied. The scope of work in Phase III for the large generator room was to establish base data for dimensioning of the fire extinguishing system.

Personnel from Ginge-Kerr Offshore and British Petroleum, including the inventor and developer of the nozzles Dr. Panos Papavergos, have been participating in the planning, performance and evaluation of the experiments. This has been a unique opportunity of getting together the experience from the inventor, the developer, the system designers the researchers and the offshore operators into the execution of the work.

The reporting from Phase I and Phase II of the experiments has been separated into a common Main Report and two separate Technical Reports. The main report covers discussion and conclusions while the Technical Reports gives a more thorough presentation of the experimental setup and the methods used for calibration and calculation. The Technical Reports also contains a complete set of curves from each experiment.

For Phase III a separate Main Report and Technical Report has been made resulting in a total of 5 reports from the three experimental phases.

2 EXPERIMENTAL PLAN AND TEST SET-UP

2.1 Phase I: The test hall and the smoke collection hood

The tests in Phase I were performed in a test enclosure of 30 m³, located in the large fire test hall at SINTER NBL. The dimensions of the hall are 18x36 m² floor area and a maximum height of 28 m. The hall is equipped with a displacement ventilation system supplying conditioned air from ducts in the floor, and extracting smoke at the ceiling.

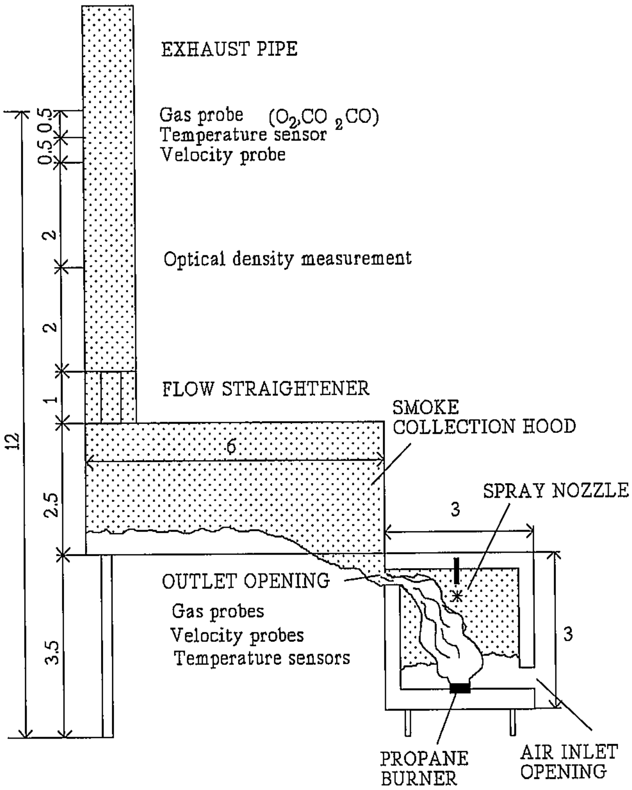

Figure 2.1 *Experimental setup of Phase I of the water spray experiments showing a side view of the enclosure with smoke collection hood and exhaust pipe. All figures in m.*

As shown in Figure 2.1, the enclosure where the fire and extinguishment tests of Phase I were performed is built below a smoke collection hood. The smoke leaves the collection hood through an exhaust pipe, which goes to the ambient through the test hall ceiling. No separate fans are installed for smoke extraction from the collection hood, but the test hall is to some extent pressurised during an experiment to promote smoke flow through the exhaust pipe.

2.2 Phase I: The test compartment

The test compartment has previously been used in projects examining the development of liquid pool fires /1/, /2/ in addition to extinguishing tests with different water spray systems /3/. Originally the enclosure was built as a 1:4 scale model of a typical offshore module. For extinguishing experiments the model is modified to withstand the introduction of a water spray inside. The main dimensions of the test compartment are shown in Figure 2.2 and Figure 2.3.

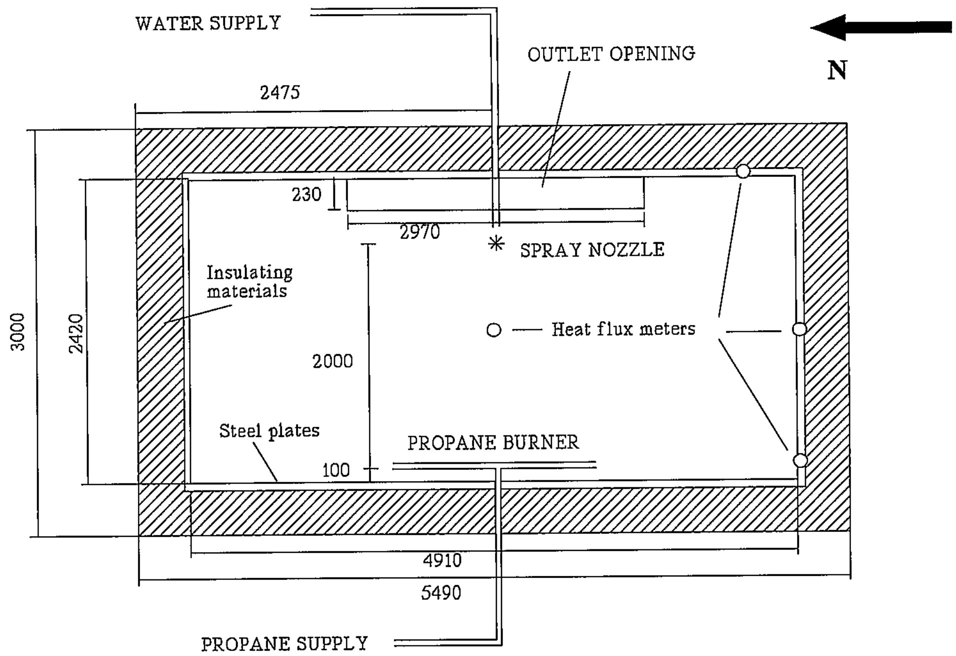

Figure 2.2 *Plan view of the test compartment, central cross section. Dimensions in mm.*

The air inlet opening covers the width of the enclosure, and is 350 mm high. The outlet opening is located centrally at the top of the rear wall, with a width of 2970 mm, and a height of 230 mm.

The walls and the ceiling are constructed of similar materials. Light weight aggregate concrete blocks named SIPOREX are used due to the load carrying capacity, and two layers of insulating materials are used as inner lining. The inner surfaces are covered with plates of the SKAMOLEX type (ceramic). The floor has a base of light weight aggregate concrete, followed by a layer of normal concrete, a thin layer of light weight aggregate concrete, the SKAMOLEX insulation plates, and at last a cover of corrugated steel plates to catch the water. The construction and dimensions of the wall and floor are shown in Figure 2.4.

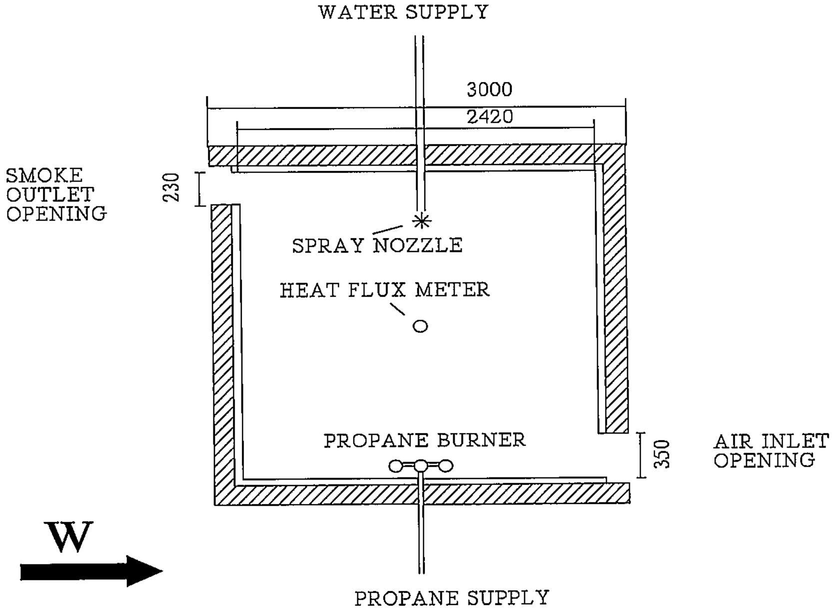

Figure 2.3 *Side view of the test enclosure, central cross section. Dimensions in mm.*

The propane matrix burner used in the experiments is constructed of three parallel 25 mm diameter steel pipes with closed ends and with a common central gas supply. The length of the pipes is 1250 mm, mounted with a centre distance of 100 mm. About 200 holes with 1 mm diameter are drilled in two lines at the upper half of the pipes' perimeter. The propane supply is distributed evenly over a surface area of 0.25 x 1.25 m^2, which is comparable to the pool area used in previous liquid pool fire tests in the same model /1/, /2/. The spray nozzle is located centrally in the ceiling, at a level of about 250 mm below the inner lining.

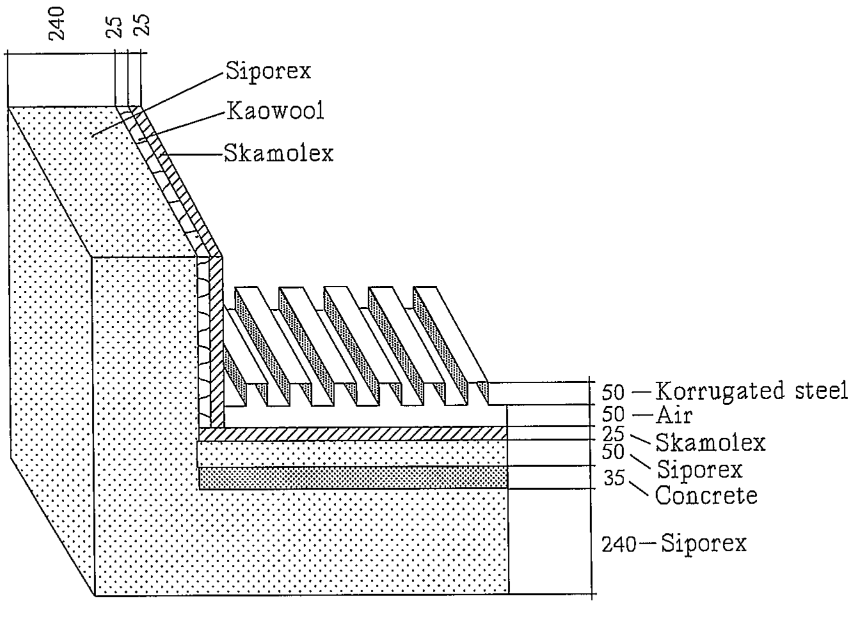

Figure 2.4 *Cross-sectional view of the floor and walls of the test compartment. The ceiling is constructed similar to the wall. Dimensions in mm.*

The propane matrix burner is only used in the experiments FTEST 1 - 2 and FINOZ 1 - 13 in addition to FINOZ 32[1]. In the experiments FINOZ 14 - 16 a propane jet fire is used as illustrated by Figure 2.5. In FINOZ 17 to 20 a diesel spray fire is used with location of the nozzle as shown in Figure 2.6. The same nozzle and location was used for the lubrication oil spray in FINOZ 30 - 31. In FINOZ 21 to 29 a steel tube was placed in the test enclosure as illustrated in Figure 2.7 which also shows the location of the insulation mat and tray used in some of the experiments. The location of the thermocouples on the steel tube is illustrated by a cross section of the tube in Figure 2.8.

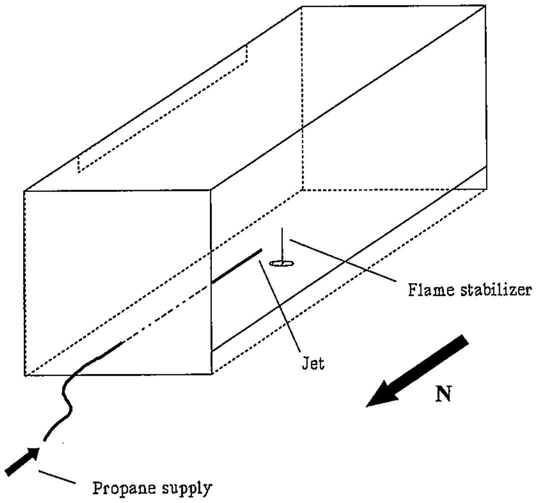

Figure 2.5 *Location of propane jet and flame stabilizer.*

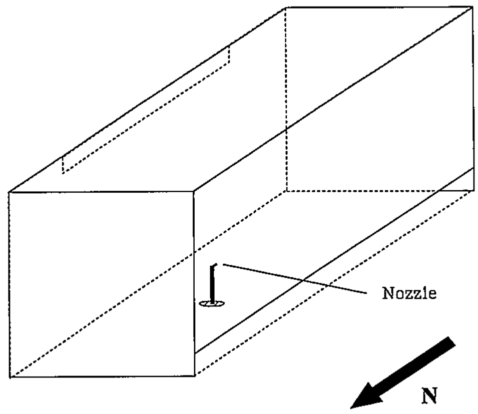

Figure 2.6 *Location of nozzle for diesel spray*

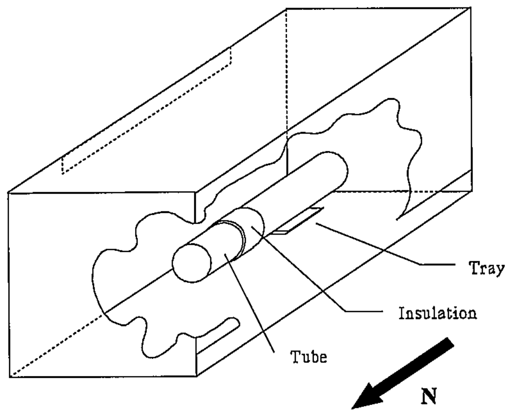

Figure 2.7 *Location of steel tube with insulation and tray for pool fire.*

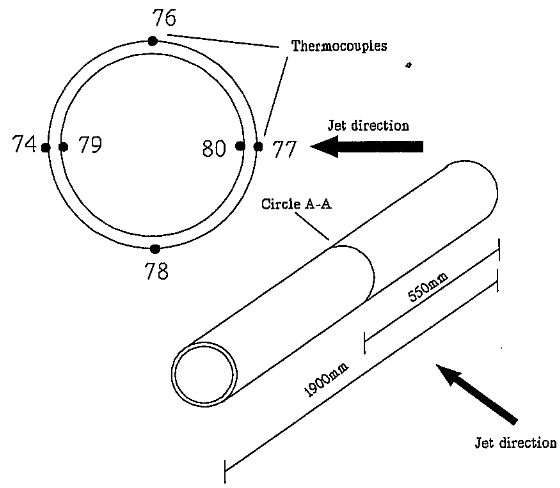

Figure 2.8 *Location of thermocouples No. 74 and 76-80 placed on the steel tube.*

[1] A survey of the test names with essential test parameters is given in Section 2.4 and 3.1

2.3 Phase I: The spray nozzles

The nozzles used in both Phase I and II of the experiments are of a twin fluid type (air and water) developed by Dr. Panos Papavergos and patented by BP Research, Sunbury England. From different types available, four nozzles were selected and tested in Phase I. Typical characteristics for nozzles used in Phase I is given in Table 2.1 /4/.

Table 2.1 *Typical characteristics of spray nozzles used in Phase I of the experiments*

NOZZLE TYPE	TEST/FILE	Median Droplet Diameter (Volume)
Jet 5 l/min 60°	FINOZ 1	125 - 240 μm
Jet 10 l/min 60°	FTEST 2, FINOZ 2 - 5	197 - 220 μm
Jet 10 l/min 90°	FINOZ 6 - 22, 24 -30	Supposed identical to Jet 10 l/min, 60° 197 - 220 μm
Jet 20 l/min 60°	FTEST 1	233 - 253 μm

2.4 Phase I: Parameter variation

A total of 32 tests (FINOZ 1 - 32) in addition to two calibration tests (FTEST 1 and 2) and a dummy test (No name), were performed in Phase I of the project. The following fire scenarios were used in the experiments:

2.4.1 Well ventilated propane matrix burner fire, about 1MW

A propane matrix burner was constructed of 3 parallel 25 mm diameter steel pipes with closed ends, and a common central gas supply. The length of the pipes was 1250 mm, mounted with a centre distance of 100 mm. About 200 holes with 1 mm diameter, drilled in two lines at the upper part of the pipes' perimeter, distributed the propane evenly over a surface area of 0.3 m^2.

The matrix burner was located just above floor level, and is quite similar to a liquid pool fire. The heat output is easy to control, in opposite to a liquid pool fire, and it is clean and simple to operate. The heat produced by the matrix burner was about 1 MW.

2.4.2 Reduced ventilated propane matrix burner fire, about 1MW

The same fire as in the first test series was used, with a heat output about 1 MW. The ventilation was reduced by blocking the air inlet opening with lightweight concrete blocks, leaving a small slit in the centre for ignition and inspection. At full opening the air flow rate was about 1.5 - 1.6 kg/s. With blocked inlet opening the air flow rate was about 1.3 - 1.4 kg/s.

2.4.3 Well ventilated propane jet fire, about 1 MW

A propane jet fire was flowing along the central axis of the module, from north to south (See Figure 2.5). The test FINOZ 14 was done with a 5 mm diameter nozzle, positioned 805 mm from the centre, 430 mm upstream a flame stabilizer (a vertically positioned steel pipe). The lift-off distance for this jet is about 0.4 m, and it is easily blown off without any obstruction for stabilization of the flame.

The tests FINOZ 15 and FINOZ 16 were done with a 7 mm diameter nozzle. The heat release rate of the jet was about 1MW in all three tests.

2.4.4 Well ventilated diesel spray fire, about 1 MW

The diesel spray (See Figure 2.6 for location) was formed by a Fine Spray nozzle, Jetmist 2.5 l/min, 60°, supplied with diesel instead of water. The air- and water pressures were adjusted to give a 1 MW fire.
The test FINOZ 17 included increase of water pressure to try to extinguish the diesel spray.
FINOZ 19 and 20 were done with the nozzle closer to the centre of the module, to get a better match between flame zone and water spray.

2.4.5 Diesel pool fire, well ventilated, with a hot steel tube above the pool

A 0.6 x 0.6 m^2 steel tray was located at floor level, a little off centre in the southern part of the test compartment (See Figure 2.7). Above the pool a thick walled steel tube was located, with the axis in north/south direction. The vertical distance between steel tube and Diesel pool was about 0.1 m. The tube was preventing the spray from hitting the fuel surface directly. The steel tube was heated in a central part by a propane torch, until the local steel temperature was above 700 °C[2]. Then Diesel oil was pumped into the steel tray and ignited by the torch. The propane torch was then turned off, and the pool fire was left burning until a steady-state had been obtained before the water spray was activated.

2.4.6 Lubricating oil spray fire, well ventilated, about 1 MW

The same setup as for the Diesel oil spray tests described in Section 2.4.4 was used. The only variation was the fuel which was a lubricating oil, Shell Tellus T 32, instead of Diesel oil.

2.4.7 Lubricating oil pool fire, well ventilated, with a hot tube above the pool

The same setup as for the Diesel oil pool fire tests described in section 2.4.5 was used. The only variation was the fuel which was a lubricating oil, Shell Tellus T 32, instead of Diesel oil.

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[2] The location of the thermocouples on the steel tube are given by figure 2.8

2.4.8 Hot metal surfaces

A 16.2 mm thick walled steel tube with diameter 278 mm was installed in the test compartment with the axis in the north/south direction. (See Figure 2.7 and Figure 2.8)

The tube was heated by a propane jet, from a 7 mm diameter nozzle. When the maximum measured steel temperature reached 750 °C, the cooling time history was logged. In the test FINOZ 21 the water spray was activated immediately after the jet was turned off. In FINOZ 23 the tube was left cooling without any spray, just by air.

2.4.9 Fire in insulation mats soaked with diesel or lubricating oil

The tests were done with a mat of KAOWOOL ceramic fibre, 25 mm thick, wrapped around a section of the tube (See Figure 2.7). The test FINOZ 25 was performed with a mat of insulating material around one end of the tube soaked with diesel from a pipe above the mat. In FINOZ 25 the insulation mat was 250 mm wide. The test procedure was: Heating the tube by a propane jet, impinging at a section 0.55 m off centre of the tube, until the maximum surface temperature reached about 750 °C. Then diesel was pumped into the 0.6 m x 0.6 m pool below the tube, and simultaneously pumped onto the insulation mat from above. The jet was then turned off, and the fire was developing both in the pool and in the insulation. After about 5 minutes the insulation was soaked with diesel, which was burning all around the tube. The spray was then activated.

In FINOZ 27 the procedure was changed a little. The width of the insulation mat was reduced to 0.2 m. The pool fire was not activated, and 1 litre of diesel oil was poured upon the insulation mat in about 3-4 minutes. The spray was activated when the flames were surrounding the tube, after the diesel supply had been switched off.

In FINOZ 28 the same procedure as in FINOZ 27 was followed. The only difference in conditions was ventilation. Most of the air inlet opening was blocked, leaving only a 0.5 m wide opening at the centre.

2.5 Phase II: The test enclosure

The test compartment used in Phase II of the experiments is based on SINTEF NBL's **Multipurpose Fire Test Rig (MFTR)** which in short terms can be described as a flexible, module-based enclosure with variable dimensions up to 12x6x6 m (LxWxH).The dimensions of the enclosure used to represent the turbine hood was about 10x4x4 m (LxWxH). A 3-dimensional view showing the size of the module used in Phase II is given in Figure 2.9. The walls of the module are insulated with 150 mm of ceramic fibre (KAOWOOL) with 1 mm stainless steel plates on the inside of the module and 2 mm corrugated steel plates on the outside as shown in Figure 2.10.

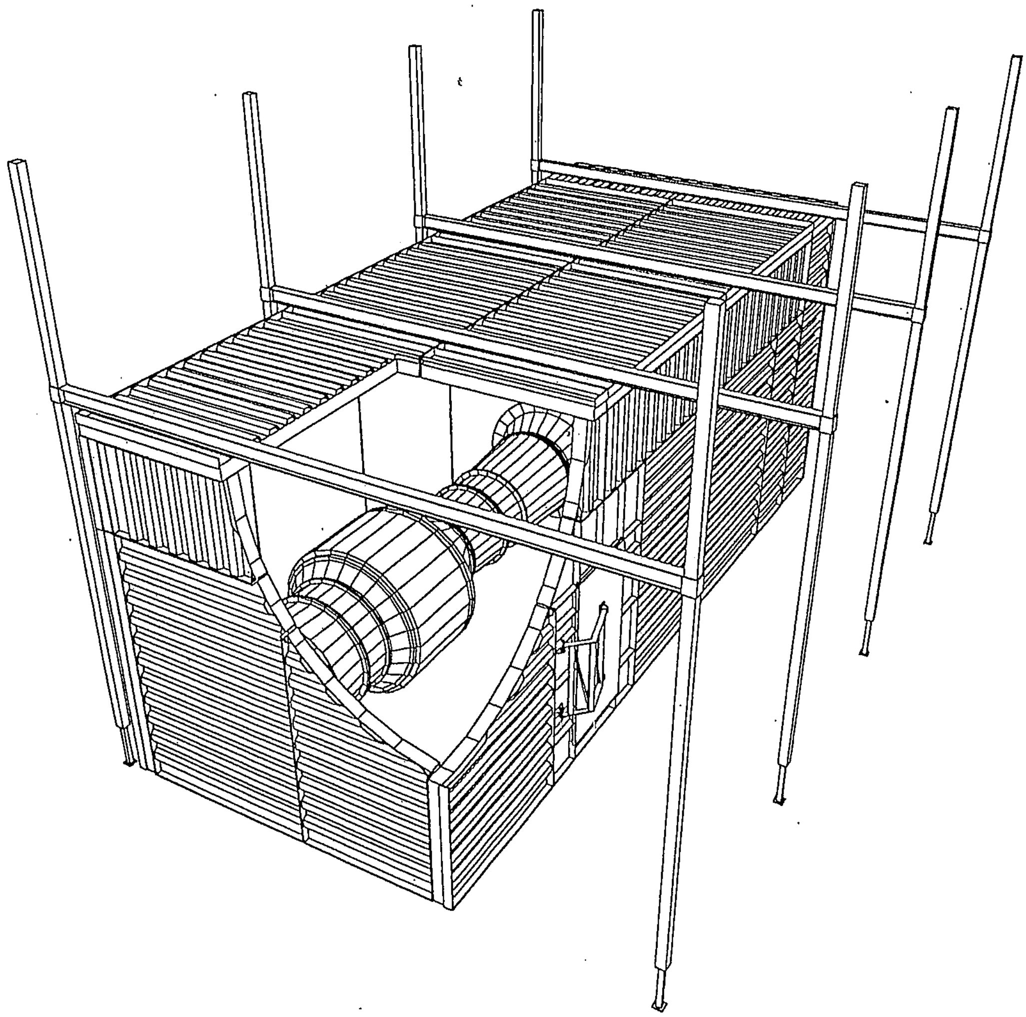

Figure 2.9 *3-dimensional illustration of the enclosure (Multi Purpouse Fire Test Rig) used in Phase II of the experiments.*

The main dimensions and orientation of the enclosure used in Phase II is shown in Figure 2.11. Figure 2.12, Figure 2.13 and Figure 2.14 gives a more detailed survey of the essential components with corresponding dimensions as used in the experiments. Location of the instrumentation of the module and the turbine mock-up is also indicated in addition to the location of the nozzles.

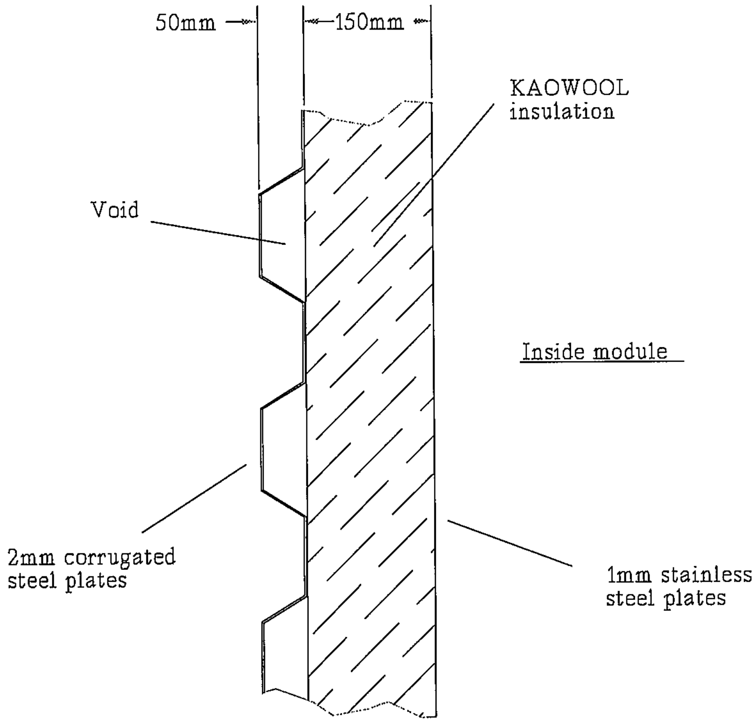

Figure 2.10 *Cross-sectional view showing the construction of the MFTR wall.*

The floor of the module is covered with a 100 mm layer of lightweight aggregate concrete of the type SIPOREX. On this floor a 500 mm high mezzanine of SIPOREX blocks with area 4550 x 2500 mm^2 is placed in the south/west corner along the southern wall as a base for the turbine mock-up. Along the northern wall a floor made of steel grating is placed in 500 mm height as an extension to the mezzanine.

The western wall is built of 200 mm thick SIPOREX blocks with openings for ventilation in- and outlet at ceiling level. In addition to the ventilation openings, there are two 500 x 500 mm windows in the wall, approximately 1 m above floor level, for inspection and video registration of the experiments.

The enclosure is equipped with a forced ventilation system with a 315 mm diameter inlet and 400 mm diameter outlet. Dampers are mounted on both in- and outlet of the ventilation channels.

The propane burner shown in the figures is used for heating of the turbine-mock up to simulate real operating conditions.

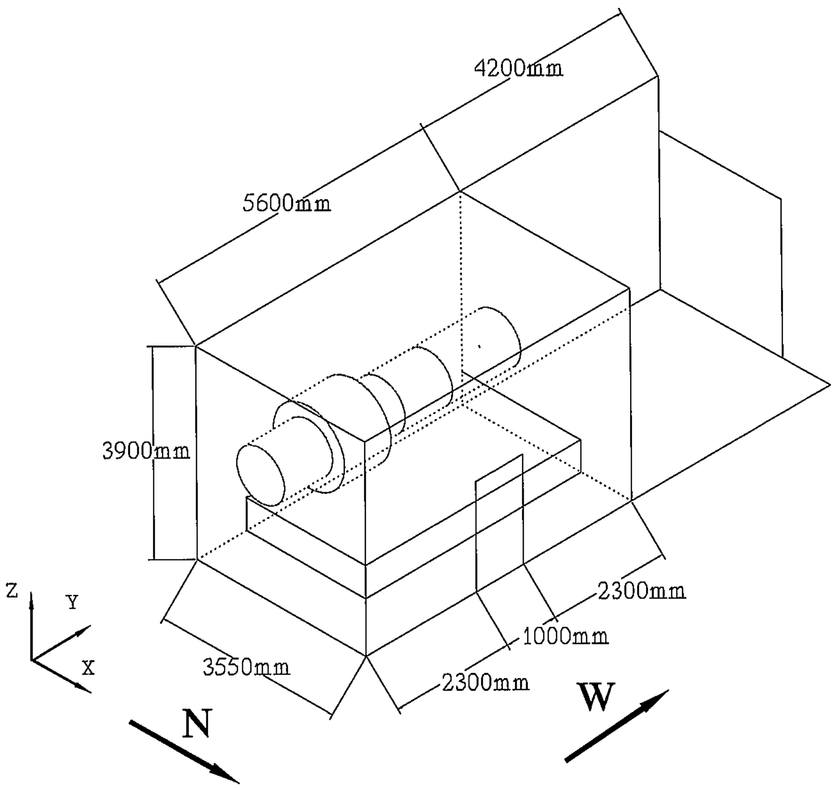

Figure 2.11 *Main dimensions and orientation of the test compartment used in Phase II*

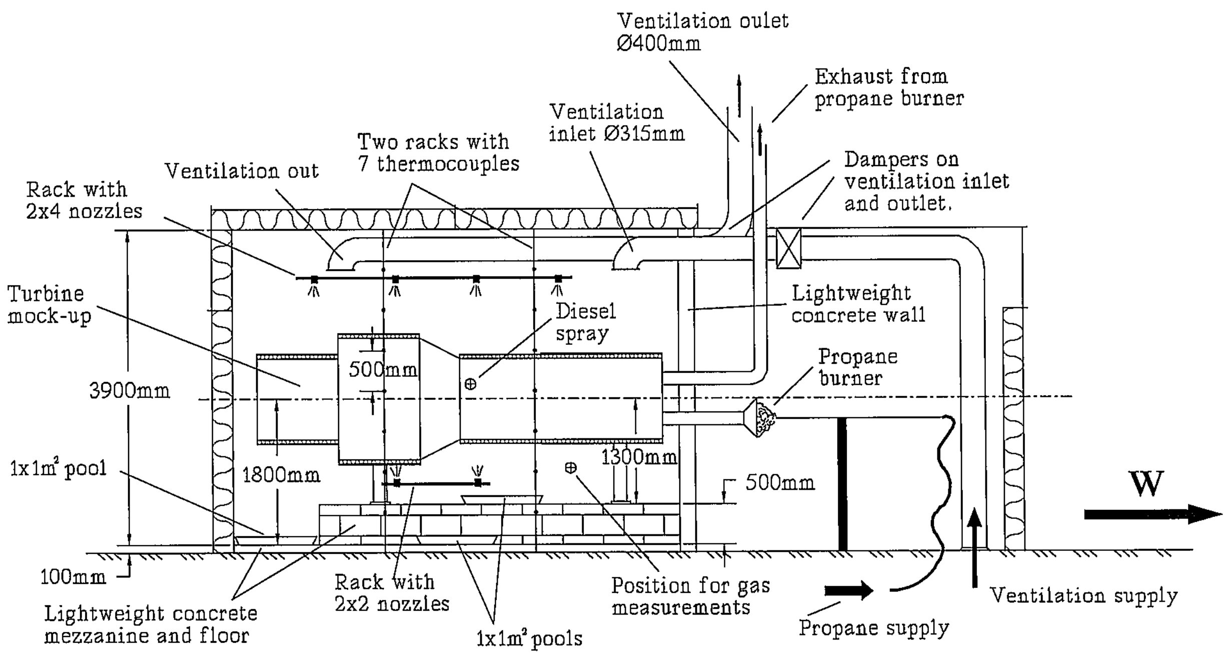

Figure 2.12 *Cross-section of the test compartment of Phase II showing the location of the turbine mock-up and essential components. (View from North)*

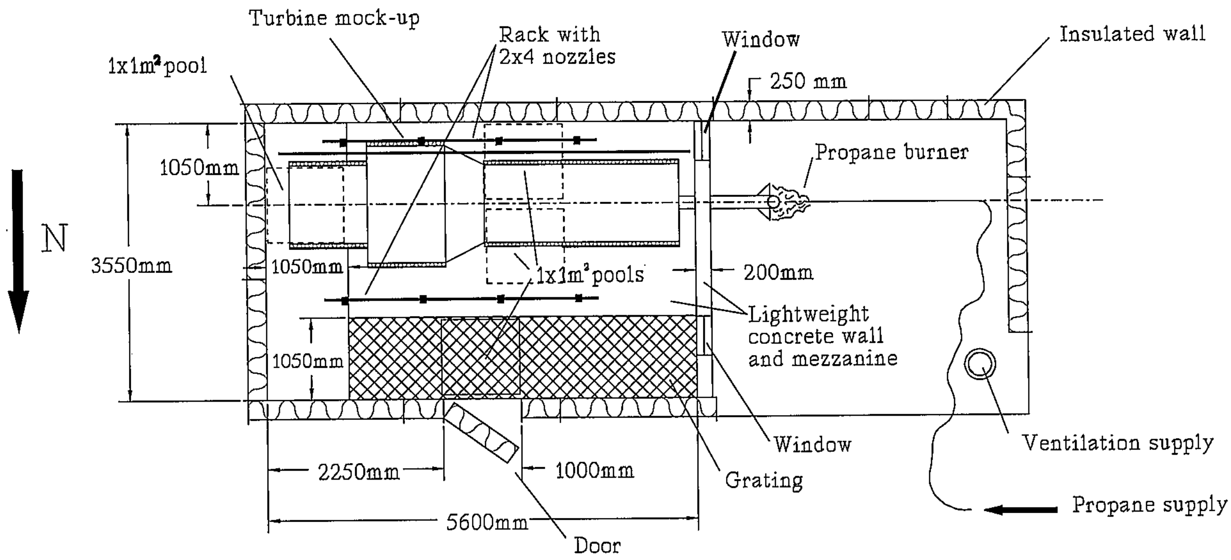

Figure 2.13 *Cross-section of the test compartment of Phase II showing the location of the tubine mock-up and essential components. (View from above)*

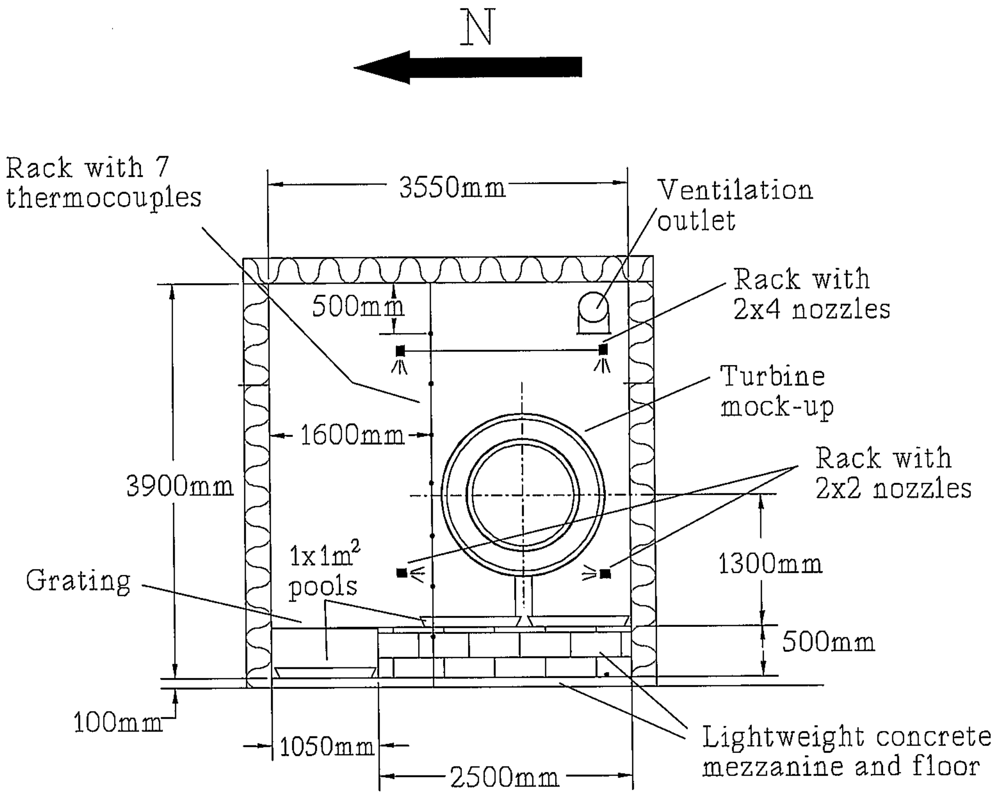

Figure 2.14 *Cross-section of the test compartment of Phase II showing the location of the turbine mock-up and essential components. View from short end side of the module. (West)*

2.6 Phase II: The turbine mock-up

The turbine mock-up used in the experiments represents a full scale model of a gas turbine on the ULA platform in the North Sea. The essential dimensions of the mock-up and the type of insulation used on different parts of the model are shown in Figure 2.15. Additional to the turbine body, piping and other realistic obstructions around the turbine were built in the hood.

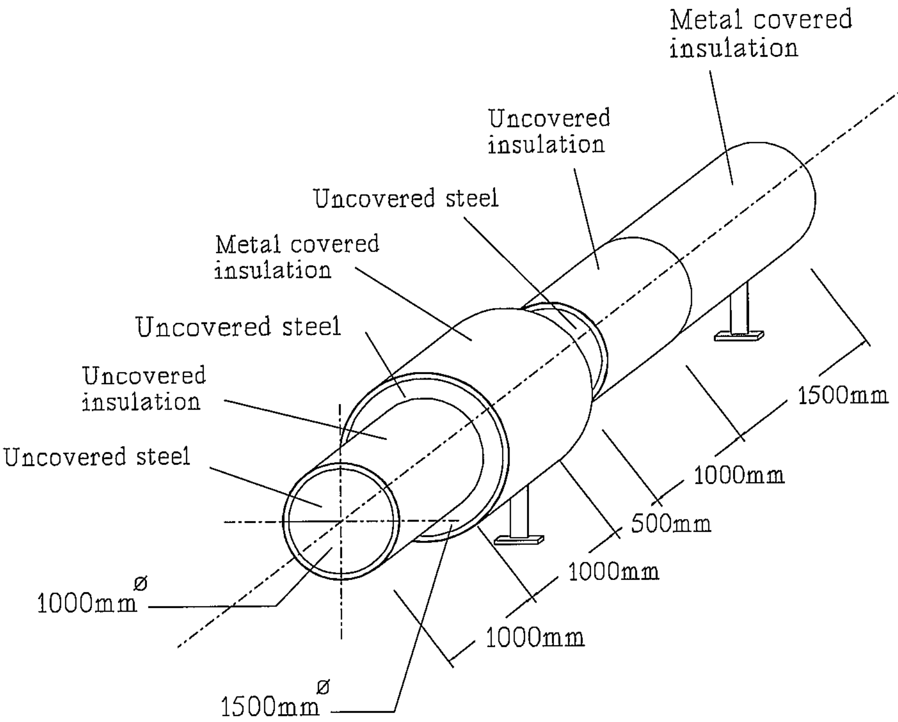

Figure 2.15 *Illustration of the turbine mock-up showing essential dimensions and locaiton of the different types of insulation used.*

2.7 Phase II: The spray nozzles

The tests in the small compartment, with a distance between fire sources and spray nozzle between 1 - 2 m, made a basis for optimization of nozzle type and operating pressure of air and water. Nozzles of the Jet-mist type were tested at a ≈1 MW propane gas matrix burner. A nozzle Jet with nominal capacity 20 l/min, 60° spray angle, extinguished the fire immediately. A nozzle of the type Jet-mist 5 l/min, 60° spray angle, did not extinguish the fire even with higher water pressure than the recommended. A nozzle of the type Jet-mist 10 l/min 60° spray angle, extinguished the fire with water application rate of about 8 l/min. A test with wider spray angle, Jet-mist 10 l/min 90°, was even more stable and gave rapid extinguishment. Typical extinguishing time for this almost free burning fire was 7-10 seconds.

From this test series a nozzle of the type Jet-mist 10 l/min, 90° spray angle, was chosen for further use in the tests. This nozzle was used in tests TURBIN 1 - 48 in Phase II of the experiments.

Nozzle Jet 10 l/min, 60° produces droplets with a Volume Median Diameter varying from 197 - 220 µm, as shown in Table 2.2 /4/. The nozzle Jet 10 l/min, 90° differs from the 60° nozzle by the direction of the exit holes only, and is supposed to produce droplets of similar diameter distribution. However, the exit velocity and direction will differ.

In the last experiment of Phase II (TURBIN 49) the nozzle Velomist 10 l/min, 60°, was tested in a low position. This nozzle produces droplets with Volume Median Diameter varying from 166 - 219 µm.

A total of 12 nozzles were used in the experiments; 2x4 in the ceiling and 2x2 below the turbine with position as indicated in Figure 2.12, Figure 2.13 and Figure 2.14.

Table 2.2 *Characteristic data for the nozzles used in Phase II of the experiments /4/.*

Nozzle type	Air pressure (bar)	Water pressure (bar)	Water flow rate (l/min)	Volume Median Diameter (µm)
Jet 10 l/min, 60°	5	5.2	12	197
Jet 10 l/min, 60°	5	4.7	10	214
Jet 10 l/min, 60°	4	3.3	10	206
Jet 10 l/min, 60°	3	3.1	10	220
Jet 10 l/min, 60°	5	1.9	5	201
Jet 10 l/min, 60°	4	1.8	5	203
Velomist 10 l/min, 60°	5	7.4	12	200
Velomist 10 l/min, 60°	5	6.2	10	186
Velomist 10 l/min, 60°	4	5.5	10	205
Velomist 10 l/min, 60°	3	4.8	10	219
Velomist 10 l/min, 60°	5	3.5	5	166
Velomist 10 l/min, 60°	4	3.1	5	172

Volume Median Diameter is defined as the diameter of a droplet in the spray where 50% of the total volume has smaller diameter, and 50% has bigger diameter.

2.8 Phase II: Water application rate

Essential parameters for the water application rates used in the turbine hood experiments of Phase II, are given in Table 2.3. The water and air pressures were measured at the end of one branch of the piping system, representing minimum pressure of a nozzle in the system. The water flow rates are based on interpolation of values from a table of flow rates versus water and air pressure for the nozzle Jetmist 10 l/min, 60°/4/. This nozzle is quite similar to the one used, Jetmist 10 l/min, 90°. The flow rate of Velomist 10 l/min, 60° is taken from the same type of table.

Table 2.3 *Water application rates used in the turbine hood experiments. (Phase II)*

Test	Water pressure	Air pressure	Number of nozzles	Flow rate per nozzle	Total flow rate
TURBIN	[bar]	[bar]		[l/min]	[l/min]
1	-	-	-	-	-
2	3,2	3,7	12	9,9	118,8
3	3,1	3,7	12	9,5	114
4	3,1	3,7	12	9,5	114
5	3	3,5	12	9,4	112,8
6	3	3,5	12	9,4	112,8
7	3	3,6	12	9,3	111,6
8	3	3,6	12	9,3	111,6
9	3,7	4	8	10,9	87,2
10	3,7	4	8	10,9	87,2
11	3,7	4	8	10,9	87,2
12	3,8	4,2	8	10,6	84,8
13	3	3,5	12	9,4	112,8
14	3,1	3,6	12	9,6	115,2
15	3	3,6	12	9,3	111,6
16	3	3,5	12	9,4	112,8
17	3,1	3,6	12	9,6	115,2
18	3,1	3,7	12	9,5	114
19	3	3,6	12	9,3	111,6
20	3	3,5	12	9,4	112,8
21	3	3,5	12	9,4	112,8

Test	Water pressure	Air pressure	Number of nozzles	Flow rate per nozzle	Total flow rate
TURBIN	[bar]	[bar]		[l/min]	[l/min]
22	3	3,6	12	9,3	111,6
23	3,1	3,5	12	9,7	116,4
24	3	3,4	12	9,5	114
25	3,6	3,6	12	11,3	135,6
26	3	3,6	10	9,3	93
27	-	-	-	-	-
28	4	4	6	11,6	69,6
29	3,2	3,8	2	9,7	19,4
30	4,1	4,1	2	11,6	23,2
31	4,1	4,6	4	9,9	39,6
32	3,3	3,4	6	10,6	63,6
33	3,7	4	8	10,9	87,2
34	3,7	4	8	10,9	87,2
35	3,1	3,5	12	9,7	116,4
36	3,1	3,3	6	9,9	59,4
37	3,5	5,1	6	8,3	49,8
38	3,6	5,2	6	8,3	49,8
39	3,1	5,6	8	7,2	57,6
40	5	5,5	8	11,2	89,6
41	4	4,5	8	10	80
42	5,9	6,1	2	9,8	19,6
43	5,3	5,5	2	10	20
44	5,1	5,3	2	11,1	22,2
45	4,8	5	6	10,4	62,4
46	4,5	4,8	6	10,3	61,8
47	5	5,2	4	10,4	41,6
48	5,2	5,6	4	9,6	38,4
49	4,4	4,5	2	7,7	15,4

2.9 Phase II: Pools and diesel spray

Pool fires and diesel spray fires in addition to fires in insulation soaked with diesel were used as fire scenarios during in the tests. For the pool fires, 1x1 m^2 steel trays with diesel were used with variation in location for the different tests as shown in Figure 2.16.

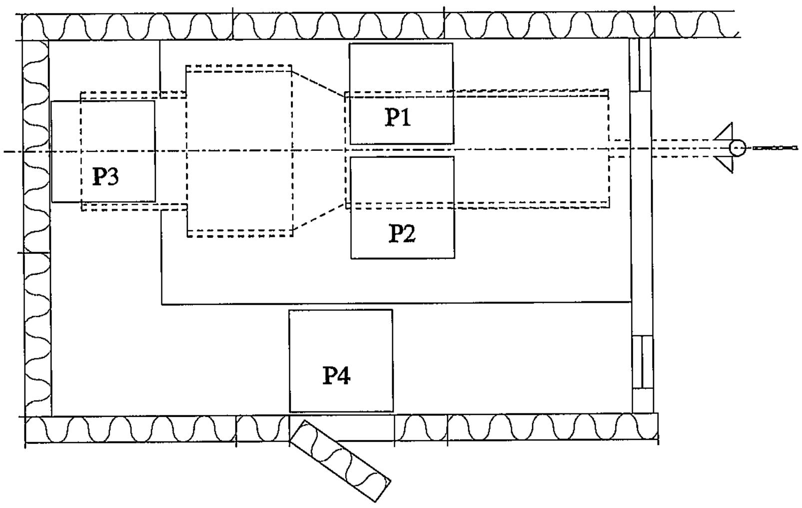

Figure 2.16 *The location of pools for the different tests in Phase II of the experiments.*

The location of the diesel spray used in some of the experiments is indicated in Figure 2.17. The different orientations of the spray are denoted S1: Spray directed onto hot steel surface only; S2 : Spray directed onto hot metal surface and uncovered insulation mat and S3 : Spray directed onto uncovered insulation mat. From test TURBINE 19 onwards the Diesel spray was run without air for atomizing. This was to simulate a leakage from a pressurized fuel pipe.

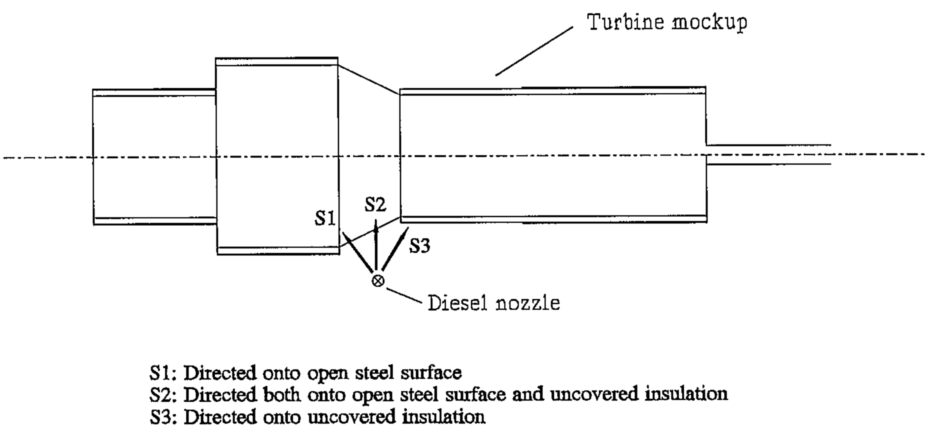

Figure 2.17 *The location of the diesel spray for the different tests in Phase II.*

2.10 Phase II: Test procedure

A normal test procedure in Phase II of the experiments was:

1. Start ventilation
2. Fill Diesel oil into the pools which are to be in use
3. Fill in a small amount of Gasoline to ease ignition
4. Ignite pilot flames (Small 1 litre boxes with diesel oil and a wick)
5. Ignite the pool(s)
6. Start and ignite the Diesel spray (If any)
7. Close the door (Optional: Door open)
8. Close the dampers of the ventilation system (Optional: Dampers open)
9. Preburn time, fire development
10. First shot of water spray, duration: Most tests: 10 [s]. (Optional: Other duration)
11. Observe if the fire is extinguished or not
12. Observe if re-ignition occurs in insulation mats
13. Additional shots of water spray
14. Inspect the equipment and the inventory, check if there is fuel left in the pools, or if manual ignition of the insulation mats is possible

2.11 Phase II: Parameter variation

The experiments in Phase II were logged with the file name TURBIN followed by a two digit number which identifies each specific test.

Table 2.4 shows the parameter variations in the experiments of Phase II.

Legend for the table is:

- P1 - P4 : Pool position. (See Figure 2.16)
- S1 - S3 : Spray position and direction. (See Figure 2.17)
- Turbine : H : Hot , C: Cold. H* : Still hot , but not heated to max temperature before experiment start
- Door and Vent: O : Open.
  CA : Closed after the water spray was activated
  CB : Closed before the water spray was activated.

Table 2.4 Parameter variations in the experiments of Phase II.

Test No.	P1	P2	P3	P4	S1	S2	S3	Hot/cold	Door	Vent	Mats	Additive
1												
2	X				X			H	O	O	Y	
3	X				X			C	O	O	Y	
4	X				X			H	O	O	Y	
5	X	X		X	X			H	O	O	Y	
6	X	X		X				H	CA	CA	Y	
7	X	X		X		X		H	CA	CA	Y	
8	X	X		X				H	O	O	Y	
9	X	X	X					H	O	O	Y	
10	X	X	X			X		H	O	O	Y	
11	X	X	X			X		H	CA	O	Y	
12	X	X	X			X		H	CA	(O)	Y	
13	X	X	X			X		H	O	O	Y	
14	X	X	X			X		H	O	O	Y	
15	X	X	X			X		H	O	O	Y	
16								H	CB		Y	
17	X	X	X			X		H	O	O	Y	
18	X	X	X			X		H	O	O	Y	
19							X	H	O/C	O/C	Y	
20							X	H	CB	CB	Y	
21							X	H	CB	CB	Y	
22							X	H	CB	CB	Y	
23							X	H	CB	CB	Y	F 107 6%
24							X	H	CB	CB	Y	F 107 3%
25							X	H	CB	CB	Y	F 107 3%
26							X	H	CB	CB	Y	F 107 3%
27	X	X	X				X	C	CB	CB	N	
28	X	X	X				X	C	CB	CB	N	
29	X	X	X				X	C	CB	CB	N	
30			X					C	CB	CB	N	

Test No.	P1	P2	P3	P4	S1	S2	S3	Hot/cold	Door	Vent	Mats	Additive
31			X					C	CB	CB	N	
32			X					C	CB	CB	N	
33			X					C	CB	CB	N	
34			X					C	CB	CB	N	
35			X					C	CB	CB	N	
36			X					C	CB	CB	N	
37			X					C	CB	CB	N	
38			X					C	CB	CB	N	
39			X					C	CB	CB	N	
40			X					C	CB	CB	N	
41			X					C	CB	CB	N	
42	X	X	X				X	C	CB	CB	N	
43			X					C	CB	CB	N	
44			X					C	CB	CB	N	
45	X	X					X	H	CB	CB	Y,3	
46	X	X	X				X	H*	O	O	Y,3	
47	X	X	X				X	H*	O	O	Y,3	
48	X	X	X				X	H*	O	O	Y,3	
49			X					H*	CB	CB	N	

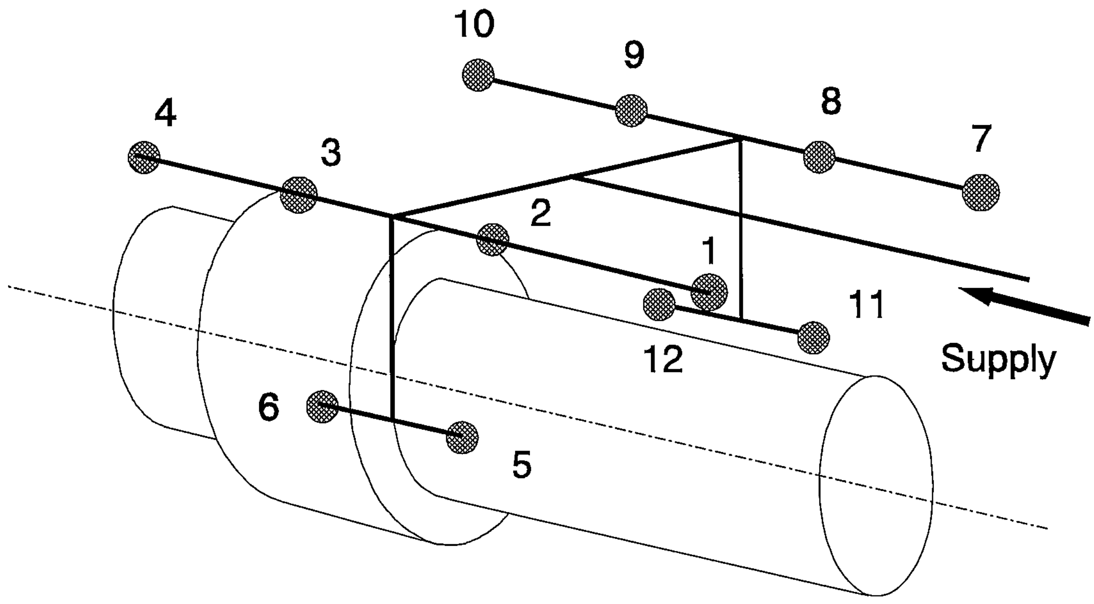

Figure 2.18 *Positions of spray nozzles in the turbine hood used in Phase II.*

Table 2.5 shows the number of nozzles which were activated in each test. The nozzle numbers refers to Figure 2.18.

Table 2.5 *Survey of nozzles activated in each test in Phase II. Nozzle numbers refers to Figure 2.18.*

Nozzle number	1	2	3	4	5	6	7	8	9	10	11	12
TURBIN 1												
TURBIN 2	x	x	x	x	x	x	x	x	x	x	x	x
TURBIN 3	x	x	x	x	x	x	x	x	x	x	x	x
TURBIN 4	x	x	x	x	x	x	x	x	x	x	x	x
TURBIN 5	x	x	x	x	x	x	x	x	x	x	x	x
TURBIN 6	x	x	x	x	x	x	x	x	x	x	x	x
TURBIN 7	x	x	x	x	x	x	x	x	x	x	x	x
TURBIN 8	x	x	x	x	x	x	x	x	x	x	x	x
TURBIN 9		x	x	x		x	x		x	x	x	
TURBIN 10		x	x	x		x	x		x	x	x	
TURBIN 11		x	x	x		x	x		x	x	x	
TURBIN 12		x	x	x		x	x		x	x	x	
TURBIN 13	x	x	x	x	x	x	x	x	x	x	x	x
TURBIN 14	x	x	x	x	x	x	x	x	x	x	x	x
TURBIN 15	x	x	x	x	x	x	x	x	x	x	x	x
TURBIN 16	x	x	x	x	x	x	x	x	x	x	x	x
TURBIN 17	x	x	x	x	x	x	x	x	x	x	x	x
TURBIN 18	x	x	x	x	x	x	x	x	x	x	x	x
TURBIN 19	x	x	x	x	x	x	x	x	x	x	x	x
TURBIN 20	x	x	x	x	x	x	x	x	x	x	x	x
TURBIN 21	x	x	x	x	x	x	x	x	x	x	x	x
TURBIN 22	x	x	x	x	x	x	x	x	x	x	x	x
TURBIN 23	x	x	x	x	x	x	x	x	x	x	x	x
TURBIN 24	x	x	x	x	x	x	x	x	x	x	x	x
TURBIN 25	x	x	x	x	x	x	x	x	x	x	x	x
TURBIN 26	x	x	x	x	x	x	x	x	x	x	x	x
TURBIN 27												
TURBIN 28	x	x	x	x	x	x						
TURBIN 29					x	x						
TURBIN 30					x	x						

Nozzle number	1	2	3	4	5	6	7	8	9	10	11	12
TURBIN 31		x	x		x	x						
TURBIN 32	x	x	x	x	x	x						
TURBIN 33	x	x	x	x	x	x	x	x				
TURBIN 34	x	x	x	x	x	x			x	x		
TURBIN 35	x	x	x	x	x	x	x	x	x	x	x	x
TURBIN 36	x	x	x				x	x	x			
TURBIN 37	x	x	x				x	x	x			
TURBIN 38		x	x	x				x	x	x		
TURBIN 39		x	x	x		x		x	x	x		x
TURBIN 40		x	x	x		x		x	x	x		x
TURBIN 41		x	x	x		x		x	x	x		x
TURBIN 42					x	x						
TURBIN 43					x	x						
TURBIN 44	x						x					
TURBIN 45	x	x	x	x	x	x						
TURBIN 46	x	x	x	x	x	x						
TURBIN 47		x	x		x	x						
TURBIN 48		x	x		x	x						
TURBIN 49					x	x						

3 RESULTS

This chapter gives a brief presentation of key data from the experiments. All results from the experiments including a complete set of curves from each test are presented in detail in the Technical Reports from Phase I and II of the project. Data files from each test exists at SINTEF NBL in addition to video recordings from most of the experiments.

3.1 Phase I: Tests in a 30 m^3 fire compartment.

3.1.1 Well ventilated propane matrix burner fire, about 1 MW

A propane matrix burner with surface area of 0.3 m^2 was located at floor level of the fire compartment. The heat output of the burner was about 1 MW. One spray nozzle was located centrally, 2 m above the burner. The ventilation of the fire compartment was induced by the fire itself, and the air flow rate was about 1.5 - 1.6 kg/s.

File	Nozzle	Water pressure bar	Air pressure bar	Mass rate l/min	Result
FTEST 1	Jet 20 l/min, 60°	≈5	≈5	≈24	Extinguished
FTEST 2	Jet 10 l/min, 60°	4.7	5	≈10	Extinguished
FINOZ 1	Jet 5 l/min, 60°	4.4	5.2	≈9	Not extinguished
EXTRA	Jet 5 l/min, 60°	3	4	≈5	Not extinguished
FINOZ 2	Jet 10 l/min, 60°	4.9	5.0	10.8	Extinguished in 7.8 sec.
FINOZ 3	Jet 10 l/min, 60°	2.9	3.8	8.3	Extinguished in 16 sec.
FINOZ 4	Jet 10 l/min, 60°	2.8	4.0	7.6	Not extinguished
FINOZ 5	Jet 10 l/min, 60°	3.2	5.0	7.1	Extinguished in 12 sec.
FINOZ 6	Jet 10 l/min, 90°	3.9	5.1	8.5	Extinguished in 7 sec.
FINOZ 7	Jet 10 l/min, 90°	1.7	4.1	4.6	Not extinguished
FINOZ 8	Jet 10 l/min, 90°	3.8	5.0	7.9	Extinguished in 9.4 sec.
FINOZ 32	Jet 10 l/min, 90°	3.9	5.1	8.4	Extinguished in 1 min 12 sec.

The difference in time to extinguishment between test FINOZ 6/8 and FINOZ 32 is probably caused by an air jet (from the nozzle used in the fuel spay tests) introducing a disturbance to the flow in the fire compartment.

3.1.2 Reduced ventilated propane matrix burner fire, about 1 MW

A propane matrix burner with surface area of 0.3 m^2 was located at floor level of the fire compartment. The heat output of the burner was about 1 MW. One spray nozzle was located centrally, 2 m above the burner. The ventilation of the fire compartment was induced by the fire itself, but the air inlet opening was partly blocked. The air flow rate was about 1.3 - 1.4 kg/s.

File	Nozzle	Water pressure bar	Air pressure bar	Mass rate l/min	Result
FINOZ 9	Jet 10 l/min, 90°	1.5	4.0	4.1	Not extinguished
FINOZ 10	Jet 10 l/min, 90°	1.8	4.1	4.9	Not extinguished
FINOZ 11	Jet 10 l/min, 90°	2.7	4.1	7.3	Extinguished in 32 sec.
FINOZ 12	Jet 10 l/min, 90°	3.0	5.1	6.5	Extinguished in 1 min 5 s
FINOZ 13	Jet 10 l/min, 90°	3.1	5.1	6.7	Extinguished in 19.5 s

The difference in time to extinguishment between test FINOZ 12 and FINOZ 11/13 is probably due to the lower flow rate in FINOZ 12. This experiment shows the lowest water application rate with extinguishment. However, small differences in spray performance due to manual operation may occur, as well as variation in flow conditions in the fire compartment due to the fire dynamics.

3.1.3 Well ventilated propane jet fire, about 1 MW

A propane jet fire was flowing along the central axis of the module, from north to south (Figure 2.5). The test FINOZ 14 was done with a 5 mm diameter nozzle, positioned 805 mm from the centre, 430 mm upstream a flame stabilizer (a vertically positioned steel pipe). FINOZ 15 and FINOZ 16 were done with a 7 mm diameter nozzle.

File	Nozzle	Water pressure bar	Air pressure bar	Mass rate l/min	Result
FINOZ 14	Jet 10 l/min, 90°	3.9	5.2	8.3	Extinguished in 7 s
FINOZ 15	Jet 10 l/min, 90°	3.9	5.2	8.2	Extinguished in 3-4 s
FINOZ 16	Jet 10 l/min, 90°	3.4	5.2	7.2	Extinguished in 8.9 sec.

3.1.4 Well ventilated diesel spray fire, about 1 MW

A diesel spray formed by a Fine Spray Nozzle, Jetmist 2.5 l/min, 60°, supplied with diesel instead of water was giving a 1 MW fire. The spray was directed horizontally, along the north/south centerline of the test compartment (Figure 2.6). The test FINOZ 17 included increase of water pressure to try to extinguish the diesel spray, since the first attempt of extinguishing was not successful. FINOZ 19 and FINOZ 20 were done with the nozzle closer to the centre of the module, to get a better match between flame zone and water spray.

File	Nozzle	Water pressure bar	Air pressure bar	Mass rate l/min	Result
FINOZ 17	Jet 10 l/min, 90°	3.7	5.0	8.9	Not extinguished
FINOZ 18					Test heat output
FINOZ 19	Jet 10 l/min, 90°	3.7	5.0	8.1	Extinguished in 1 min 26 s
FINOZ 20	Jet 10 l/min, 90°	3.4	5.0	7.5	Extinguished in 20 s

The difference in time to extinguishment between test FINOZ 19 and FINOZ 20 has no obvious reason. Small differences in spray performance due to manual operation may occur, as well as variation in flow conditions in the fire compartment due to the fire dynamics.

3.1.5 Diesel pool fire, well ventilated, with a hot steel tube above the pool

A diesel pool fire originating from a 0.6 x 0.6 m^2 tray was located at floor level, below a thick walled steel tube (Figure 2.7). The Fine Water Spray Nozzle was located directly above the pool, first hitting the steel tube. Prior to ignition of the pool the steel tube was heated by a propane torch to a temperature above 700°C in a central area.

File	Nozzle	Water pressure bar	Air pressure bar	Mass rate l/min	Result
FINOZ 22	Jet 10 l/min, 90°	3.9	5.0	8.5	Extinguished in 58 s
FINOZ 24	Jet 10 l/min, 90°	3.8	5.1	8.2	Extinguished in 43 s
FINOZ 26	Jet 10 l/min, 90°	3.4	4.9	7.5	Extinguished in 36 s

3.1.6 Lubricating oil spray fire, well ventilated, about 1 MW

A spray of lubrication oil, type Shell Tellus T 32, formed by a Fine Spray Nozzle, Jetmist 2.5 l/min, 60°, supplied with lubricating oil instead of water was giving a 1 MW fire. The spray was directed horizontally, along the north/south centerline of the test compartment (Figure 2.6).

File	Nozzle	Water pressure bar	Air pressure bar	Mass rate l/min	Result
FINOZ 30	Jet 10 l/min, 90°	3.9	5.1	8.4	Extinguished in 4 min 8 s.
FINOZ 31	Jet 10 l/min, 90°	3.8	5.1	8.3	Extinguished in 59 s

FINOZ 30 had a very long pre-burn time before the spray was activated, due to problems getting a stable spray of oil. The floor and the whole fire compartment was hot, and the oil droplets which penetrated the water spray and hit the floor self ignited outside the cover area of the water spray. The hot floor outside the cover area explains the difference in time to extinguishment to FINOZ 31.

3.1.7 Lubricating oil pool fire, well ventilated, with a hot tube above the pool

A lubrication oil pool fire originating from a 0.6 x 0.6 m^2 tray was located at floor level, below a thick walled steel tube (Figure 2.7). The lubrication oil was of the type Shell Tellus T 32. The Fine Water Spray Nozzle was located directly above the pool, first hitting the steel tube. Prior to ignition of the pool the steel tube was heated by a propane torch to a temperature above 700°C in a central area.

File	Nozzle	Water pressure bar	Air pressure bar	Mass rate l/min	Result
FINOZ 29	Jet 10 l/min, 90°	3.9	5.2	8.3	Extinguished in 25 s

3.1.8 Hot metal surfaces

A steel tube with thick walls was heated by a propane torch. When the maximum measured steel temperature reached 750 °C, the cooling time history was logged. In test FINOZ 21 the water spray was activated immediately after the propane torch was turned off. In FINOZ 23 the tube was left cooling without any spray, just by air.

File	Nozzle	Water pressure bar	Air pressure bar	Mass rate l/min	Result
FINOZ 21	Jet 10 l/min, 90°	3.8	5.2	8.0	Steel temp. was reduced to 200°C 18 min. after jet off.
FINOZ 23	-	-	-	-	Steel temp. was reduced to 200°C 37 min. after jet off.

3.1.9 Fire in insulation mats soaked with diesel or lubricating oil

The tests were done with a mat of KAOWOOL ceramic fibre, 25 mm thick, wrapped around a section of the tube (Figure 2.7). The test procedure was: Heating the tube by a propane jet, impinging at a section 0.55 m off centre of the tube, until the maximum surface temperature was about 750 °C. Then diesel was pumped into the 0.6 m x 0.6 m pool below the tube, and simultaneously pumped onto the insulation mat from above. The jet was then turned off, and the fire was developing both in the pool and in the insulation. After about 5 minutes the insulation was soaked with diesel, which was burning all around the tube. The spray was then activated.

In FINOZ 27 the procedure was changed a little. The width of the insulation mat was reduced to 0.2 m. The pool fire was not activated, and 1 litre of diesel oil was poured upon the insulation mat in about 3-4 minutes. The spray was activated when the flames were surrounding the tube, after the diesel supply had been switched off.

In FINOZ 28 the same procedure as in FINOZ 27 was followed. The only difference in conditions was ventilation. Most of the air inlet opening was blocked, leaving only a 0.5 m wide opening at the centre.

File	Nozzle	Water pressure bar	Air pressure bar	Mass rate l/min	Result
FINOZ 25	Jet 10 l/min, 90°	3.6	5.0	8.0	Not extinguished
FINOZ 27	Jet 10 l/min, 90°	3.2	?	?	Not extinguished
FINOZ 28	Jet 10 l/min, 90°	4.2	5.0	9.5	Not extinguished

3.2 Phase II: Full scale verification in laboratory turbine hood

The experiments were performed in a full scale model of a turbine hood on the Ula platform in the North Sea. Inner dimensions of the turbine hood was 5.5 x 3.5 x 3.9 m (L x W x H). A steel mock-up of the turbine body was located inside, internally heated by propane to simulate the conditions of a running turbine. The turbine hood was mechanically ventilated with a realistic air change rate.
The fire sources identified by the producer of the turbine, ABB-Stahl, were diesel oil or natural gas from the fuel supply system, lubricating oil from the lubricating system and hydraulic oil from a hydraulic driven ventilation fan.

The most critical fire scenarios and the most suitable Fine Spray Nozzle were chosen based on the results and experience from Phase I.

The scope of the experiments in Phase II was to verify that the Fine Water Spray System can extinguish real fires which may occur in the turbine hood, and identify important features of the system design and operational mode. A special task was to identify design parameters like minimum spray nozzle number and optimum location, in addition to spraying sequence considering a restricted time span of 10 [s] duration of one "shot".

3.2.1 Main results

Main results from Phase II of the experiments are given in Table 3.10 on Pages 30 - 51.

Graphical presentation of the results from each experiment is given in the Technical report from Phase II /5/. Data files in Lotus Symphony spreadsheet format of all experiments and video recordings from most of the experiments exist at SINTEF NBL.

Table 3.10 contains the following information:

Fire characteristics: Type and location of fire source

Ventilation conditions: Operation of ventilation dampers, opening and closing the door

Spray nozzle configuration: Type and position of Fine Water Spray Nozzles activated in each experiment

Execution of experiment, including Spray sequence: A short log of the main events of the experiment, with indication of time of ignition of fires, operation of vent dampers and door, duration of spray fires and activation of Fine Water Spray Nozzles.

Result, including time to extinguishment: Main conclusions of the experiment, with comments on the result. The time to extinguishment is based on the following criteria: Visual observations (if possible), minimum oxygen concentration and/or max temperature below 300°C

Table 3.10 Main results from experiments in the turbine hood of Phase II.

Experiment No.	Fire characteristics	Ventilation conditions		Spray nozzle configuration. High+low	Execution of experiment, including Spray sequence. "Shot" means activation of water spray.	Result, including time to extinguishment.
		Door	Ventilation dampers			
TURBIN 1	Propane jet, about 1 MW. Cold turbine.	Closed	Closed after 30 [s]	0	No spray	About 60 [s] after closing the ventilation ducts. Extinguished by oxygen starvation.
TURBIN 2	1 pool below turbine, close to the south wall (P1) + Diesel spray onto hot turbine.	Open	Open	8 + 4	Pre-burn time with door open and ventilation running: 30 [s] First shot of 10 [s]	Extinguished immediately, approximately after 3 - 4 [s]
TURBIN 3	1 pool below turbine, close to the south wall (P1) + Diesel spray onto **cold** turbine.	Open	Open	8 + 4	Pre-burn time with door open and ventilation running: 30 [s] 1 shot of 10 [s]	Extinguished immediately, approximately after 5 - 6 [s]
TURBIN 4	1 pool below turbine, close to the south wall (P1) + Diesel spray onto hot turbine. (S1)	Open	Open	8 + 4	Pre-burn time with door open and ventilation running: 30 [s] 1 shot of 10 [s] Diesel spray on 20 [s] after water spray off.	Extinguished immediately, approximately after 5 - 6 [s]
TURBIN 5	3 pools, one below turbine (P1), one in sump inside door, below grating (P4), and one in sump at east wall (P3) + Diesel spray onto hot turbine. (S1)	Open	Open	8 + 4	Pre-burn time with door open and ventilation running: 30 [s] 1 shot of 10 [s]	Extinguished after 13 [s]
TURBIN 6	3 pools, one below turbine (P1), one in sump inside door, below grating (P4), and one in sump at east wall (P3)	Open, closed 5 [s] after water spray on	Open, closed 5 [s] after water spray on	8 + 4	Pre-burn time with door open and ventilation running: 30 [s] 1 shot of 10 [s]	Extinguished after 10 [s] The pool below the grating (P4), just inside the door, was burning longer than the other pools.

Experiment No.	Fire characteristics	Ventilation conditions		Spray nozzle configuration. High+low	Execution of experiment, including Spray sequence. "Shot" means activation of water spray.	Result, including time to extinguishment.
		Door	Ventilation dampers			
TURBIN 7	3 pools, one below turbine (P1), one in sump inside door, below grating (P4), and one in sump at east wall (P3)	Open	Open	8 + 4	Pre-burn time with door open and ventilation running: 30 [s] 1 shot of 10 [s]	Extinguished after 17 [s] The pool below the grating (P4), just inside the door, was burning longer than the other pools.
TURBIN 8	3 pools, one below turbine (P1), one in sump inside door, below grating (P4), and one in sump at east wall (P3) + Diesel spray onto hot turbine, directed both onto hot steel surface and uncovered insulation. (S2)	Open, But partly blocked, lower part. Closed after 210 [s]	Open, closed after 210 [s]	8 + 4	Pre-burn time with door open and ventilation running: 30 [s] 1. shot: 10 [s] Pools (P1+P3) + spray (S2) extinguished Delay: 45 [s] 2. shot: 15 [s] Delay: 45 [s] 3. shot: 20 [s] Delay: 35 [s] Doors and dampers shut 4. shot: 15 [s] Pool (P4) extinguished	2 pools + spray extinguished after 10 [s], 1 pool (P4) still burning. (P4) was located just inside the door, with air supply from outside. In this experiment (different from TURBIN 5,6 and 7) the inflowing air was distorted by the partly blocked door opening, and the resulting flow seemed to prevent the water droplets or water vapour from reaching the pool surface. Last pool extinguished after 215 [s] when door and ventilation ducts were closed. Last pool (P4) extinguished after 215 [s], after closing the door and ventilation ducts.
TURBIN 9	3 pools, 2 below turbine,(P1 +P2), 1 in sump at east wall (P3) Diesel spray did not function	Open	Open	6 + 2	Pre-burn time with door open and ventilation running: 30 [s] 1 shot of 10 [s]	Extinguished after 10 [s]
TURBIN 10	3 pools, 2 below turbine,(P1 +P2), 1 in sump at east wall (P3) + Diesel spray onto hot turbine, directed both onto hot steel surface and uncovered insulation. (S2)	Open	Open	6 + 2	Pre-burn time with door open and ventilation running: 35 [s] 1 shot of 10 [s] Diesel spray continuing 30 [s] after water spray off.	Extinguished after 4 - 5 [s]

Experiment No.	Fire characteristics	Ventilation conditions		Spray nozzle configuration. High+low	Execution of experiment, including Spray sequence. "Shot" means activation of water spray.	Result, including time to extinguishment.
		Door	Ventilation dampers			
TURBIN 11	3 pools, 2 below turbine,(P1 +P2), 1 in sump at east wall (P3) + Diesel spray onto hot turbine, directed both onto hot steel surface and uncovered insulation. (S2)	Closed 15 [s] after ignition	Open	6 + 2	Pre-burn time : 30 [s] 1 shot of 10 [s] Diesel spray continuing 20 [s] after water spray off.	Extinguished after 4-5 [s]
TURBIN 12	3 pools, 2 below turbine,(P1 +P2), 1 in sump at east wall (P3). + Diesel spray onto hot turbine, directed both onto hot steel surface and uncovered insulation. (S2)	Closed 15 [s] after ignition	Inlet closed when water spray shut off, outlet open.	6 + 2	Pre-burn time : 40 [s] 1 shot of 10 [s] Diesel spray continuing 30 [s] after water spray off.	Extinguished after 4 - 5 [s]
TURBIN 13	3 pools, 2 below turbine,(P1 +P2), 1 in sump at east wall (P3). + Diesel spray onto hot turbine, directed both onto hot steel surface and uncovered insulation. (S2)	Open	Open	8 + 4	Pre-burn time with door open and ventilation running: 30 [s] 1 shot of 10 [s] Diesel spray off when water spray off.	Extinguished after 4 - 5 [s]
TURBIN 14	3 pools, 2 below turbine,(P1 +P2), 1 in sump at east wall (P3). + Diesel spray onto hot turbine, directed both onto hot steel surface and uncovered insulation. (S2)	Open	Open	8 + 4	Pre-burn time with door open and ventilation running: 40 [s] 1 shot of 10 [s] Diesel spray off when water spray off.	Extinguished after 4 - 5 [s]

Experiment No.	Fire characteristics	Ventilation conditions		Spray nozzle configuration. High+low	Execution of experiment, including Spray sequence. "Shot" means activation of water spray.	Result, including time to extinguishment.
		Door	Ventilation dampers			
TURBIN 15	3 pools, 2 below turbine,(P1 +P2), 1 in sump at east wall (P3). + Diesel spray onto hot turbine, directed both onto hot steel surface and uncovered insulation. (S2)	Open	Open	8 + 4	Pre-burn time with door open and ventilation running: 40 [s] t = 0 : 3 pools and Diesel spray ignited 40 : water spray on 50 : water spray off 50 : Diesel spray off	Extinguished after 4 - 5 [s]
TURBIN 16	No fire, hot turbine	Closed 10 [s] before water spray on.		8 + 4	1 shot of 10 [s]	Checking the cooling behaviour of the turbine mock-up.
TURBIN 17	3 pools, 2 below turbine,(P1 +P2), 1 in sump at east wall (P3). + Diesel spray onto hot turbine, directed both onto hot steel surface and uncovered insulation. (S2)	Open	Open	8 + 4	Pre-burn time with door open and ventilation running: 45 [s] t = 0 : 3 pools and Diesel spray ignited 45 : water spray on 55 : water spray off 55 : Diesel spray off	Extinguished after 4 - 5 [s]
TURBIN 18	3 pools, 2 below turbine,(P1 +P2), 1 in sump at east wall (P3). + Diesel spray onto hot turbine, directed both onto hot steel surface and uncovered insulation. (S2)	Open	Open	8 + 4	Pre-burn time with door open and ventilation running: 40 [s] t = 0 : 3 pools and Diesel spray ignited 40 : water spray on 50 : water spray off 50 : Diesel spray off	Extinguished after 5 - 6 [s]

Experiment No.	Fire characteristics	Ventilation conditions		Spray nozzle configuration. High+low	Execution of experiment, including Spray sequence. "Shot" means activation of water spray.	Result, including time to extinguishment.
		Door	Ventilation dampers			
TURBIN 19	Diesel spray onto hot turbine, directed towards uncovered insulation, (S3). No air is supplied with the Diesel spray.	Open, closed just before the 3. shot with water	Open, closed just before the 3. shot with water	8 + 4	t = 0 : Diesel spray ignited 35 : water spray on (1.shot) 40 : flames extinguished 45 : water spray off 85 : re-ignition in insulation mats 85 : water spray on (2. shot) 90 : flames extinguished 95 : water spray off 95 : Diesel spray off 180 : re-ignition in insulation mats 195 : closed door and ventilation 195 : water spray on (3. shot) 200 : flames extinguished 435 : re-ignition in insulation mats water spray on for 10 [s] (4. shot) fire in insulation not extinguished water spray on 25 [s] (5. shot) fire in insulation not extinguished water spray on 40 [s] (6. shot) fire in insulation extinguished after 25 [s] 840 : re-ignition in insulation mats 1260 : flames extinguished, no Diesel left	Extinguishment of Diesel spray obtained immediately, but much Diesel was soaked into the uncovered insulation. After a while, the Diesel penetrated through the insulation, hit the hot metal surface, evaporated, and heated to the self-ignition temperature of Diesel. The oxygen concentration in the turbine hood had then become sufficiently high to provide ignition conditions in the insulation.

Experiment No.	Fire characteristics	Ventilation conditions		Spray nozzle configuration. High+low	Execution of experiment, including Spray sequence. "Shot" means activation of water spray.	Result, including time to extinguishment.
		Door	Ventilation dampers			
TURBIN 20	Diesel spray onto hot turbine, directed towards uncovered insulation, (S3). No air is supplied with the Diesel spray.	Closed 12 [s] after Diesel spray on.	Closed when 1. shot water spray was turned on.	8 + 4	t = 0 : Diesel spray onto hot steel surface and insulation mats 4 : self-ignition of Diesel spray 12 : door closed 50 : Diesel spray off 60 : ventilation closed 60 : water spray on (1. shot) flames extinguished 70 : water spray off 170 : re-ignition in insulation mats 185 : water spray on (2. shot) 195 : water spray off : flames extinguished : fire reignited in the insulation mats	As long as the fire in the insulation mat is relatively large, it is extinguished by the water spray. When the fire becomes smaller, it can not be extinguished. The production of water vapour for inerting the enclosure is not sufficient to prevent air to penetrate into the insulation, where ignitable Diesel vapour exists close to the hot metal surface.
TURBIN 21	Diesel spray onto hot turbine, directed towards uncovered insulation, (S3). No air is supplied with the Diesel spray.	Closed 25 [s] after the Diesel spray was turned on	Closed after the Diesel spray was ignited, before the first shot with water spray.	8 + 4	t = 0 : Diesel spray on 10 : ignited with torch 25 : door closed 30 : ventilation off 75 : Diesel spray off 80 : water spray on (1. shot) 90 : water spray off flames extinguished 440 : re-ignition in insulation 470 : water spray on (2. shot) 480 : water spray off flames extinguished 890 : re-ignition in insulation 995 : water spray on (3. shot) not extinguished 3 extra shots of 10 [s] water did not extinguish the fire in the insulation	As long as the fire in the insulation mat is relatively large, it is extinguished by the water spray. When the fire becomes smaller, it can not be extinguished. The production of water vapour for inerting the enclosure is not sufficient to prevent air to penetrate into the insulation, where ignitable Diesel vapour exists close to the hot metal surface.

Experiment No.	Fire characteristics	Ventilation conditions		Spray nozzle configuration. High+low	Execution of experiment, including Spray sequence. "Shot" means activation of water spray.	Result, including time to extinguishment.
		Door	Ventilation dampers			
TURBIN 22	Diesel spray onto hot turbine, directed towards uncovered insulation, (S3). No air is supplied with the Diesel spray.	Closed 15 [s] after the Diesel spray was turned on.	Closed 30 [s] after the Diesel spray was turned on, before the first shot with water spray.	8 + 4	t = 0 : Diesel spray on 10 : ignited with torch 25 : door closed 30 : ventilation off 75 : Diesel spray off 80 : water spray on (1. shot) 90 : water spray off flames extinguished 150 : water spray on (2. shot) 160 : water spray off 450 : water spray on (3. shot) 460 : water spray off This sequence of 10 [s] water spray every fifth minute was repeated until a number of 9 shots had been released. 1380 : re-ignition in insulation A 10. shot of water did not extinguish the fire	A preventive sequence of 10 [s] shots, one after a preburn time, then one more after 1 minute, and then repeated every 5 minutes, was tested. This sequence prevented re-ignition in the insulation for 23 minutes, but re-ignition then occurred. The temperature of the steel below the uncovered insulation was still well above self ignition temperature of the Diesel at the time of re-ignition.

Experiment No.	Fire characteristics	Ventilation conditions		Spray nozzle configuration. High+low	Execution of experiment, including Spray sequence. "Shot" means activation of water spray.	Result, including time to extinguishment.
		Door	Ventilation dampers			
TURBIN 23	Diesel spray onto hot turbine, directed towards uncovered insulation, (S3). No air is supplied with the Diesel spray. FIRESTOP 107 added to the water in the tank, 6%	Closed 35 [s] after the Diesel spray was turned on.	Closed 30 [s] after the Diesel spray was turned on, before the first shot with water spray	8+ 4 Firestop 107, 6%	t = 0 : Diesel spray on 10 : ignited with torch 25 : door closed 30 : ventilation off 60 : water spray on (1. shot) 70 : water spray off flames extinguished 100 : Diesel spray off 150 : water spray on (2. shot) 160 : water spray off 450 : water spray on (3. shot) 460 : water spray off This sequence of 10 [s] water spray every fifth minute was repeated until a number of 7 shots had been released. No re-ignition of the fire in the insulation mat occurred.	A preventive sequence of 10 [s] shots, one after a preburn time, then one more after 1 minute, and then repeated every 5 minutes, was tested. 6 % Firestop 107 was added to the water. This sequence prevented re-ignition in the insulation.

Experiment No.	Fire characteristics	Ventilation conditions		Spray nozzle configuration. High+low	Execution of experiment, including Spray sequence. "Shot" means activation of water spray.	Result, including time to extinguishment.
		Door	Ventilation dampers			
TURBIN 24	Diesel spray onto hot turbine, directed towards uncovered insulation, (S3). No air is supplied with the Diesel spray. FIRESTOP 107 added to the water in the tank, 3%	Closed 25 [s] after the Diesel spray was turned on.	Closed 30 [s] after the Diesel spray was turned on, before the first shot with water spray.	8 + 4 Firestop 107, 3%	t = 0 : Diesel spray on 10 : ignited with torch 25 : door closed 30 : ventilation off 60 : water spray on (1. shot) 70 : water spray off flames extinguished 105 : Diesel spray off 150 : water spray on (2. shot) 160 : water spray off 450 : water spray on (3. shot) 460 : water spray off This sequence of 10 [s] water spray every fifth minute was repeated until a number of 8 shots had been released. No re-ignition of the fire in the insulation mat occurred.	A preventive sequence of 10 [s] shots, one after a preburn time, then one more after 1 minute, and then repeated every 5 minutes, was tested. 3 % Firestop 107 was added to the water. This sequence prevented re-ignition in the insulation.

Experiment No.	Fire characteristics	Ventilation conditions		Spray nozzle configuration. High+low	Execution of experiment, including Spray sequence. "Shot" means activation of water spray.	Result, including time to extinguishment.
		Door	Ventilation dampers			
TURBIN 25	Diesel spray onto hot turbine, directed towards uncovered insulation, (S3). No air is supplied with the Diesel spray. FIRESTOP 107 added to the water in the tank, 3%	Closed 35 [s] after the Diesel spray was turned on.	Closed 35 [s] after the Diesel spray was turned on, before the first shot with water spray.	8 + 4 Firestop 107, 3%	t = 0 : Diesel spray on 10 : ignited with torch 25 : door closed 30 : ventilation off 60 : water spray on (1. shot) 70 : water spray off flames extinguished 105 : Diesel spray off 1020 : re-ignition in insulation mats 1070 : water spray on (2. shot) 1080 : water spray off flames extinguished 1185 : water spray on (3. shot) 1195 : water spray off flames extinguished 2080 : re-ignition in insulation 2120 : water spray on (4. shot) 2130 : water spray off not extinguished 2250 : ventilation opened, door opened	A sequence with one shot of water lasting 10 [s], after a preburn time of 60 [s], extinguished the fire. The fire was at that time almost self-extinguished due to oxygen starvation. The fire re-ignited in the insulation about 16 minutes after this shot of water, was extinguished again by a 10 [s] shot, but reignited after about 2 minutes. One more 10 [s] shot extinguished the fire, but a third re-ignition occurred about 15 minutes later. This fire was so small that it was not extinguished by a shot of 10 [s], and it was left burning.

Experiment No.	Fire characteristics	Ventilation conditions		Spray nozzle configuration. High+low	Execution of experiment, including Spray sequence. "Shot" means activation of water spray.	Result, including time to extinguishment.
		Door	Ventilation dampers			
TURBIN 26	Diesel spray onto hot turbine, directed towards uncovered insulation (S3). No air is supplied with the Diesel spray. 3% FIRESTOP 107 added to the water in the tank.	Door closed 40 seconds after ignition of Diesel spray and opened after 43 minutes.	Closed 30 [s] after the Diesel spray was turned on, before the first shot with water spray.	8 + 2 Firestop 107, 3%	t = 0 : Diesel spray on 10 : ignited with torch 30 : ventilation off 40 : door closed 90 : water spray on (1. shot) 100 : water spray off flames extinguished 120 : Diesel spray off 400 : water spray on (2. shot) 410 : water spray off 600 : water spray on (3. shot) 610 : water spray off This sequence was repeated, until a number of 8 shots had been released. No re-ignition of the fire in the insulation mat occurred.	A preventive sequence of 8 shots, one after a preburn time, and a 10 [s] shot repeated every 5 minutes, was tested. 3 % Firestop 107 was added to the water. This sequence prevented re-ignition in the insulation. After 43 minutes the door was opened and a torch was used to test if there was remaining Diesel in the insulation mat. The fire was ignited, and burned for a long time.
TURBIN 27	3 pools, 2 below turbine,(P1 +P2), 1 in sump at east wall (P3). + Diesel spray (S3) onto cold turbine. Uncovered insulation mats removed from the turbine. 4 small boxes with diesel and a wick was located in the corners of the enclosure, 3 at a high position and 1 at floor level, close to the door.	Door closed max 10 [s] after Diesel spray ignited.	Ventilation closed when Diesel spray was ignited.	No nozzles activated.	4 small boxes were ignited before the pools were ignited. t = 0 : 3 pools were ignited 8 : Diesel spray ignited 15 : ventilation dampers shut 20 : door closed 33 : fire at maximum 72 : Oxygen concentration start increase 78 : Max temp. below 300°C	Self-extinguishing occurred within 60 [s] after the door was closed. Minimum Oxygen concentration at self extinguishment was 8.7 %. Maximum CO_2 concentration was 8.1 %, and maximum CO concentration was 7630 ppm. Maximum average temperature in the hood was 375 °C.

Experiment No.	Fire characteristics	Ventilation conditions		Spray nozzle configuration. High+low	Execution of experiment, including Spray sequence. "Shot" means activation of water spray.	Result, including time to extinguishment.
		Door	Ventilation dampers			
TURBIN 28	3 pools, 2 below turbine,(P1 +P2), 1 in sump at east wall (P3). + Diesel spray (S3) onto cold turbine. Uncovered insulation mats removed from the turbine. 4 small boxes with diesel and a wick was located in the corners of the enclosure, 3 at a high position and 1 at floor level, close to the door.	Door closed max 10 [s] after Diesel spray ignited.	Ventilation closed 45 [s] after the Diesel spray was ignited.	4 nozzles high, north (1,2,3,4) + 2 nozzles low,- north (5,6)	4 small boxes were ignited before the pools were ignited. t = 0 : 3 pools were ignited 10 : Diesel spray ignited 20 : door closed 55 : ventilation dampers shut 65 : fire at maximum 70 : water spray on 75 : fire extinguished 75 : Diesel spray off 80 : water spray off	The fire was on the point of self-extinguishment before the water spray was turned on. The water spray was run about 10 [s], and the fire was extinguished in 3-4 [s] (visual), 12 [s] (Oxygen minimum), 15-20 [s] (max temp 300°C). The resolution in data logging is 5 [s], and the best estimate of extinguishing time is 5 [s].
TURBIN 29	3 pools, 2 below turbine,(P1 +P2), 1 in sump at east wall (P3). + Diesel spray (S3) onto cold turbine. Uncovered insulation mats removed from the turbine. 4 small boxes with diesel and a wick was located in the corners of the enclosure, 3 at a high position and 1 at floor level, close to the door.	Door closed max 10 [s] after Diesel spray ignited.	Ventilation closed 30 [s] after the Diesel spray was ignited.	0 nozzles at high position, 2 at low position (5,6)	4 small boxes were ignited before the pools were ignited. t = 0 : 3 pools were ignited 10 : Diesel spray ignited 20 : door closed 30 : ventilation dampers shut 55 : fire at maximum 65 : water spray on 68 : fire extinguished 75 : water spray off 80 : Diesel spray off	The fire was at the limit of self-extinguishment due to oxygen starvation when the water spray was turned on. The fire was extinguished in 3-4 [s] (visual). Oxygen minimum occurred before water spray activation.

Experiment No.	Fire characteristics	Ventilation conditions		Spray nozzle configuration. High+low	Execution of experiment, including Spray sequence. "Shot" means activation of water spray.	Result, including time to extinguishment.
		Door	Ventilation dampers			
TURBIN 30	1 pool in sump at east wall (P3) Uncovered insulation mats removed from the turbine. 4 small boxes with diesel and a wick was located in the corners of the enclosure, 3 at a high position and 1 at floor level, close to the door.	Door closed max 40 [s] after the pool was ignited.	Ventilation closed 50 [s] after the pool was ignited.	2 nozzles at low position, No. 5 + 6. No nozzles at high position	4 small boxes were ignited before the pools were ignited. t = 0 : 1 pool were ignited 40 : door closed 50 : ventilation dampers shut 70 : water spray on 80 : water spray off 120 : oxygen minimum 120 : Max temp below 300°C	Not extinguished by the water spray. No flames were seen but the fire was propably burning with small flames Minimum oxygen and max temp. below 300°C were measured about 40 [s] after the water spray was turned off. Flames were seen above the pool after about 7 minutes, when the oxygen concentration had reached about 18%. The fire ended, most probable due to lack of fuel.
TURBIN 31	1 pool in sump at east wall (P3) Uncovered insulation mats removed from the turbine. 4 small boxes with diesel and a wick was located in the corners of the enclosure, 3 at a high position and 1 at floor level, close to the door.	Door closed max 10 [s] after the pool was ignited.	Ventilation closed 20 [s] after the pool was ignited.	2 nozzles high, central position, north, (2,3) 2 nozzles at low, central position, north, (5,6)	4 small boxes were ignited before the pools were ignited. t = 0 : 1 pool were ignited 10 : door closed 20 : ventilation dampers shut 30 : water spray on 40 : water spray off 120 : oxygen minimum 120 : Max temp below 300°C	Not extinguished by the water spray. Pool extinguished about 40 [s] after the water spray was turned off, due to oxygen starvation (minimum oxygen, max temp below 300°C). To check if there were any fuel left in the trays, three pools and 4 boxes were manually reignited after the test. All fires were then extinguished within a 20 [s] spray.
TURBIN 32	1 pool in sump at east wall (P3) Uncovered insulation mats removed from the turbine. 4 small boxes with diesel and a wick was located in the corners of the enclosure, 3 at a high position and 1 at floor level, close to the door.	Door closed max 10 [s] after the pool was ignited.	Ventilation closed 20 [s] after the pool was ignited.	4 nozzles high position, north, (1,2,3,4) 2 nozzles at low, central position, north, (5,6)	4 small boxes were ignited before the pools were ignited. t = 0 : 1 pool were ignited 10 : door closed 20 : ventilation dampers shut 30 : water spray on 40 : water spray off 120 : oxygen minimum 120 : Temp max, about 300° C.	Not extinguished by the water spray. No flames were seen, but the fire was probably burning with small flames. Minimum oxygen was measured about 80 [s] after the water spray was turned off. Flames were observed at the pool after about 7 minutes. The fire was burning until the oxygen concentration was about 16.5 %, and was at the limit of self-extinguishment when a second shot of water was introduced. The fire was then permanently extinguished.

Experiment No.	Fire characteristics	Ventilation conditions		Spray nozzle configuration. High+low	Execution of experiment, including Spray sequence. "Shot" means activation of water spray.	Result, including time to extinguishment.
		Door	Ventilation dampers			
TURBIN 33	1 pool in sump at east wall (P3). Uncovered insulation mats removed from the turbine. 4 small boxes with diesel and a wick was located in the corners of the enclosure, 3 at a high position and 1 at floor level, close to the door.	Door closed max 10 [s] after the pool was ignited.	Ventilation closed 20 [s] after the pool was ignited.	6 nozzles high position (1,2,-3,4,7,8) 2 nozzles at low, central position, north, (5,6)	4 small boxes were ignited before the pools were ignited. t = 0 : 1 pool were ignited 15 : door closed 25 : ventilation dampers shut 44 : water spray on 58 : water spray off 255 : flames seen above the pool 410 : water spray on 420 : water spray off	Not extinguished by the water spray. No flames were seen, but the fire was probably burning with small flames. Minimum oxygen was measured about 120 [s] after the water spray was turned off. Flames were observed at the pool about 5.5 minutes after the first water spray. The fire was burning until the oxygen concentration was just below 18%, and a second shot of water was introduced. The fire was then permanently extinguished.
TURBIN 34	1 pool in sump at east wall (P3) Uncovered insulation mats removed from the turbine. 4 small boxes with diesel and a wick was located in the corners of the enclosure, 3 at a high position and 1 at floor level, close to the door.	Door closed max 15 [s] after the pool was ignited.	Ventilation closed 20 [s] after the pool was ignited.	6 nozzles high position (1,2,-3,4,9,10) 2 nozzles at low, central position, north, (5,6)	4 small boxes were ignited before the pools were ignited. t = 0 : 1 pool were ignited 15 : door closed 20 : ventilation dampers shut 40 : water spray on 51 : water spray off 130 : flames seen above the pool 255 : water spray on 265 : water spray off	Not extinguished by the water spray. No flames were seen, but the fire was probably burning with small flames.Flames were observed at the pool about 80 [s] after the water spray was turned off. Minimum oxygen was measured about 150 [s] after the water spray was turned off. A second shot of water was introduced. The fire was then permanently extinguished.
TURBIN 35	1 pool in sump at east wall (P3) Uncovered insulation mats removed from the turbine. 4 small boxes with diesel and a wick was located in the corners of the enclosure, 3 at a high position and 1 at floor level, close to the door.	Door closed max 15 [s] after the pool was ignited.	Ventilation closed 20 [s] after the pool was ignited.	8 nozzles high position (1,2,-3,4,7,8,9,10) 4 nozzles at low, central position, (5,6-,11,12)	4 small boxes were ignited before the pools were ignited. t = 0 : 1 pool were ignited 15 : door closed 20 : ventilation dampers shut 31 : water spray on 43 : water spray off 50 : flames seen above the pool 200 : water spray on 219 : water spray off	Not extinguished by the water spray. Flames were observed at the pool immediately after the first water spray. A second shot of water was introduced 1.5 minutes after the first. The fire was still burning, reaching a minimum oxygen concentration of 15% about simultaneously with the end of the second water spray. The fire was then permanently extinguished. The maximum measured temperature was never reaching 300°C.

Experiment No.	Fire characteristics	Ventilation conditions		Spray nozzle configuration. High+low	Execution of experiment, including Spray sequence. "Shot" means activation of water spray.	Result, including time to extinguishment.
		Door	Ventilation dampers			
TURBIN 36	1 pool in sump at east wall (P3) Uncovered insulation mats removed from the turbine. 4 small boxes with diesel and a wick was located in the corners of the enclosure, 3 at a high position and 1 at floor level, close to the door.	Door closed max 10 [s] after the pool was ignited.	Ventilation closed 10 [s] after the pool was ignited.	6 nozzles high position (1,2,3,-7,8,9) 0 nozzles at low position.	4 small boxes were ignited before the pools were ignited. t = 0 : 1 pool were ignited 10 : door closed 10 : ventilation dampers shut 15 : water spray on 35 : water spray off 40 : flames seen above the pool 165 : water spray on 185 : water spray off	Not extinguished by the 20 [s] water spray. Flames were observed at the pool immediately after the first water spray. A second shot of water was introduced 2 minutes after the first. The fire was still burning, reaching a minimum oxygen concentration of 14% about simultaneously with the end of the second water spray. The fire was then permanently extinguished. The maximum measured temperature passed 300°C just before the second water spray.
TURBIN 37	1 pool in sump at east wall (P3) Uncovered insulation mats removed from the turbine. 4 small boxes with diesel and a wick was located in the corners of the enclosure, 3 at a high position and 1 at floor level, close to the door.	Door closed max 15 [s] after the pool was ignited.	Ventilation closed 18 [s] after the pool was ignited.	6 nozzles high position (1,2,3,-7,8,9) 0 nozzles at low position	4 small boxes were ignited before the pools were ignited. t = 0 : 1 pool were ignited 15 : door closed 18 : ventilation dampers shut 22 : water spray on 42 : water spray off 50 : flames seen above the pool 192 : water spray on 212 : water spray off	Not extinguished by the 20 [s] water spray. Flames were observed at the pool immediately after the first water spray. A second 20 [s] shot of water was introduced 2.5 minutes after the first. The fire was still burning, reaching a minimum oxygen concentration of 13.5% about simultaneously with the end of the second water spray. The fire was then permanently extinguished. The maximum measured temperature increased to above 300°C after the first water spray, and had been reduced below 300° C at the start of the second water spray.

Experiment No.	Fire characteristics	Ventilation conditions		Spray nozzle configuration. High+low	Execution of experiment, including Spray sequence. "Shot" means activation of water spray.	Result, including time to extinguishment.
		Door	Ventilation dampers			
TURBIN 38	1 pool in sump at east wall (P3) Uncovered insulation mats removed from the turbine. 4 small boxes with diesel and a wick was located in the corners of the enclosure, 3 at a high position and 1 at floor level, close to the door.	Door closed max 14 [s] after the pool was ignited.	Ventilation closed 18 [s] after the pool was ignited.	6 nozzles high position (2,3,4-,8,9,10) 0 nozzles at low position	4 small boxes were ignited before the pools were ignited. t = 0 : 1 pool were ignited 14 : door closed 17 : ventilation dampers shut 20 : water spray on 34 : water spray off 40 : flames seen above the pool 600 : water spray on 610 : water spray off extinguished	Not extinguished by the 20 [s] water spray. Flames were observed at the pool immediately after the first water spray. Minimum oxygen was measured about 160 [s] after the water spray was turned off. No flames were seen, but the fire was probably burning with small flames. Flames were observed about 6 minutes after first shot of water was turned off, keeping an oxygen concentration of about 18% A second shot of water was introduced 9.5 minutes after the first. No flames were observed after this. The maximum measured temperature increased to above 300°C after the first water spray, and had been reduced about 200° C at the start of the second water spray.
TURBIN 39	1 pool in sump at east wall (P3) Uncovered insulation mats removed from the turbine. 4 small boxes with diesel and a wick was located in the corners of the enclosure, 3 at a high position and 1 at floor level, close to the door.	Door closed max 17 [s] after the pool was ignited.	Ventilation closed 18 [s] after the pool was ignited.	6 nozzles high position (2,3,4-,8,9,10) 2 nozzles at low position, close to the pool, (6,12)	4 small boxes were ignited before the pools were ignited. t = 0 : 1 pool were ignited 17 : door closed 18 : ventilation dampers shut 20 : water spray on 38 : water spray off 45 : flames seen above the pool 180 : almost self extinguished, O_2 concentration 14% 360 : vent dampers opened pool burning 460 : water spray on 480 : water spray off extinguished	Not extinguished by the 20 [s] water spray. Flames were observed at the pool immediately after the first water spray. Minimum oxygen was measured about 140 [s] after the water spray was turned off. No flames were seen, but the fire was probably burning with small flames. Flames were observed after while, and were growing bigger when the oxygen concentration reached about 19% A second shot of water was introduced 7 minutes after the first. No flames were seen after this, but it was not certain if there were any fuel left in the tray. The maximum measured temperature increased to above 300°C after the first water spray. Then minimum oxygen concentration of about 14% was reached, and the temperature decreased to 130° C at minimum.The temperature increased to about 230° C before the start of the second water spray.

Experiment No.	Fire characteristics	Ventilation conditions		Spray nozzle configuration. High+low	Execution of experiment, including Spray sequence. "Shot" means activation of water spray.	Result, including time to extinguishment.
		Door	Ventilation dampers			
TURBIN 40	1 pool in sump at east wall (P3) Uncovered insulation mats removed from the turbine. 4 small boxes with diesel and a wick was located in the corners of the enclosure, 3 at a high position and 1 at floor level, close to the door.	Door closed max 12 [s] after the pool was ignited.	Ventilation closed 15 [s] after the pool was ignited.	6 nozzles high position (2,3,4-,8,9,10) 2 nozzles at low position, close to the pool, (6,12)	4 small boxes were ignited before the pools were ignited. t = 0 : 1 pool were ignited 12 : door closed 15 : ventilation dampers shut 20 : water spray on 30 : water spray off 40 : water spray on 50 : water spray off 60 : water spray on 70 : water spray off 80 : water spray on 90 : water spray off 120 : flames seen above the pool 170 : water spray on 190 : water spray off extinguished due to oxygen starvation	A series of 10 [s] shots of water with 10 [s] interval. The first 4 shots did not extinguish the fire, and the oxygen concentration was kept at about 19%. The fire was extinguished during fifth spray sequence, when the duration of the spray was increased to 20 [s]. The fire had however increased in size between the fourth and fifth spray, and the oxygen concentration had been reduced to about 17% when the fifth spray was started. All measured temperatures were very low in this experiment, not passing 100°C during the first four sprays. When the fire was growing between the fourth and the fifth spray the temperature had increased to about 250°C when the fifth spray was started.
TURBIN 41	1 pool in sump at east wall (P3) Uncovered insulation mats removed from the turbine. 4 small boxes with diesel and a wick was located in the corners of the enclosure, 3 at a high position and 1 at floor level, close to the door.	Door closed max 10 [s] after the pool was ignited.	Ventilation closed 15 [s] after the pool was ignited.	6 nozzles high position (2,3,4,8,9,10) 2 nozzles at low position, close to the pool, (6,12)	4 small boxes were ignited before the pool was ignited. t = 0 : 1 pool were ignited 12 : door closed 15 : ventilation dampers shut 18 : water spray on 38 : water spray off 58 : water spray on 78 : water spray off extinguished	Short interval between closing the door and ventilation dampers and the spray activation, followed by two 20 [s] spray sequences with 20 [s] delay between. Extinguished during second spray sequence. No high temperatures were measured in the turbine hood. The oxygen concentration was just below 19% after extinguishment.

Experiment No.	Fire characteristics	Ventilation conditions		Spray nozzle configuration. High+low	Execution of experiment, including Spray sequence. "Shot" means activation of water spray.	Result, including time to extinguishment.
		Door	Ventilation dampers			
TURBIN 42	3 pools, 2 below turbine,(P1 +P2), 1 in sump at east wall (P3). + Diesel spray (S3) onto cold turbine. Uncovered insulation mats removed from the turbine. 4 small boxes with diesel and a wick was located in the corners of the enclosure, 3 at a high position and 1 at floor level, close to the door.	Door closed max 20 [s] after the pool was ignited.	Ventilation closed 29 [s] after the pool was ignited.	2 nozzles at low position, just inside the door, (5,6). The spray did not hit the base of the fire directly.	4 small boxes were ignited before the pools were ignited. t = 0 : 3 pools were ignited 10 : Diesel spray ignited 20 : door closed 29 : ventilation dampers shut 31 : water spray on 42 : water spray off 53 : oxygen minimum 55 : max temp 300°C 86 : Diesel spray off	Large fire. All pools, the Diesel spray and the small boxes were extinguished within 22 [s] from spray activation (min. oxygen, 15.5%), 24 [s] (temp. passed 300°C).
TURBIN 43	1 pool in sump at east wall (P3). Uncovered insulation mats removed from the turbine. 4 small boxes with diesel and a wick was located in the corners of the enclosure, 3 at a high position and 1 at floor level, close to the door.	Door closed max 10 [s] after the pool was ignited.	Ventilation closed 15 [s] after the pool was ignited.	2 nozzles at low position, just inside the door, (5,6). The spray did not hit the base of the fire directly.	4 small boxes were ignited before the pool was ignited. t = 0 : 1 pool were ignited 18 : door closed 20 : ventilation dampers shut 22 : water spray on 132 : extinguished 142 : water spray off	Small fire. Short delay between closing the door and ventilation dampers and the spray activation, followed by a spraying sequence of about 2 minutes. Only two nozzles at a low position were used, and the pool was not directly hit by the spray. The pool and the boxes were extinguished 1.5 minutes after the spray was started. The oxygen concentration was then about 15%.

Experiment No.	Fire characteristics	Ventilation conditions		Spray nozzle configuration. High+low	Execution of experiment, including Spray sequence. "Shot" means activation of water spray.	Result, including time to extinguishment.
		Door	Ventilation dampers			
TURBIN 44	1 pool in sump at east wall (P3). Uncovered insulation mats removed from the turbine. 4 small boxes with diesel and a wick was located in the corners of the enclosure, 3 at a high position and 1 at floor level, close to the door.	Door closed max 8 [s] after the pool was ignited.	Ventilation closed 10 [s] after the pool was ignited.	2 nozzles at high position, far away from the pool, (1,7)	4 small boxes were ignited before the pool was ignited. t = 0 : 1 pool were ignited 8 : door closed 10 : ventilation dampers shut 12 : water spray on 130 : water spray off not extinguished 250 : 2. spray sequence on 270 : max temp. below 300° C 280 : oxygen conc. minimum, 15.2% 370 : 2. spray off	Short delay between closing the door and ventilation dampers and the spray activation, followed by a spraying sequence of about 2 minutes. Only two nozzles at a high position were used, as far as possible away form the pool. The pool and the boxes were not extinguished by the first spray, but were extinguished after 20-30 [s] of the second spray.
TURBIN 45	2 pools below turbine, (P1 +P2), + Diesel spray (S3) hitting 3 stripes of insulation mats. One of the stripes was uncovered, one was covered with Aluminium foil, and one was impregnated with Firestop 102. Hot turbine with steel temp. about 300°C (uncovered steel surface) - 480°C (steel covered by insulation).	Door closed 10 [s] after the Diesel spray was ignited.	Ventilation closed 13 [s] after the Diesel spray was ignited.	4 nozzles high position (1,2,3,4) 2 nozzles at low position, at the door, (5,6)	t = 0 : 2 pools were ignited 16 : Diesel spray ignited 26 : door closed 29 : ventilation dampers shut 48 : water spray on 58 : water spray off 58 : max temp. below 300°C 58 : fires extinguished (visual observation) 78 : Diesel spray off 88 : min. oxygen 17.7 % 171 : open door 976 : Diesel spray on 1036 : Diesel spray off 1620 : Manual ignition with a torch 1860 : ventilation closed 1865 : water spray on 1875 : water spray off not extinguished 1910 : water spray on 1935 : water tank empty, spray off. not extinguished	The three insulation mats wrapped around the hot turbine mock-up were hit by the burning Diesel spray. All fires, both pool and spray fires, were extinguished by the first 10 [s] water spray.The oxygen concentration after extinguishment was 17.7%. No re-ignition in the insulation mats occurred within 16 minutes, so another spray of Diesel was introduced. This spray did not ignite, and the mats were manually ignited by a torch after about 27 minutes. The stripes with uncovered insulation and the one covered with Aluminium foil burnt all over, but the stripe of uncovered insulation impregnated with Firestop 102 burnt at the open edges only.

Experiment No.	Fire characteristics	Ventilation conditions		Spray nozzle configuration. High+low	Execution of experiment, including Spray sequence. "Shot" means activation of water spray.	Result, including time to extinguishment.
		Door	Ventilation dampers			
TURBIN 46	3 pools, 2 below turbine, (P1 +P2), 1 in sump at the east wall (P3), + Diesel spray (S3) hitting 3 stripes of insulation mats. One of the stripes was uncovered, one was covered with Aluminium foil, and one was impregnated with Firestop 102. 4 small boxes with diesel and a wick was located in the corners of the enclosure, 3 at a high position and 1 at floor level, close to the door. Warm turbine with steel temp. about 100°C (uncovered steel surface) - 150°C (steel covered by insulation).	Door open.	Vents open.	4 nozzles high position (1,2,3,4) 2 nozzles at low position, at the door, (5,6)	4 small boxes were ignited before the pools were ignited. t = 0 : 3 pools were ignited 5 : Diesel spray ignited 24 : water spray on 32 : pools extinguished, Diesel spray still burning (visual observation) 35 : water spray off 55 : Diesel spray off 63 : 2. water spray on 74 : 2. water spray off 85 : max temp below 300°C All fires extinguished	Big fire with full ventilation and open door. The pools were extinguished in 8 [s] (visual observation) after water spray activation. The Diesel spray was still burning. The Diesel spray was then turned off, but the fire remained in the insulation mats. After the second shot all fires, both the spray and the fire in insulation mats were extinguished. The water spray was hitting the base of the remaining fires directly in the second shot.

Experiment No.	Fire characteristics	Ventilation conditions		Spray nozzle configuration. High+low	Execution of experiment, including Spray sequence. "Shot" means activation of water spray.	Result, including time to extinguishment.
		Door	Ventilation dampers			
TURBIN 47	3 pools, 2 below turbine, (P1 +P2), 1 in sump at the east wall (P3), + Diesel spray (S3) hitting 3 stripes of insulation mats. One of the stripes was uncovered, one was covered with Aluminium foil, and one was impregnated with Firestop 102. Warm turbine with steel temp. about 90°C (uncovered steel surface) - 130°C (steel covered by insulation).	Door open.	Vents open.	2 nozzles high position (2,3) 2 nozzles at low position, at the door, (5,6)	t = 0 : 3 pools were ignited 5 : Diesel spray ignited 25 : water spray on 35 : water spray off Pools extinguished, Diesel spray not extinguished 50 : Diesel spray off 65 : 2. water spray sequence on 75 : 2. water spray off small fire burning in insulation mat, below turbine mock-up 180 : 3. water spray on 190 : 3. water spray off not extinguished 260 : 4. water spray on 280 : 4. water spray off not extinguished	Big fire with full ventilation and open door.The first shot of 10 [s] extinguished the pools, but the Diesel spray was still burning. The use of 4 nozzles only was below the limit for immediate extinguishment of the pool- and spray fire during the first shot of 10 [s]. The Diesel spray was turned off just before the second shot of water. The fire in the insulation mats was continuing, even after 4 shots. The duration of the 4. shot was increased to 20 [s].
TURBIN 48	3 pools, 2 below turbine, (P1 +P2), 1 in sump at the east wall (P3), + Diesel spray (S3) hitting 3 stripes of insulation mats. One of the stripes was uncovered, one was covered with Aluminium foil, and one was impregnated with Firestop 102. Warm turbine with steel temp. about 70°C (uncovered steel surface) - 90 -100°C (steel covered by insulation).	Door open	Vents open	2 nozzles high position (2,3) 2 nozzles at low position, at the door, (5,6)	t = 0 : 3 pools were ignited 5 : Diesel spray ignited 20 : water spray on 45 : water spray off Pool fires extinguished, Diesel spray fire not extinguished 60 : Diesel spray off 120 : 2. water spray sequence on 140 : 2. water spray off small fire burning in insulation mat, below and around the turbine mock-up 350 : 3. water spray on 370 : 3. water spray off not extinguished	Big fire with full ventilation and open door. Pool fires were extinguished by the first shot of 25 [s], but the Diesel spray was still burning. The fire in insulation mats were not completely extinguished, but reduced to a minimum. A person could stay inside the module after the 3. water spray, without special protective measures.

Experiment No.	Fire characteristics	Ventilation conditions		Spray nozzle configuration. High+low	Execution of experiment, including Spray sequence. "Shot" means activation of water spray.	Result, including time to extinguishment.
		Door	Ventilation dampers			
TURBIN 49	1 pool at sump at east wall (P3). 4 small boxes with diesel and a wick was located in the corners of the enclosure, 3 at a high position and 1 at floor level, close to the door. Warm turbine with steel temp. about 90 - 100°C.	Door closed 12 [s] after the pool was ignited.	Ventilation closed 12 [s] after the pool was ignited.	2 nozzles (No 5 + 6) at low position, at the door, not hitting the pool directly. **Different noz-zle type: Velomist 10 l/min, 60°.**	4 small boxes were ignited, before the pool was ignited. t = 0 : pool ignited 12 : doors closed, 12 : ventilation dampers shut 14 : water spray on flames getting low, signs of oxygen starvation 134 : water spray off fire in pool 255 : 2. water spray on 375 : 2. water spray off still a small fire in pool. Finally the fire went out, probably due to lack of fuel.	2 nozzles, type Velomist 10 l/min, 60°, not hitting the pool fire directly, did not extinguish one pool fire of 1 m^2 after 2 shots of 120 [s] each.

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3.2.2 Essential average- and maximum values

A survey of essential maximum- and average values from the experiments in the turbine hood of Phase II is given in Table 3.11.

Table 3.11 *Survey of essential maximum- and average values from the results in Phase II.*

TEST / TURBINE	O2 MIN [VOL %]	CO2 MAX [VOL %]	CO MAX [ppm]	Press. FLOOR MAX+ [Pa]	Press. CEIL. MAX + [Pa]	Press. FLOOR MAX- [Pa]	Press. CEIL. MAX- [Pa]	Turbine T INS. [°C]	Turbine T STEEL [°C]	T A. MAX [°C]
1	16.5	3.2	775	95	121	-187	-177	467	340	131
2	-	-	-	-	-	-	-	-	-	-
3	18.5	1.5	164	9	21	-4	-7	20	49	326
4	17.9	2.2	177	11	21	-9	1	488	371	415
5	17.6	2.4	1087	13	36	-8	-2	505	335	330
6	15.5	3.7	1600	136	156	-172	-163	501	335	277
7	15.8	3.5	1270	7	22	-12	0	505	331	287
8	16.3	3.2	1054	128	136	-132	-116	535	846	328
9	16.6	3.2	1092	6	21	-6	0	541	362	236
10	13.7	4.9	1495	16	29	-6	2	497	537	483
11	15.6	3.8	695	106	131	-103	-99	509	713	380
12	15.7	3.7	652	146	168	-133	-137	503	665	411
13	17.4	2.6	358	11	23	-17	-3	516	688	337
14	16.1	3.6	1215	18	46	-9	-1	525	654	431
15	16.2	3.6	514	9	27	-6	-1	512	697	367
16	20.7		47	207	212	-59	-59	514	344	89
17	16.4	3.4	551	9	25	-9	-3	494	687	388
18	16.2	3.6	534	9	26	-15	-1	534	703	406
19	17.0	2.7	1051	75	83	-58	-60	536	620	362
20	17.5	2.4	882	151	167	-14	-8	534	644	393
21	13.8	4.7	6694	157	178	-356	-362	401	602	297
22	15.8	3.4	2789	334	337	-65	-69	383	646	262
23	15.2	3.5	5411	52	68	-279	-277	372	455	286
24	13.9	4.4	3934	101	124	-175	-178	381	627	334
25	14.9	3.6	4916	55	67	-268	-205	379	611	282
26	15.0	3.8	2937	61	70	-373	-362	371	526	247
27	8.7	8.1	7629	9	21	-29	-4			376
28	12.5	6.2	3622	249	270	-406	-407			436
29	13.6	5.2	2195	186	201	-116	-93			349
30	13.7	5.2	1694	106	111	-12	-4			204
31	14.2	4.7	2173	125	134	-21	-11			210
32	15.1	4.2	1110	234	240	-35	-27			192
33	15.7	3.8	1038	168	173	-134	-127			176
34	14.8	4.4	1309	73	82	-157	-144			181
35	14.8	4.4	1553	152	154	-426	-427			151
36	13.7	5.1	1620	93	94	-362	-349			224

TEST / TURBINE	O2 MIN [VOL %]	CO2 MAX [VOL %]	CO MAX [ppm]	Press. FLOOR MAX+ [Pa]	Press. CEIL. MAX + [Pa]	Press. FLOOR MAX- [Pa]	Press. CEIL. MAX- [Pa]	Turbine T INS. [°C]	Turbine T STEEL [°C]	T A. MAX [°C]
37	13.5	5.3	1633	118	122	-282	-269			178
38	13.8	5.1	1856	113	111	-118	-103			246
39	13.8	5.1	1757	174	177	-210	-196			186
40	16.9	2.9	1210	268	280	-371	-355			110
41	18.7	1.6	500	112	114	-24	-19			54
42	15.5	3.9	922	223	267	-60	-38			277
43	15.2	4.2	1573	142	153	-72	-54			186
44	14.9	4.4	1069	100	100	-58	-42			159
45	17.7	2.3	1042	89	135	-435	-422			340
46				11	21	-11	-11			337
47				22	22	-15	-4			269
48				15	27	-14	-5			263
49				70	78	-16	-4			238

4 DISCUSSION OF RESULTS

4.1 Extinguishment of flames versus inerting

There are two main methods of extinguishing oil and gas fires; instantaneous extinguishment of flames or inerting of the atmosphere of an enclosed space. The fundamental extinguishing mechanisms are not really different, but from an engineering point of view the dimensioning and design of a fire mitigation system will be different for the two methods. The water flow rate and total amount of water required for extinguishment will also be different.

Extinguishment of flames takes place when the conditions in the flaming zone of a fire reach a critical combination of temperature and mixture of oxygen, so called **inert** condition. To extinguish a liquid or gas fire it is normally sufficient to keep the critical combination for a very short time, and one may denote this as instantaneous extinguishment. If the fuel may be isolated from all ignition sources after instantaneous extinguishment, permanent extinguishment is obtained.

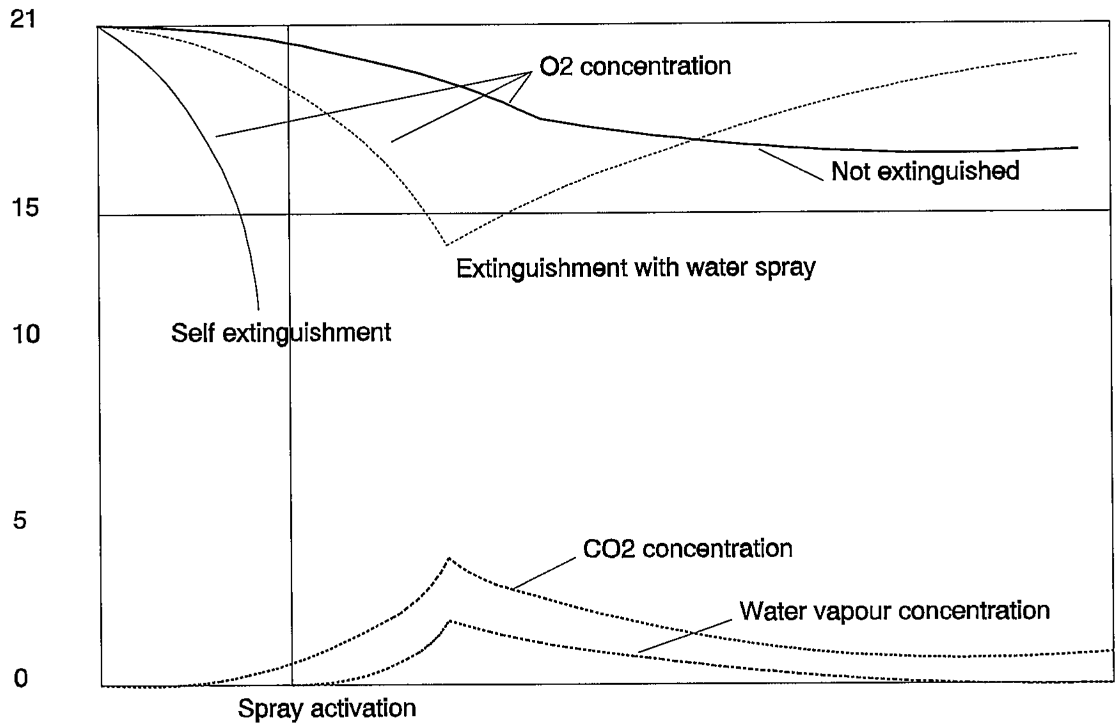

Figure 4.1 *Typical gas concentrations in an enclosure with large fire (Self-extinguished)Medium-size fire (Extinguished by water spray) and small fire (Not extinguished)*

Inerting of a room requires that the conditions of the total enclosure reach the critical combination. The principle of inerting a room is to keep the atmosphere of the enclosed space at inert condition as long as the risk of re-ignition occurs.

An empirical correlation representing the conditions of instantaneous flame extinguishment has been worked out by SINTEF NBL for gas and pool fires /3/. The correlation is a non-dimensional number, denoted Spray Heat Absorption Ratio (SHAR), which is a proportion of the heat removed from the fire by a water spray and the heat produced by the fire. A water spray giving a SHAR value slightly above 0.3 seems to extinguish liquid pool fires and gas fires. The heat absorbed by a spray with a SHAR value of 0.3 is sufficient to produce water vapour reducing the local oxygen concentration to about 15 %, and simultaneously lower the flame temperature below the critical value for extinguishment. A water spray having a SHAR value of 0.3 absorbs 30% of the heat produced by the fire.

The critical oxygen concentration for extinguishment with the Fine Water Spray system found in the present turbine hood experiments (Phase II) was about 15 - 18%. This means that about 15 - 30 % of the original oxygen in the enclosure has been replaced by other inert gases.

This will give an indication of how much water is needed for extinguishing enclosed spaces by inerting. The sum of CO_2 and water vapour, which are the main inerting components in a fire atmosphere, is then a result of fire size, enclosure volume and ventilation. These processes are shown graphically in Figure 4.1.

The first curve marked "Self extinguishment" represents the result of a large fire related to the room size. A large fire will very fast consume available oxygen in the compartment, and if the supply of air is limited the fire goes under-ventilated. With no air supply to the fire it will finally extinguish due to oxygen starvation. In the experiment, TURBIN 27 an average temperature of 375 °C in the enclosure was reached, and the oxygen concentration reached a level of 8.7%. This fire was extinguished due to oxygen starvation. In the experiment the fire originated from 3 pools with Diesel of 1 m^2 size, and a Diesel spray fire.

The second curve in Figure 4.1 marked "Extinguishment with water spray" represents a medium size fire, large enough to produce temperatures above 100°C in the fire enclosure. A fire of this size will be extinguished by a fine water spray. The small droplets will cool the gases inside the enclosure, and water vapour will be produced. This water vapour will add inert gas to the CO_2 produced by the fire itself. In the experiments these type of fires were originating from 2 or 3 pool fires of 1 m^2 size. A typical example is TURBIN 6 with a maximum average temperature of 277 °C in the enclosure, and a minimum oxygen concentration of 15.5%. Similar performance was seen in TURBIN 42, with 3 pools and a Diesel spray.

The combined effect of cooling and inerting leads to extinguishment. The oxygen concentration after extinguishment will be higher than for a self extinguished fire without water spray, and the average temperature will be lower. Both conditions lead to less damage and hazard to people.

The third curve of Figure 4.1 is marked "Not extinguished". A small fire in a large enclosure will not be extinguished by inerting, even if the spray is continuous. The temperature following the fire may stabilize below 100°C, and very little water vapour is produced. Air leakages to the enclosure will feed the fire, and oxygen starvation will never occur. A fire of this type is typically less than a 1 m^2 Diesel pool. An example which represents a Not extinguished fire is TURBIN 35. The maximum average temperature is 151 °C, and the minimum oxygen concentration is 14.8%. Even this fire size is large enough to consume more oxygen than is supplied through leakages in the construction and will be self extinguished by oxygen starvation. The fire will not be extinguished by the water spray unless a direct hit is obtained. This is however a relatively small fire with little damage to the test enclosure.

4.2 Fire types and extinguishing characteristics

The Fine Water Spray system has been tested against a variety of fire types. From all of the present tests, both with restricted ventilation and with excess of air supply, a ranked list of the fire types, and how easy they may be extinguished, is presented. The ranking starts with fires of Category I, which are easily extinguished by the water spray, continues with fires of Category II, which are more challenging for the water spray system, and ends with a Category III, which requires direct hit of the fire base with the water spray or an additive to the water, to extinguish the fire.

4.2.1 Fires of category I

Large underventilated gas fires
Large underventilated pool fires
Large underventilated oil spray fires

These fires are close to the point of self-extinguishment due to lack of oxygen. A small addition of water, dispersed in small droplets, will cool the flames, and the water vapour, which is produced after the cooling process, creates an overpressure in the enclosure, preventing air from the ambient to enter the enclosure.

4.2.2 Fires of category II

Large well ventilated gas fires
Large well ventilated pool fires
Large well ventilated oil spray fires
Large well ventilated oil spray fires hitting a hot metal surface

These fires may be extinguished provided that the Fine Water Spray covers the base of the fire, and is oriented so that the small droplets may penetrate through the buoyant fire plume. An experience from Phase I, with an oil spray fire cross-flowing the Fine Water Spray, was that the oil fire was extinguished in the spray zone, but re-ignited when the oil hit a hot steel floor after passing the spray.

Tests were performed where Diesel oil and lubricating oil were sprayed directly onto a hot steel surface, with temperature well above the self-ignition temperature of the oil. The fire was extinguished when the Fine Water Spray covered the space where the oil hit the hot surface, even when the metal temperature still was high.

4.2.3 Fires of category III

Medium size (about 1 m^2) well ventilated "hidden" pool fires

This type of fire may be difficult to extinguish, since the water droplets are following the air flow pattern in the vicinity of the fire. To extinguish a fire, the water droplets have to reach the base of the flame zone. If the fires are hidden from direct impingement of the spray, the fire base may be supplied with air without water droplets. Some of the largest droplets may deposit on surfaces and obstacles on their way into the flames, and will not be effective.

The only way to ensure extinguishment of well ventilated hidden fires is to hit the base of the fire directly with the Fine Water Spray.

Small pool fires (less than 1 m^2).
Fire in insulation mats soaked with oil.

This types of fires is difficult to extinguish with the Fine Water Spray system as designed in this project. The chosen nozzle, Jetmist 10 l/min, 90 ° spray angle, produces a spray with the Droplet Median Diameter of about 200 μm. A possible explanation to the difficulty of extinguishing a very small fire with this nozzle, may be that the contact time between the droplets and the flames is too short to heat and evaporate the water in the flame zone. A more efficient spray may then be one with a larger proportion of smaller droplets.

Regarding the fire in insulation mats, this type of fire may be extinguished if the fire heat output is above a certain level.

Fire in insulation mats soaked with oil, with hot metal surface below the insulation.

This type of fire was successfully extinguished in the first place, but after a time period the oil re-ignited. A possible explanation to this fire phenomenon is that diesel oil is evaporating in the vicinity of the hot metal surface, air with sufficient oxygen penetrates the insulation mats from the ambient, and after a while the conditions for self-ignition is obtained.

To prevent re-ignition the oxygen concentration in the room must be kept low as long as the metal temperature is above the self ignition temperature of the fuel.

Effect of additives on insulation fires

Additives of the type Firestop 107 added to the water was effectively promoting extinguishment in insulation mats, where pure water spray did not manage to extinguish. Impregnating the insulation mats with Firestop 102 prevented re-ignition of the mats, and effectively prevented fire in a mat when un-impregnated mats beside it was ignited.

4.3 Typical times to flame extinguishment

Flame extinguishment takes place when a water spray hits the flame zone of a fire directly. In the experiments of Phase I the water spray was located to cover the flame zone of the fire. A typical time from water spray activation to extinguishment of a 1 MW propane matrix fire was 7-16 [s]. The longest time was corresponding with the lowest water application rates. A typical sequence of events of an extinguished gas fire was as follows:

- Before spray activation the flames from the propane matrix burner were upright, leaning somewhat to the rear wall of the test compartment. The flames were about 2 m high, reaching the ceiling.

- When the Fine Water Spray was activated the flames were distorted and blown sideways. The water spray penetrated down to the base of the fire. The fire was still burning, but with a more flickering performance. Water vapour was observed at the outskirts of the fire and at the air inlet and outlet openings. Water vapour is visible when it condensates to water droplets, at a temperature below 100 °C.

- The flames became bluish, and were not visible in the vicinity of the matrix burner. Blue flames were flickering around in the test compartment.

- All flames suddenly disappeared, and the fire was extinguished.

This effect was also seen in the tests of Phase II, with a total room coverage with spray nozzles. All fires were then extinguished within 10 [s].

4.4 Typical times to extinguishment by room inerting

In Phase II of the experiments the flames of the large and medium-size fires almost filled the turbine hood before the Fine Water Spray was activated. Black smoke was flowing through the openings of the hood and through the upper part of the door if it was open. The black smoke blocked the visibility, and made observation of flames difficult.

2-4 [s] after spray activation the smoke turned grey, mixed with water vapour, and flames disappeared before the shot of 10 [s] duration was ended. In this type of extinguishment the overpressure inside the enclosure forced smoke and water vapour out through all openings of the turbine hood for a short period, even at floor level. No oxygen-rich air from the ambient could enter the hood in that period.

In some of the large fires with open door and ventilation running, one of the pools located close to the door continued to burn after the other pools were extinguished. After 10-17 [s] this pool was extinguished as well.

In the Phase II experiments with only one 1 m^2 diesel pool fire at the eastern end of the turbine hood, in the sump below the turbine mock-up, the fire was not extinguished immediately by a 10 [s] shot of water. In most cases the fire lasted a period of about half a minute after the spray was turned off. The longest time before extinguishment was 1.5 minutes (TURBIN 31). The fire was then oxygen starved, but the cooling effect from the spray had an influence of the extinguishing process.

Variation of spraying time and interval between shots was also tested in Phase II. A 10 [s] shot of water was sufficient for extinguishing large fires, but did not extinguish a 1 m^2 pool fire immediately.

A series of 10 [s] sprays with 10 [s] interval (TURBIN 40) did not extinguish the 1 m^2 pool fire at all. 8 nozzles were used. The first shot reduced the flames, and the following shots did not produce enough vapour or cool the small flames sufficiently to extinguish the fire.

A test with two 20 [s] sprays with a 20 [s] interval (TURBIN 41), again with the same 8 nozzles, extinguished a 1 m^2 pool fire during the second spraying sequence. The first shot then produced a certain amount of vapour, partly inerting the fire, and the 20 [s] interval gave the fire a chance to grow sufficiently to consume more oxygen, and to evaporate more water in the second shot.

A test with 2 nozzles only (TURBIN 43), but with a 2 minutes (120 [s]) spraying time, extinguished a 1 m^2 pool fire after 110 [s]. The nozzles were then located at a low level, pointing horizontally towards the turbine mock-up, as the pool fire was located in the sump at the east wall, hidden from direct hit by the water spray, but about 3 m from the nearest spray nozzle.

In a similar test, but with the nozzles located at the ceiling level, at the opposite end of the enclosure as the 1 m^2 pool fire, the fire was not extinguished in the first shot of 2 minutes. The fire was extinguished after 20-30 [s] of a second shot, after a 2 minutes interval.

A general comment to the difference in time to extinguishment is that local flow of droplets and contact time between droplets and flames may vary inside the turbine hood. Some combinations of nozzle location and fire may promote quick extinguishment, as other combinations may work against rapid extinguishment. The spraying time and the interval between sprays are also variables which may be optimized to obtain effective use of an amount of water.

4.5 Water application rate - flame extinguishment

Figure 4.2 shows results from former SINTEF experiments with different water sprays /3/. The experiments have been carried out in the same 30 m^3 test enclosure as used in Phase I, and with the same propane matrix burner. Three different spray nozzles, using water only, operating at pressures from 1 - 10 bar were tested. A minimum water application rate required for extinguishment was found for each nozzle. The different sprays were characterized by different Median Droplet Diameter, based on manufacturer's data, in the range from ≈ 600 μm to 1500 μm. The line in Figure 4.2 separates the regime for extinguishment from the regime where extinguishment did not occur. Based on data from the former SINTEF tests the line showed a trend, pointing towards a minimum required water application rate of 8 - 10 l/min for a water spray with Median Droplet Diameter about 200 μm.

From the present tests series in Phase I with well ventilated propane matrix fires a minimum of about 8 l/min was found for extinguishment of a 1 MW fire. This flow rate is fitting exactly into the trend foreseen from earlier tests done at SINTEF, as shown in Figure 4.2. The water application rate required for extinguishment varied a little with spray angle, and the lowest data point represents the water application rate with reduced ventilation.

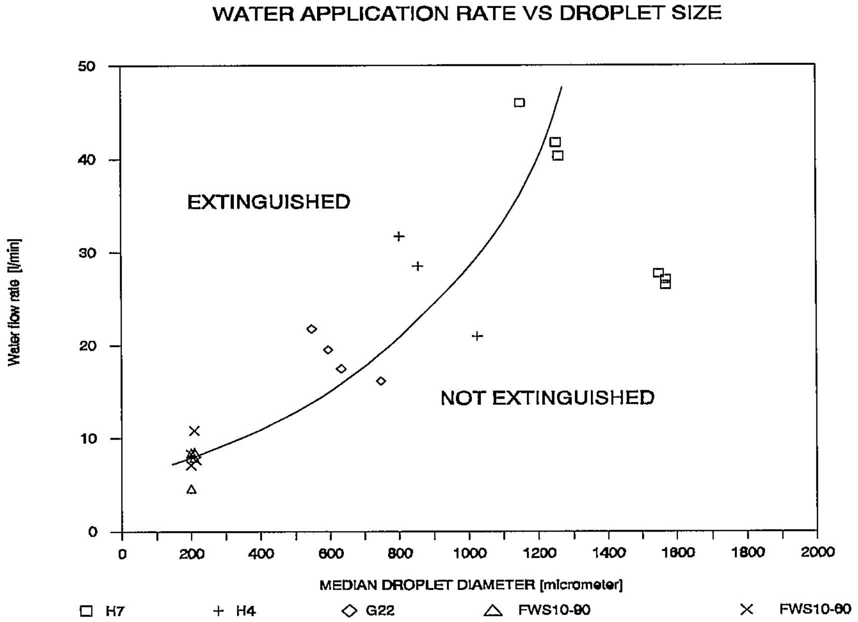

Figure 4.2 *Water application rates for different nozzles tested at a 1 MW fire in a well ventilated enclosure.*

None of the experiments of Phase II in the turbine hood can be described as examples of direct flame extinguishment. The Fine Water Spray did in no cases cover the base of the fires completely, and corresponding water flow rates can not be compared to the experiments of Phase I. However, the minimum water application rate resulting in extinguishment in Phase II was 19.6 l/min (TURBIN 42), with only 2 nozzles activated at low level, not hitting the fire directly, but relatively close to the pool fire.

When the same experiment was repeated with a different spray nozzle and a lower water application rate, extinguishment was not obtained (TURBIN 49). The two spray nozzles were of the type Velomist 10 l/min, 60°, and the water application rate was 15.4 l/min.

4.6 Water application rate - room inerting

In a full scale turbine hood the minimum water application rate for extinguishment of a fire is strongly dependent on several variables.

4.6.1 Ventilation conditions

Restricted ventilation leads to self-extinguishment of a fire due to oxygen starvation. Water which evaporates in the enclosure will promote self-extinguishment in two different ways: By replacing the oxygen in the air, and by creating an over-pressure which prevents fresh air from entering the room. These two processes are not taking place at the same time, which can be seen from the pressure development in the turbine hood after activation of the Fine Water Spray (See Figure 4.5). The sudden under-pressure after spray activation will promote fresh air into the turbine hood, but the duration of the under-pressure is short.

4.6.2 Fire size

A large fire produces more heat than a small fire, and the amount of water vapour produced in the room is much depending on the heat release rate. The fire size is also decisive for the consumption of oxygen in the room, and hence the time before self extinguishment.

4.6.3 Spraying sequence

It has been observed that the spraying time and the delay between spray "shots" influence the result of the extinguishment. A spray time of 10 [s] seems to be short compared to optimum, possibly due to the total mixing time of gases inside the turbine hood. The optimum spraying time seems to be dependent of room volume, and is increasing with increasing room size.

The time delay of 10 [s] between spray "shots" also seemed to be short compared to optimum. A possible reason is that the first "shot" of water takes out most of the heat of the surroundings of the fire, and interferes with the flames when the droplets reach the flame zone. If a second "shot" is introduced to soon after the first and the fire is not completely extinguished, the fire has no time to produce heat to evaporate more water for inerting the room. If the fire is left burning for some time, in the order of a minute, it has grown to a size where sufficient water vapour can be produced to inert the room, together with the reduction of oxygen concentration caused by the combustion itself.

4.6.4 Fire source

The type and location of the fire source may influence the possibility of extinguishing a fire by room inerting. A jet- or spray fire produces more turbulence and mixing inside the room than a pool fire or a fire in an insulation mat. This effect promotes more rapid extinguishment. The location of the fire related to the spray nozzles, walls and objects will influence the interaction between water droplets and the flame zone. This will decide the time before extinguishment, and even be critical if parts of the water is hitting cold surfaces before interacting with the flames.

4.6.5 Geometry of the fire surroundings (Enclosure, obstacles, openings, grating etc.)

The same comments as for the fire source are valid for the surroundings of the fire. The offset of water onto obstacles and enclosure is highly dependent on geometry of the surroundings of the fire, and the location of spray nozzles.

4.6.6 Spray Nozzle

The water droplet velocity and direction will also influence the efficiency of the water spray in inerting a room. The impulse flux of the water spray, the product of the mass flow rate and the velocity, is characterizing the effect of the spray on mixing inside the room. Low exit velocity of the water droplets will lead to less mixing than high velocity. The Fine Water Spray nozzle Jet 10 l/min 90 ° has relatively high exit velocity of the droplets, and introduces a quite high degree of mixing inside the room. This is based on qualitative observation and comparison with other spray nozzles.

4.7 Water required for extinguishment

The minimum amount of water required for extinguishment is found for the two different extinguishing methods. For instantaneous extinguishment of flames from a 1 MW pool or gas matrix fire, a minimum water application rate is about 8 l/min for the nozzle type Jetmist 10 l/min, 90° spray angle, located about 2 m above the fire base. The time to extinguishment has been found to be in the order of 7-10 seconds, for the 30 m^3 enclosure the tests were done in. The fires were very well ventilated, and there are good reasons to say that this water application rate will be the same for an open pool or matrix fire as well. The minimum amount of water needed for instantaneous extinguishment of the 1 MW propane matrix fire with this nozzle configuration is in the range of 0.9 - 1.3 l. It must be emphasized that this is a number valid for the spray from this fire/nozzle configuration only, and is not a universal number. However, this fire/nozzle configuration is representative for the fires in the turbine hood geometry and the chosen technology of the tests.

From the turbine hood tests with closed ventilation dampers another number for the minimum amount of water needed for extinguishment may be found. The total volume of the laboratory turbine hood is about 70 m^3.

A large fire was effectively extinguished by 2 nozzles and a 10 [s] shot, as in TURBIN 42. The total amount of water used was about 4-5 litres. Then the oxygen consumption by the fire itself is substantially promoting the extinguishing process.

To extinguish a small fire in the same enclosure about 30 - 40 litres of water was used, TURBIN 43.

A correlation for the amount of water needed for extinguishment of fires in an enclosure of given volume may then be elaborated:

$$M_{water} = m_{water} * V$$

where M_{water} : Total amount of water (litres)
m_{water} : specific water fraction, (litres/m^3)
V : volume of the enclosure (m^3).

The minimum specific water fraction calculated from the mentioned tests will be:

Large fires in enclosed spaces: m_{water} = 0.06 - 0.07 litres/m^3
Small fires in enclosed spaces: m_{water} = 0.4 - 0.6 litres/m^3

This proportion is valid for the actual turbine hood geometry and size, and for the Fine Water Spray nozzle Jet 10 l/min 90° only as it is not verified for any other conditions.

4.8 Typical temperatures

A typical temperature development for the small scale test enclosure of Phase I is shown in Figure 4.3

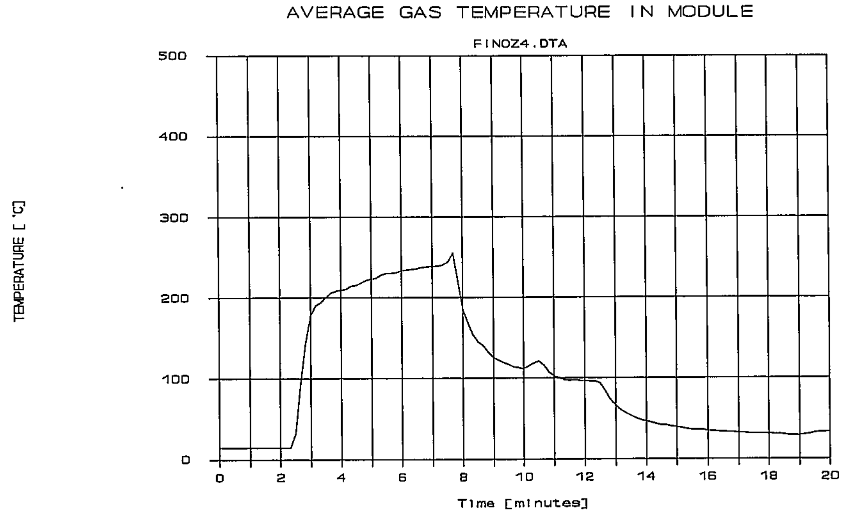

Figure 4.3 *Temperature development in the 30 m^3 enclosure. Test FINOZ 4.*

The average temperature based on about 40 thermocouples inside the enclosure rises quickly up to about 200 °C the first minute after ignition, and rises more slowly to 230 - 250 °C for well ventilated fires. Corresponding maximum average temperature is about 350°C for fires with reduced ventilation. After spray activation the average temperature decreases to 120°C in tests where the water flow rate is insufficient for extinguishment.

A temperature development for the full scale turbine hood is shown in Figure 4.4. The fire is originating from one Diesel pool of 1 m^2 (TURBIN 43). The smoke temperature at the ceiling level rises to above 300 °C. When the spray from 2 nozzles only is activated, the fire is extinguished after about 1.5 minutes. Then the temperature drops relatively fast to about 200 °C, decreasing more slowly to 100°C.

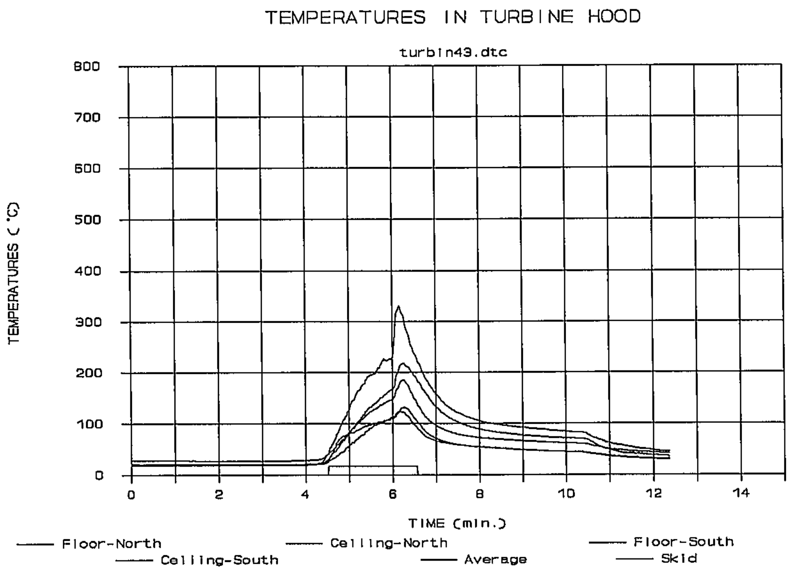

Figure 4.4 *Temperature development in the turbine hood in a 1 m^2 Diesel pool fire (Test TURBIN 43)*

4.9 Typical pressures

The pressure differences between the test enclosure and the ambient was measured both in the small scale fire enclosure of Phase I and in the laboratory turbine hood of Phase II. The pressure difference measured in the small scale tests were insignificant, less than 10 Pa (0.0001 bar)

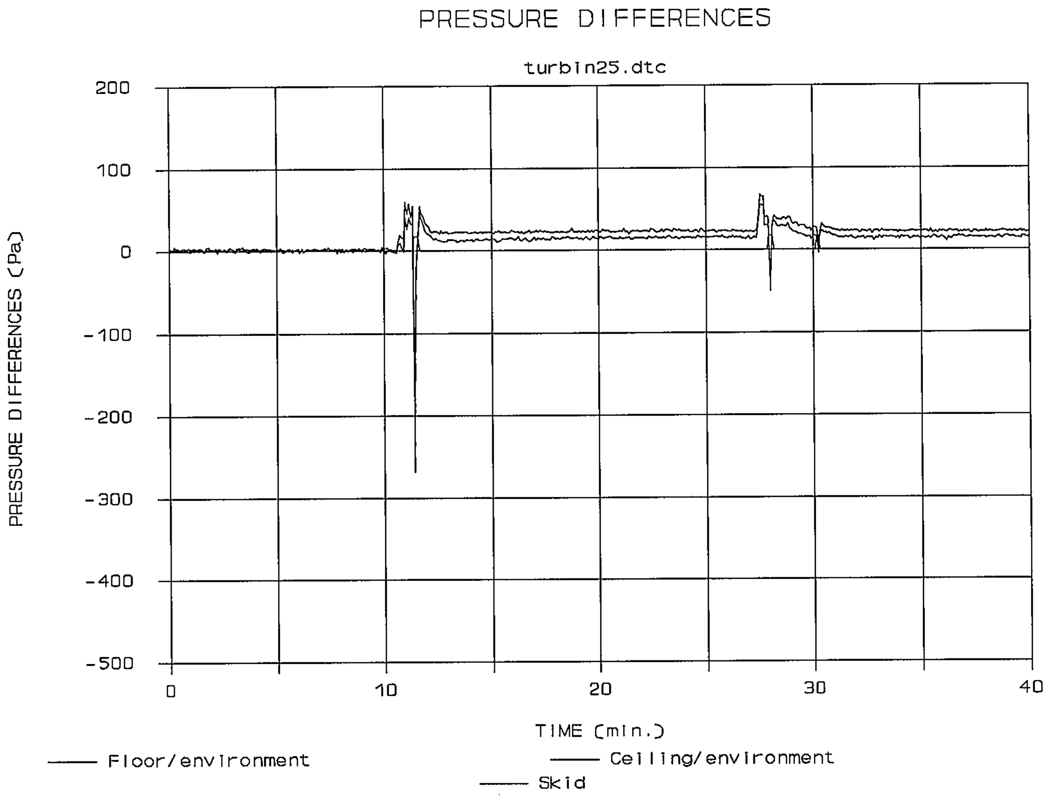

Figure 4.5 *Typical pressure development in a fire enclosure when ventilation dampers are shut, and a fine water spray is released. (Curve from the test TURBIN 25)*

Typical pressure development for a test from Phase II with the vent dampers closed immediately before spray activation is shown in Figure 4.5. The pressure development in the turbine hood is characterized by a rapid drop in pressure immediately after introduction of the Fine Water Spray, and a stabilization about ambient pressure after a short period. The overpressure in the turbine hood is induced by the fire itself and reaches a level of about 50 Pa (0.0005 bar) when the vent dampers are closed. The under-pressure measured shortly after activation of the Fine Water Spray system is measured to about 250 Pa in TURBIN 25, and to a maximum of 350 Pa (0.0035 bar) in other experiments. This pressure development gives no risk of structural collapse or damage, and has no practical consequences. The levels of pressure increase or decrease are dominated by leakages of the building.

4.10 Gas concentrations

Concentration of Oxygen in dry air is nominally 20.8%.

In the tests of Phase I with restricted ventilation, the oxygen concentration at the outlet opening was about 16 % minimum. This depletion of oxygen is caused by the combustion itself; very little can be related to the inerting effect of water vapour.

In the turbine hood experiments of Phase II, the oxygen concentration was measured at a level 0.5 m above floor, about centrally in the enclosure. The Oxygen concentration in the turbine hood when a fire was self extinguished (TURBIN 27) was about 9 % Corresponding CO_2 concentration was 8%, and CO concentration was about 0.76. (7600 ppm).

In experiments where the Fine Water Spray extinguished the fire, the minimum Oxygen concentration was in the range from 12.5 - 18 % Corresponding maximum CO_2 concentration was in the range from 2 - 6 %, and CO concentration was in the range from 0.1 - 0.6 % (1000 - 6000 ppm).

As a guide to the hazard related to these gas concentrations the following tenability limits may be given /6/:

Oxygen concentration (vol %)	Effect
20.9 - 14.4	No significant effect, slight loss of exercise tolerance.
14.4 - 11.8	Slight effect on memory and mental performance, reduced exercise tolerance.
11.8 - 9.6	Severe incapacitation, loss of consciousness.
9.6 - 7.8	Loss of consciousness, death.

Tolerance levels for the concentration of CO_2 and CO are:

Gas	Incapacitation limit for 30 minutes exposure	Lethal concentration after 30 minutes exposure
CO_2	10 %	14.6 %
CO	1400 - 1700 ppm	4500 ppm

From the values measured in the experiments, one can see that if a fire continues to burn until self extinguishment due to oxygen starvation, the hazard to personnel inside the fire exposed room is significant, both for low O_2, CO_2 and CO concentration.

If the fire is extinguished by the Fine water Spray system, the concentration of oxygen and CO_2 never reaches a critical level for human exposure, and the concentration of CO is never reaching the same high level as for a self extinguished fire.

4.11 Positioning of nozzles

The nozzles were mounted in 12 fixed positions, with a possibility to close each of them individually. Number of nozzles open, and position of open nozzles, were varied to find the minimum number necessary for extinguishing, and to find the effect of nozzle distance from the fire base. Four nozzles were positioned lower in the turbine hood, pointing horizontally towards the area where diesel and gas leakages are most probable to occur. Eight nozzles were mounted at ceiling level, pointing downwards, evenly distributed.

In the first part of the test series of Phase II with the laboratory turbine hood, all 12 nozzles were used. 4 nozzles, 2 at the ceiling and 2 at the lower level, were then blocked, without any significant difference in extinguishing ability. Further reduction of number of nozzles was tested, and only small differences in extinguishing time were observed. These tests, TURBIN 2 - TURBIN 29, were done with relatively large fires with either Diesel spray and/or more than 2 Diesel pools. The pre-burn time of the fire before spray activation was about 30 [s] or more. Examination of the resulting trends of gas concentrations shows that the large fires had reduced oxygen concentration at the moment of activation of the Fine Water Spray, which promoted extinguishment.

For large fires, both well ventilated and with ventilation dampers closed, the number and position of nozzles are of minor importance regarding the efficiency of the Fine Water Spray system. The explanation of this effect is probably that the mixing of water droplets with hot combustion products and inventory of the turbine hood is mainly dominated by the vivid fire induced flow in the hood.

In TURBIN 43 and TURBIN 44 the only difference of conditions were the distance between the nozzles and the 1 m^2 pool fire. The spray did not hit the fire directly in either of the experiments. A longer distance between the spray and the fire requires a longer spraying time before extinguishment. These experiments show that it is possible to extinguish even small fires in an enclosure without direct hit, provided that the fire and the spray create sufficiently effective mixing of water droplets with the flames.

A very small fire, like the fire in a small paint box or a small fire in an insulation mat, may be impossible to extinguish with a fine water spray without a direct hit. These fire are however so small that they may easily be extinguished manually.

4.12 Additives

Adding FIRESTOP 107 to the water in the systems tank made extinguishment of fires in insulation mats soaked with Diesel oil possible. Tests with similar conditions showed that a concentration of 3% FIRESTOP 107 in the water spray was sufficient. Re-ignition of the fire in insulation mats was prevented by a combination of additive to the water spray and a preventive sequence of water sprays every 5 minutes.

A part of an uncovered insulation mat was saturated by FIRESTOP 102, and then dried. This part of the insulation mat was difficult to ignite, and only the edges of the mat was burning after Diesel was sprayed upon it. The tests were done with a hot turbine, which in other tests had lead to re-ignition in the mats.

4.13 Cooling of turbine mock-up

The cooling of hot surfaces by the fine water spray was recorded and the temperature development was reported to ABB Stal during the test period. About 100 shots of water spray were released against hot metal surfaces. The steel of the turbine mock-up was examined by penetrating liquid for cracks before and after the tests, and no damage or cracks were observed.

4.14 Water intrusion into electrical equipment

A lamp fixture of the type which is formerly used offshore, and a non-activated flame detector were mounted in the fire turbine hood. Both equipments survived the spray and fire environment, except that the plastic cover of the lamp fixture was deformed in the severe fires. The lamps were still working after the series of fire experiments.

5 CONCLUSIONS

1. The Fine Water Spray system is very effective in extinguishing big fires.

2. Ventilation controlled fires are easily extinguished by the Fine Water Spray system.

3. Small fires are difficult to extinguish with the Fine Water Spray system, except when the spray directly hits the fire base.

4. Fires from fuel soaked into insulation mats are the most difficult fires to extinguish permanently with the Fine Water Spray system. Re-ignition frequently occur after some minutes, even if the original fire was extinguished by the first water spray.

5. The additive FIRESTOP 107 used in a 3% solution in the spray water prevented re-ignition in the insulation mats soaked with Diesel oil when a sequence of 10 [s] shots of spray was repeated. The preventive sequence was: First shot of 10 [s], intermission 60 [s], second shot of 10 [s]. Then shots of 10 [s] repeated every 5 minutes, until the steel temperature of the turbine was below the self ignition temperature of Diesel oil.

6. Insulation mats impregnated with Firestop 102, were very difficult to ignite and re-ignition after an extinguished fire did not occur, even if the mats contained Diesel oil. When ignited by a torch the Diesel oil soaked insulation mats impregnated with Firestop 102 were burning at the edges only, different from un-impregnated mats which were burning all over the surface.

7. The Fine Water Spray system operates as a total flooding fire suppression system when the fire size is big related to the room size.

8. It is possible to extinguish all critical fires (above 1 m^2 Diesel pool fire) in a turbine hood by the Fine Water Spray system with a water spray duration of 10 seconds, provided that the number of operating nozzles is sufficient.

9. The extinguishment mechanism of the Fine Water Spray is a combination of inerting the combustion zone by water vapour and cooling of the reacting products. This effect can be obtained locally in the flame zone of a fire, independent of confinement, and in enclosed spaces.

10. The Fine Water Spray system is working in two different extinguishing modes. These are: **Extinguishment of flames** or **Inerting of the enclosure.** The first mode requires a certain water application rate, directed against the base of the fire. The second mode requires a certain total amount of water applied into the enclosure, and the application rate influences the time to extinguishment only.

11. When a small number of nozzles is installed in an enclosure, a sequence of 120 [s] water spray, intermission 120 [s] and then a second 120 [s] water spray is an efficient way of extinguishing small fires. This sequence is more efficient than one single water spray of longer duration. When direct hit of the fire base is not possible a spraying time of 20 [s] is more efficient in extinguishing the tested fires by the first spray than a 10 [s] spray.

12. The minimum amount of water required for rapid extinguishment of a large fire (2 - 3 Diesel pool fires and a Diesel spray fire) in a the 70 m^3 turbine hood is 4 - 5 litres. This amount corresponds to the specific water fraction m_{water} = 0.06 - 0.07 litres/m^3. A corresponding specific water fraction m_{water} = 0.4 - 0.6 litres/m^3 is valid for small fires in large enclosures, where the spray from the nozzles does not cover the bases of all fire sources. This proportion is valid for the actual turbine hood geometry and size, and for the Fine Water Spray nozzle Jet 10 l/min 90° only as it is not verified for any other conditions.

13. The pressure development in the turbine hood is characterized by a rapid drop immediately after introduction of the Fine Water Spray, and a stabilizing about ambient pressure after a short period. The overpressure in the turbine hood is induced by the fire itself, when the ventilation dampers are shut down.

14. The Oxygen concentration in the turbine hood when a fire was self extinguished (TURBIN 27) was about 9 % Corresponding CO_2 concentration was 8%, and CO concentration was about 0.76. (7600 ppm). In the experiment where Fine Water Spray extinguished the fire, the minimum Oxygen concentration was in the range from 12.5 - 18 % Corresponding maximum CO_2 concentration was in the range from 2 - 6 %, and CO concentration was in the range from 0.1 - 0.6 % (1000 - 6000 ppm).

15. The conditions after extinguishment with the Fine Water Spray are much less hazardous for people than after a fire extinguished by oxygen starvation only. The concentration of oxygen and CO_2 are not critical for human exposure, and the concentration of CO is below critical values for 30 minutes in all experiments where the ventilation damper were closed and the water spray activated shortly after ignition of the fire.

16. Many large fires would be self-extinguished by lack of oxygen in closed spaces, regardless of the fire fighting system. The positive effect of the Fine Water Spray system is that the burning time of the fire is reduced, and the temperatures inside the enclosure are reduced to a level where the damage is small.

17. The inerting effect of water vapour decreases when the temperature is below the condensation point of water, 100°C. This means that the long-term inerting effect of the Fine Water Spray system is reduced both by leakages in the enclosure and by condensation of water vapour.

18. The exit velocity of the water droplets is important regarding efficiency of the spray system. A high exit velocity combined with a Median Droplet Diameter of about 200 μm seems to be an near optimal combination for extinguishing hydrocarbon fires in enclosures with ceiling height up to 4 m.

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7 APPENDIX I P&ID of extinguishing system