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The VINNOVA water mist research project: A description of the 250 m^3 machinery space tests

SP Swedish National Testing and Research Institute

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Abstract

This report describes water mist and water spray system tests inside a simulated machinery space. The tests were conducted inside a compartment measuring 8,0 m by 6,25 m with a ceiling height of 5,0 m. The corresponding volume was 250 m^3. The walls and the ceiling were constructed from steel plates. The test compartment replicates an intermediate size machinery space compartment onboard a ship.

Heptane pool fires were used as the fire source. The fires had nominal heat release rates of 250 kW, 500 kW, 1 MW and 2 MW, respectively and were completely shielded by a horizontal obstruction steel plate measuring 2 m by 2 m.

Four different systems were tested; (1) a water spray system flowing 250 L/min at 2 bar (this system was designed according to the SOLAS convention), (2) a low-pressure system flowing 48 L/min at 12 bar, (3) a high-pressure system flowing 30 L/min at 70 bar and (4) a high-pressure, low-flow system flowing 2 L/min at 75 bar. In addition to the tests using these three systems, free burn tests were conducted inside the compartment.

This report contains a description of the test set-up, its instrumentation, the fire test procedures and a limited presentation of the results. A more thorough analysis of the test results will be made in subsequent reports, articles and papers.

Key words: Water mist, water sprays, machinery space, fire, fire tests, halon alternative.

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Preface

About two-thirds of all fires on board ships start in the machinery space. An estimation made by Det Norske Veritas indicates that the direct cost for a fire is in the order of 1 – 4 million US$ for a cargo vessel - and much more for a passenger vessel. Obviously, a fire in the machinery space also represents a hazard for the crew members and fire fighters and may lead to a situation where passengers need to be evacuated from the vessel.

Traditionally, Halon and Carbon Dioxide (CO_2) gas extinguishing systems are those most commonly used in machinery spaces. With the phase-out of Halon and increasing safety concerns regarding the use of CO_2, the need for alternative extinguishing agents has emerged. Developments during the 1990s have shown that water mist has the potential to replace, or to provide an alternative to, traditional fire protection systems. Water has many advantages as a fire extinguishant: it is inexpensive, non-toxic, safe for personnel and does not represent a risk to the external environment. Its implementation in marine applications does, however, have some implications for vessel stability that must be considered during system design.

The primary objective of the project is to investigate and demonstrate the potential use of water mist in large machinery spaces on board ships. To reach this goal, several full-scale tests need to be conducted and sufficient scaling rules need to be developed. The following parts were included in the project:

- Full scale machinery space water mist system tests in three different size volumes.
- The development of scaling rules.
- Formulation of the requirements for water mist systems for large machinery spaces.
- Serve as an input for the forthcoming revision of IMO MSC/Circ.668 and 728.
- Prepare an implementation of the international SOLAS requirements.

This report contains a description of the test set-up, its instrumentation, the fire test procedures and a limited presentation of the results. A more thorough analysis of the test results will be made in subsequent reports, articles and papers.

The first part of the project is reported in SP Report 2003:19, “The VINNOVA water mist research project: A description of the 500 m^3 machinery space tests”.

The project was financed by VINNOVA, the Swedish Agency for Innovation Systems, project no. 2001-06225 together with Marioff Corporation Oy (Finland) and Tyco Fire Products (USA). The internal project no. was BRs 6081.

1 The fire test compartment

The test compartment measured 8,0 m by 6,25 m and had a ceiling height of 5,0 m. The corresponding volume was 250 m^3. The walls and the ceiling were constructed from nominally 2 mm thick steel. The compartment was fitted with one doorway opening at floor level. The doorway opening had a sliding steel door, measuring 2,5 m by 2,3 m. This door was open during the ignition of the tests fires, but was closed immediately thereafter.

The ceiling had two positive pressure relief vents, both with hatches. The largest of the vents measured 1,0 m by 2,9 m (2,9 m^2) and was positioned centric at the ceiling. For the majority of the tests, the hatch was sealed closed. However, during some tests, this hatch was fully open during the entire test. These tests were conducted in order to evaluate the performance of the systems tested under other ventilation conditions. For additional tests, the sliding steel door was opened 1,16 m, which provided for an area similar to the ceiling vent, i.e. 2,9 m^2.

The smaller of the vents measured 0,75 m by 0,75 m each (0,56 m^2) and was positioned close to one of the ceiling corners. The hatch of the small vent was allowed to open and close during the test to relieve the positive pressure inside the test compartment.

2 The fire scenarios

Only heptane pool fires were used. The fires had a nominal heat release rate of 250 kW, 500 kW, 1 MW and 2 MW, respectively and were completely shielded by a horizontal obstruction steel plate measuring 2 m by 2 m. The thickness of the steel plate was a nominal 4 mm. No tests where the fire was exposed were conducted.

The pool fires were arranged in circular trays with diameters chosen to provide the desired heat release rate. The rim height of the trays was 150 mm and trays were filled with 50 mm of fuel. Additional water was added to provide a freeboard of 50 mm. The 250 kW and 500 kW trays were filled with 100 mm of fuel (only). Table 1 provides information on the trays.

Table 1 The sizes of the heptane trays.

Nominal HRR	Diameter [cm]	Area [m^2]	Rim height [mm]	Amount of fuel [L]	Amount of water [L]
250 kW	45	0,16	150	16	-
500 kW	62	0,30	150	30	-
1 MW	79	0,49	150	24,5	24,5
2 MW	112	0,98	150	49	49

During the tests, the pool fire tray was placed on a load cell to determine the weight loss. The vertical distance measured from the rim of the trays to the underneath of the horizontal obstruction steel plate was 700 mm.

The reason for choosing pool fires only, was twofold. Firstly, it is possible to determine the heat release rate of the fire by means of measuring the weight loss of the fire tray. Obviously, this is however, only possible for the cases where the pool fire was obstructed from direct impingement of the water spray. Secondly, pool fires are generally more difficult to extinguish for a given fire size, compared to spray fires.

3 The water spray and the water mist systems

3.1 Water spray system in accordance with Chapter 7 of the FSS Code

Under the test compartment ceiling, a piping arrangement was fabricated consisting of a single feed gridded piping system, which was installed to minimise the difference between the flow rates of the nozzles. A supply hose was connected to one of the 40 mm mains located on opposite sides of the grid. Two 32 mm cross connections spaced 3,33 m apart were made between the mains to serve as the feed lines to the individual nozzles under the test. At a 3,33 m spacing along the cross connections, 15 mm diameter pipe drops were installed down to the pendent nozzles. The ceiling to nozzle deflector distance was 250 mm. The system was fitted with a pressure transducer so that the operator could adjust the pump output and maintain the specific flowing pressure in response to any pressure changes.

The nozzles were made by Tyco Fire products and designated Protectospray D3 24-110. The nozzles had a K-factor of 43,2 (metric) and a spray angle of 110º.

No pump unit was necessary; the water was taken directly from the public water main.

A nominal flowing pressure of 2 bar was utilised throughout the tests, which provided a flow rate per nozzle of about 62,5 L/min. The total flow rate was 250 L/min and the corresponding nominal discharge density 5 mm/min.

From the initiation of the water flow into the test compartment there was a 2 - 3 second delay before full pressure to the nozzle piping system was reached.

This system was designed according to the requirements of Chapter 7 of the FSS Code[1] (previously these requirements were found in SOLAS II-2, regulation 10).

3.2 Low-pressure water mist system (Tyco Fire Products)

The pipe-work for this system was identical with the pipe-work used for the water spray system. Four *AquaMist* AM15 (K=3,6 metric) nozzles were fitted directly into 32 mm × 15 mm reducing tees. The nozzles were installed in an upright position (per the manufacturers instructions) with a ceiling to nozzle diffuser distance of 250 mm.

The pump unit was connected to a 3 m^3 stainless steel tank that was continuously filled from the public water main with potable water.

A nominal flowing pressure of 12 bar was utilised throughout the tests, which provided a flow rate per nozzle of about 12,1 L/min. The total flow rate was 48,5 L/min and the corresponding nominal discharge density 0,97 mm/min.

From the initiation of the water flow into the test compartment there was a 2 - 3 second delay before full pressure to the nozzle piping system was reached.

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[1] International Code for Fire Safety Systems (FSS Code), Resolution MSC.98(73), International Maritime Organization, London, UK, 2001

3.3 High-pressure water mist system (Marioff Corporation Oy)

Under the test compartment ceiling, a tree type piping arrangement was fabricated consisting of a 12 mm primary stainless steel pipe along the centreline of 8 m long side of the test compartment. A total of two nozzles (K=1,9), spaced 4,0 m, were installed at either end of this pipe. The nozzles were pendent and the vertical distance from the ceiling to the tip of the nozzles was 250 mm.

A 15 mm supply pipe was connected to the centre of the 12 mm pipe, which was connected to the high-pressure pump unit.

The nozzles were designated Hi-Fog 4S 1MC 8MB 1000.

A nominal flowing pressure of approximately 80 bar was utilised throughout the tests, which provided a flow rate per nozzle of about 15 L/min. The total flow rate was 30 L/min and the corresponding nominal discharge density 0,60 mm/min.

During the tests, the flow meter was positioned on the low-pressure side of the pump. The water flow to the pump was approximately 84 L/min and 24 L/min were shunted off to the drain.

3.4 High-pressure, low flow water mist system (Lechler GmbH)

Under the test compartment ceiling, a tree type piping arrangement was fabricated consisting of a 25 mm primary stainless steel main with pairs of 2,0 m long, 12 mm diameter branch lines running perpendicular to the main line at 5,0 m intervals. A total of two nozzles (K=0,12) were installed in the test compartment. A supply pipe was connected to one end of the 25 mm main, which were connected to the high-pressure pump unit.

The nozzles were designated Lechler GmbH 212.245.

A nominal flowing pressure of 75 bar was utilised throughout the tests, which provided a flow rate per nozzle of about 1 L/min. The total flow rate was 2 L/min and the corresponding nominal discharge density 0,04 mm/min.

During the tests, the flow meter was positioned on the low-pressure side of the pump. The water flow to the pump was approximately 84 L/min and 24 L/min were shunted off to the drain.

4 Instrumentation

The test compartment was instrumented to measure both the thermal conditions inside the space, the wall and ceiling surface temperatures, the radiant heat flux from the fires, the compartment pressure as well as the gas concentrations of O_2, CO and CO_2. Table 2 provides information on all measurement positions and associated channels.

The data was recorded at a rate of about one scan per second.

4.1 Temperature measurements

One thermocouple tree was used to measure the gas temperatures inside the test compartment. The tree consisted of 10 thermocouples positioned at the following distances below the ceiling; 250 mm, 500 mm, 1000 mm, 1500 mm, 2000 mm, 2500 mm, 3000 mm, 3500 mm, 4000 mm and 4500 mm. Small angle iron shields were positioned above each measurement point to minimize wetting of the thermocouples by direct water spray impingement. The ceiling gas temperature (25 mm below the ceiling surface) was measured centric at the ceiling, right above the position of the fire source.

All thermocouples were of type K (chromel-alumel) and made from 0,5 mm wire welded together. The leads were manufactured by Pentronic AB. The quality is class 1, according to the IEC 584-1 standard, which means an accuracy of ±1,5°C in the interval -40 to +375°C and 0,04% of measured value above 375°C.

The wall surface temperatures were measured with a type K thermocouple that was spot-welded to the walls (on the inside of the test compartment). The measurement points were positioned at the centreline of the short side wall and the long side wall, respectively, 500 mm, 2500 mm and 4500 mm below the ceiling. The ceiling surface temperature was measured centric at the ceiling, right above the position of the fire source, using a thermocouple spot-welded to the ceiling.

4.2 Gas concentration measurements

4.2.1 Oxygen concentration measurements

For the measurements of the oxygen (O_2) concentration at the measurement position 4500 mm below ceiling, a Siemens Oxymat analyser having inventory number 700014 was used (channel 5). The instrument was calibrated prior to the use for a span of 14,7 - 21 vol-% oxygen. The inaccuracy is less than ±0,1 vol-% oxygen.

For the measurements of the oxygen (O_2) concentration at the measurement position 1000 mm below ceiling, a M & C Instruments, PMA 10 analyser having inventory number 700173 was used (channel 80). The instrument was calibrated prior to the use for a span of 0 – 21 vol-% oxygen. The inaccuracy is less than ±0,1 vol-% oxygen.

4.2.2 Carbon monoxide concentration measurements

The concentration of carbon monoxide (CO) was recorded at the measurement position 4500 mm below ceiling (channel 6) with a Rosemount Binos 100-2M analyser having inventory number 700394. The instrument was calibrated prior to the use for a span of 0 – 0,6 vol-% carbon monoxide. The inaccuracy is equal to, or less than ±2% of full scale.

The concentration of carbon monoxide (CO) was recorded at the measurement position 1000 mm below ceiling (channel 79) with a Siemens Ultramat 22P analyser having inventory number 700240. The instrument was calibrated prior to the use for a span of 0 – 3 vol-% carbon monoxide. The inaccuracy is equal to, or less than ±2% of full scale.

4.2.3 Carbon Dioxide concentration measurements

The concentration of carbon dioxide (CO_2) at the measurement position 4500 mm below ceiling was recorded (channel 7) with a Rosemount Binos 100-2M analyser having inventory number 700394. The instrument was calibrated prior to the use for a span of 0 – 6,0 vol-% carbon dioxide. The inaccuracy is equal to, or less than ±2% of full scale.

The concentration of carbon dioxide (CO_2) at the measurement position 1000 mm below ceiling was recorded (channel 78) with a Siemens Ultramat 22P analyser having inventory number 700240. The instrument was calibrated prior to the use for a span of 0 – 10 vol-% carbon dioxide. The inaccuracy is equal to, or less than ±2% of full scale.

4.3 Heat flux measurements

The radiant heat flux from the fires was recorded with a Schmidt Boelter transducer manufactured by Medtherm Co., positioned 4000 mm from the fire and 500 mm above floor. The instrument has a full-scale range of 0 – 20 kW/m^2. The transducer had serial number 56363.

4.4 Compartment pressure measurements

The compartment pressure was measured close to one of the corners of the test compartment using a Digima Premo 355 differential pressure transducer, having inventory number 700179. The instrument has an inaccuracy of less than 0,5% of measured value, and the response time from zero to full scale of less than one millisecond.

4.5 Humidity measurements

The humidity inside the test compartment was <u>not</u> measured during these tests.

4.6 System water pressure and water flow rate

The system water pressure was measured at two positions: at the pump, or, for the water sprays system tests, at the public water supply; and at the pipe-work grid, using Transinstrument 2000A pressure transducers.

The total water flow rate was measured using a Krohne 0 – 2000 L/min flow meter. The instrument has inventory number 701065. For the high-pressure system tests, it should be noted that the flow meter was positioned on the low-pressure side of the pump. The water flow to the pump was approximately 84 L/min and 24 L/min were shunted off. The later value was determined by collecting the water for one minute and weighing it.

4.7 The weight loss of the fire tray

The weight loss of the fire tray was determined using a load cell.

Table 2 Measurement positions and associated channels

Channel No.	Channel name	Description and position
Ch 21	TC 1	Gas temperature, 250 mm below ceiling (pos. 1)
Ch 22	TC 2	Gas temperature, 500 mm below ceiling (pos. 1)
Ch 23	TC 3	Gas temperature, 1000 mm below ceiling (pos. 1)
Ch 24	TC 4	Gas temperature, 1500 mm below ceiling (pos. 1)
Ch 25	TC 5	Gas temperature, 2000 mm below ceiling (pos. 1)
Ch 26	TC 6	Gas temperature, 2500 mm below ceiling (pos. 1)
Ch 27	TC 7	Gas temperature, 3000 mm below ceiling (pos. 1)
Ch 28	TC 8	Gas temperature, 3500 mm below ceiling (pos. 1)
Ch 29	TC 9	Gas temperature, 4000 mm below ceiling (pos. 1)
Ch 30	TC 10	Gas temperature, 4500 mm below ceiling (pos. 1)
Ch 38	TC 18	Flame temperature, close to pool fire (sheathed)
Ch 39	TC 19	Ceiling surface temp. (spot-welded) centric at ceiling (pos. 2)
Ch 40	TC 20	Gas temperature temp. (sheathed), centric at ceiling, 25 mm below ceiling (pos. 2)
Ch41	TC 21	Centric at small vent opening (pos. 5)
Ch 31	TC 11	Wall surface temp. 500 mm below ceiling (back wall, pos. 3)
Ch 32	TC 12	Wall surface temp. 2500 mm below ceiling (back wall, pos. 3)
Ch 33	TC 13	Wall surface temp. 4500 mm below ceiling (back wall, pos. 3)
Ch 34	TC 14	Wall surface temp. 500 mm below ceiling (side wall, pos. 4)
Ch 35	TC 15	Wall surface temp. 2500 mm below ceiling (side wall, pos. 4)
Ch 36	TC 16	Wall surface temp. 4500 mm below ceiling (side wall, pos. 4)
Ch 37	TC 17	Surface temperature of obstruction steel plate (welded)
Ch 42	TC 22	Exposed T/C, 2500 mm below ceiling (pos. 1)
Ch 43	TC 23	W 0,077 filter T/C, 2500 mm below ceiling (pos. 1)
Ch 44	TC 24	W 0,25 filter T/C, 2500 mm below ceiling (pos. 1)
Ch 45	TC 25	W 0,50 filter T/C, 2500 mm below ceiling (pos. 1)
Ch 46	TC 26	W 1,0 filter T/C, 2500 mm below ceiling (pos. 1)
Ch 51*	CO2	Carbon dioxide concentration, 1000 mm below ceiling (pos. 1)
Ch 52*	CO	Carbon monoxide concentration, 1000 mm below ceiling (pos. 1)
Ch 53*	O2	Oxygen concentration, 1000 mm below ceiling (pos. 1)
Ch 5**	CO2	Carbon dioxide concentration, 4500 mm below ceiling (pos. 1)
Ch 6**	CO	Carbon monoxide concentration, 4500 mm below ceiling (pos. 1)
Ch 7**	O2	Oxygen concentration, 4500 mm below ceiling (pos. 1)
Ch 56	Heat flux rate	Heat flux meter, 4500 mm below ceiling
Ch 12	Weight loss	Weight loss of fire tray
Ch 63	System pressure	Water pressure (system pressure)
Ch 54	Compartment pressure	Compartment pressure
Ch 55	Water flow rate	System water flow rate

*) Response time 8 seconds.
**) Response time 19 seconds.

5 Test fire procedures

The fires were ignited using a torch, and allowed to burn for 2 minutes (250 kW and 500 kW) or 30 seconds (1 MW and 2 MW fires) before the water flow was initiated.

From the temperature readings during the tests and from visual observations from the test compartment window it was possible to judge when the fires were extinguished. Water was left on for a couple of minutes after extinguishment to cool the test compartment. The measurements were continued for an additional period of time after the flow of water was shut off.

The level of fuel in the tray was observed after the end of the applicable tests to make sure that no limitation of fuel occurred during the test.

The data file identities were specified using the following principal code:

TestXSN(HRR)FTOF, where:

X = consecutive test number.
S = “system type”, was given either LP, WS, HP, HPLF or FB for Free Burn.
HRR = nominal heat release rate, was given either 250 (kW), 500 (kW), 1 (MW) or 2 (MW)
FT = Fire Type, was given P for Pool fire.
O = Obstruction, was given O (Obstructed)
F = Fuel, was given H (Heptane).

The name “Test10LP(500)POH” would therefore correspond to the 10th consecutive test, the first tested system (the low-pressure system), and an obstructed 500 kW heptane pool fire.

The fire test procedure was as follows:

00:00	Start of the measurement
01:00	Ignition of the fire
01:05	Closure of the steel door to the test compartment
01:30	Initiation of water (for the tests using fires with nominal HRR of 1 MW and 2 MW)
03:00	Initiation of the water (for all other fire sizes)

6 Test results and observations

This section provides a limited presentation of the test results and observations. No conclusions are given within this report. A more thorough analysis of the test results will be made in subsequent reports, articles and papers.

All times to extinguishment given in the tables below are calculated from the ignition of the fire, not from the activation of the system, in order to provide comparable data irrespective of the pre-burn time.

The following abbreviations are used in the tables, N/E=Not Extinguished, M/E=Manually Extinguished, LV=Large Ventilation opening.

Table 3 Test results and observations for the low-pressure system.

Test no.	HRR	Ventilation openings?	Fuel temp. [°C]	Water temp. [°C]	Ext. time [min: sec]	Remarks and observations	Minimum oxygen concentration [vol%]	
							1000 below ceiling	4500 mm below ceiling
1	250 kW	None	7	7	29:12	System pressure transducer out of function (Ch 61).	15:2	15,0
2	250 kW	None	8	8	28:11	Repeat of test 1. System pressure transducer out of function (Ch 61). TC22 (Ch24) out of function.	15.2	15,4
3	500 kW	None	7	8	11:18	TC22 (Ch24) out of function.	15.8	15,7
4	500 kW	None	6	9	13.13	Repeat of test 3	15,2	15,2
5	500 kW	LV	8	10	N/E – burnt out after 47:08	Upper O_2, CO and CO_2 measurements disconnected until 06:00. TC18 not in heptane pool	17,8	17,7
6	1 MW	None	21	8	06:32	Fuel heated by ‘tempered’ water	15,6	15,7
7	1 MW	None	9	7	04:58	Repeat of test 6	16,8	16,7
8	1 MW	None	8	8	06:57	Repeat of test 7, to determine the influence of the fuel temp.	15,6	15,7
9	1 MW	LV	7	8	N/E – burnt out after 26:30	TC17 on obstruction plate out of function. Upper O_2, CO and CO_2 measurements disconnected until 01:30. Compartment pressure ‘zeroed’ at 00:40.	App. 19,8	App. 19,8
10	1 MW	LV + doorway opening	7	7	N/E, burnt after at 12:50		16,6	16,4
11	2 MW	None	9	7	02:17		15,8	16,2
12	2 MW	None	16	7	02:44		16,6	16,4
13	2 MW	LV	7	10	04:40		16,3	16,3
14	2 MW	LV + doorway opening	12	9	N/E – M/E. at 06:30	Fire size too large! Risk for damage to instrumentation.		

Table 4 Test results and observations for the water spray system installed in accordance with SOLAS II/2-10.

Test no.	HRR	Ventilation openings?	Fuel temp. [°C]	Water temp. [°C]	Ext. time [min: sec]	Remarks and observations	Minimum oxygen concentration [vol%]	
							1000 below ceiling (utanför rummet)	4500 mm below ceiling (mätrum)
15	250 kW	None	8	4	42:45	Upper O_2, CO and CO_2 measurements disconnected until 07:30.	13,1	14,7*
16	250 kW	None	7	4	50:30	Repeat of test 15. Problem with load cell	13,1	14,7*
17	500 kW	None	8	4	16:30	Load cell out of function. Compartment pressure 'zeroed' at 00:35.	13,8	14,7*
18	500 kW	None	6	7	21:35		13,2	14,7*
19	500 kW	LV	8	5	N/E – burnt out after 47:35		App. 16,0	App. 16,0
20	1 MW	None	6	5	06:58		14,6	14,8
21	1 MW	None	7	5	09:40	Repeat of test 20.	13,5	14,7*
22	1 MW	LV	7	5	N/E – burnt out after 23:50		App. 15,1	App. 14,9
23	1 MW	LV + doorway opening	12	7	N/E – burnt out after 12:05	CO measurement equipment. (CH52) removed from this test.	App. 19,2	App. 19,2
24	2 MW	None	12	5	04:03		13,8	14,7*
25	2 MW	None	10	5	03:04	Repeat of test 24.	14,3	14,7
26	2 MW	LV	7	5	03:14		15,5	16,2
27	2 MW	LV	12	5	08:55	Repeat of test 26.	14,5	14,7*

Table 5 Test results and observations for the high-pressure system.

Test no.	HRR	Ventilation openings?	Fuel temp. [°C]	Water temp. [°C]	Ext. time [min: sec]	Remarks and observations	Minimum oxygen concentration [vol%]	
							1000 below ceiling	4500 mm below ceiling
28	250 kW	None	7	6	43:50	Compartment pressure strange.	13,8	14,7*
29	250 kW	None	7	5	49:03	Repeat of test 28. Wall surface temp., Ch34 out of function. Problem w/ temp. on obstruction steel plate, Ch37 after a while. Compartment pressure strange.	13,8	14,7*
30	500 kW	None	5	6	09:02		15,7	16,0
31	500 kW	None	7	6	11:36	Repeat of test 30.	15,1	15,1
32	500 kW	LV	5	5	N/E – burnt out after 45:56		App. 16,0	App. 16,0
33	1 MW	None	6	5	04:30		16,0	16,0
34	1 MW	None	11	5	05:00	Repeat of test 33.	15,8	15,7
35	1 MW	None	9		03:22	Two minutes pre burn time instead of 30 seconds. Upper O_2, CO and CO_2 measurement disconnected until 01:30.	16,2	16,3
36	1 MW	LV	15	5	App. 07:10 (Ext.)		App. 16,9	App. 16,5
41	1 MW	LV + doorway opening	5	5	N/E – burnt out after 11:15		App. 19,5	App. 19,5
37	2 MW	None	18	6	01:42		Not functioning	16,0
38	2 MW	None	5	6	01:40	Repeat of test 37. O_2 upper not connected.	16,0	16,4
39	2 MW	LV	4	6	02:04		16,3	16,4
40	2 MW	LV	14	6	02:15	Repeat of test 39.	15,9	16,3

Table 6 Test results and observations for the high-pressure, low flow system.

Test no.	HRR	Ventilation openings?	Fuel temp. [°C]	Water temp. [°C]	Ext. time [min: sec]	Remarks and observations	Minimum oxygen concentration [vol%]	
							1000 below ceiling	4500 mm below ceiling
42	250 kW	None	5	5	35:09		14,1	14,7*
43	250 kW	None	6	6	31:23	Repeat of test 42. Radiation shield in front of filter T/C's.	14,3	14,7*
44	500 kW	None	4	7	09:58		14,0	14,7*
45	500 kW	None	6	7	09:05	Repeat of test 44. Radiation shield in front of filter T/C's removed.	14,1	14,7*
46	500 kW	LV	8	6	N/E – burnt out after 24:56	Radiation shield in front of filter T/C's still removed.	App. 16,1	
47	1 MW	None	7	6	05:22		13,0	14,7*
48	1 MW	None	17	6	05:20	Repeat of test 47	13,6	14,7*
49	1 MW	LV	11	6	N/E – burnt our after 13:14		App. 13,5	14,7*
54	2 MW	None	6	7	02:35	Compartment pressure 'zeroed' at 00:40	12,1	14,7*
55	2 MW	None	6	7	02:39		11,8	14,7*

Note: No tests were conducted with the 2 MW fire with ceiling hatch open, due to the size of the fire and the limited cooling ability of the system.

Table 7 Free-burn tests, conducted without the application of water.

Test no.	HRR	Ventilation openings?	Fuel temp. [°C]	Water temp. [°C]	Ext. time [min: sec]	Remarks and observations	Minimum oxygen concentration [vol%]	
							1000 below ceiling	4500 mm below ceiling
50	250 kW	None	6	-	27:49		13,7	14,7*
51	500 kW	None	7	-	15:50	Very close to ext. at 09:38, 10:52, 11:22, 12:10, 12:17, 12:50 and 13:50.	12,7	14,7*
52	1 MW	None	7	-	06:30	Very close to ext. at 05:06 and 06:03	12,4	14,7*
53	2 MW	None	6	-	05:40	Very close to ext. at 02:10 and 05:18	10,8	14,7*

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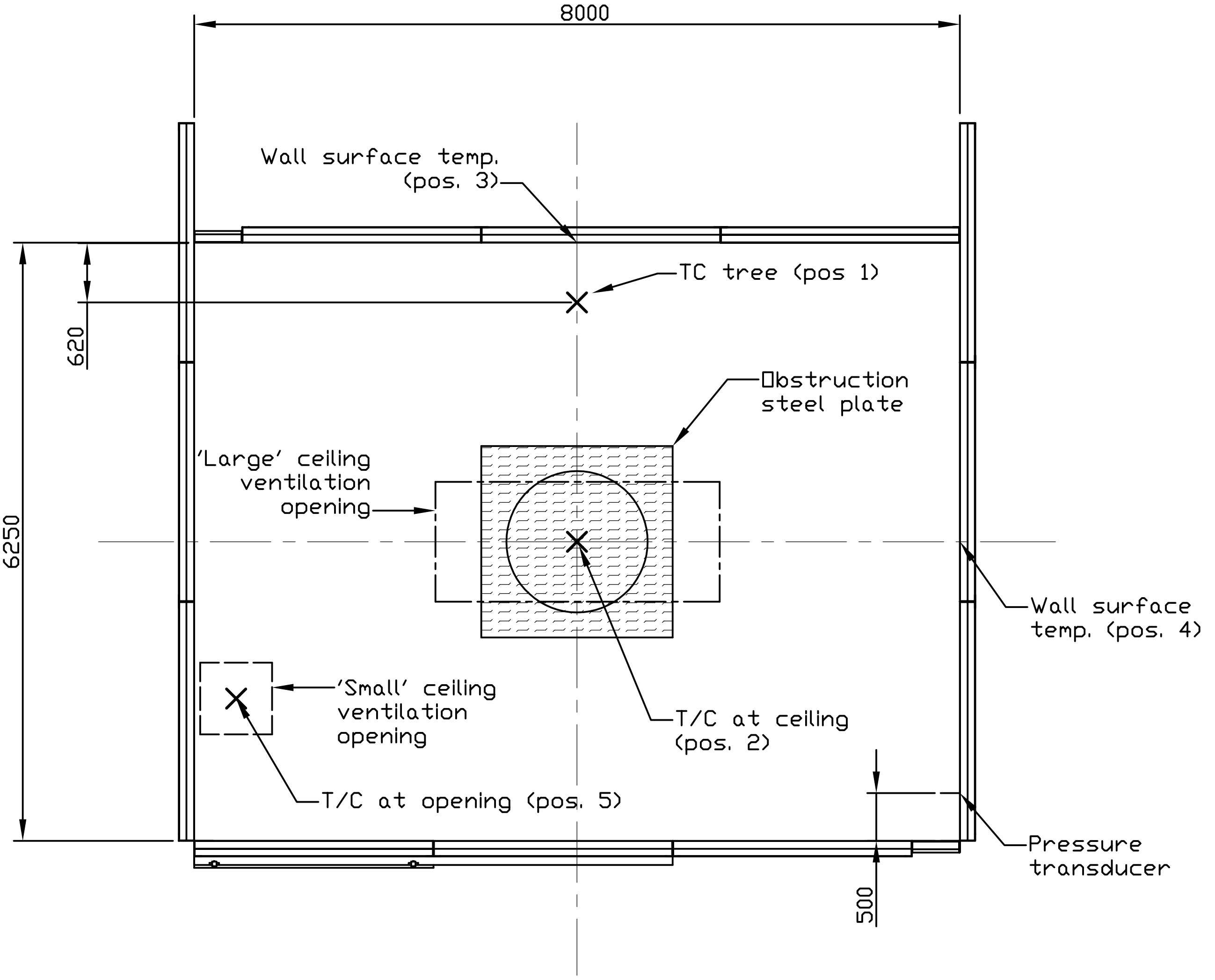
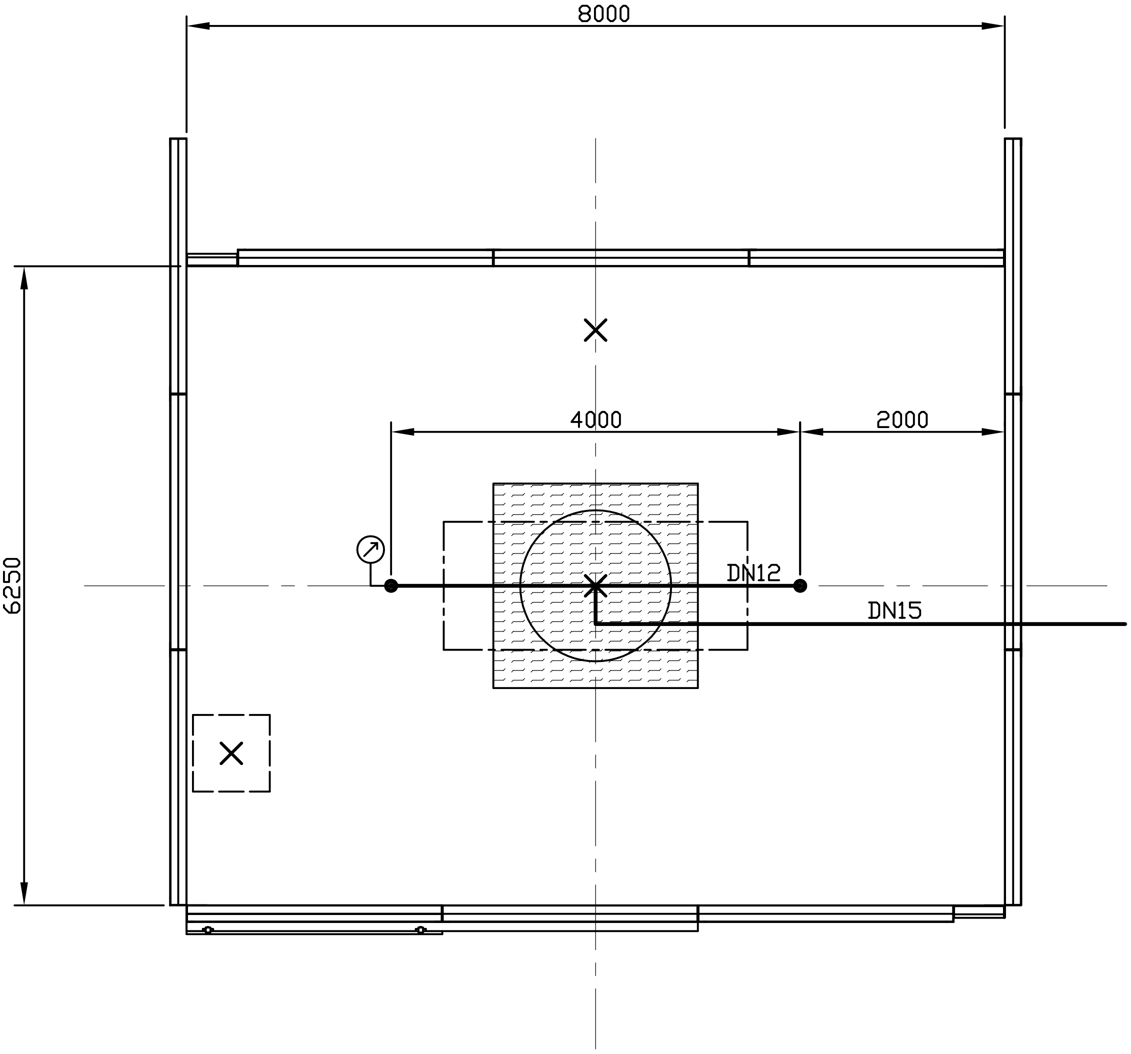
Steel module enclosure

Interior, top view

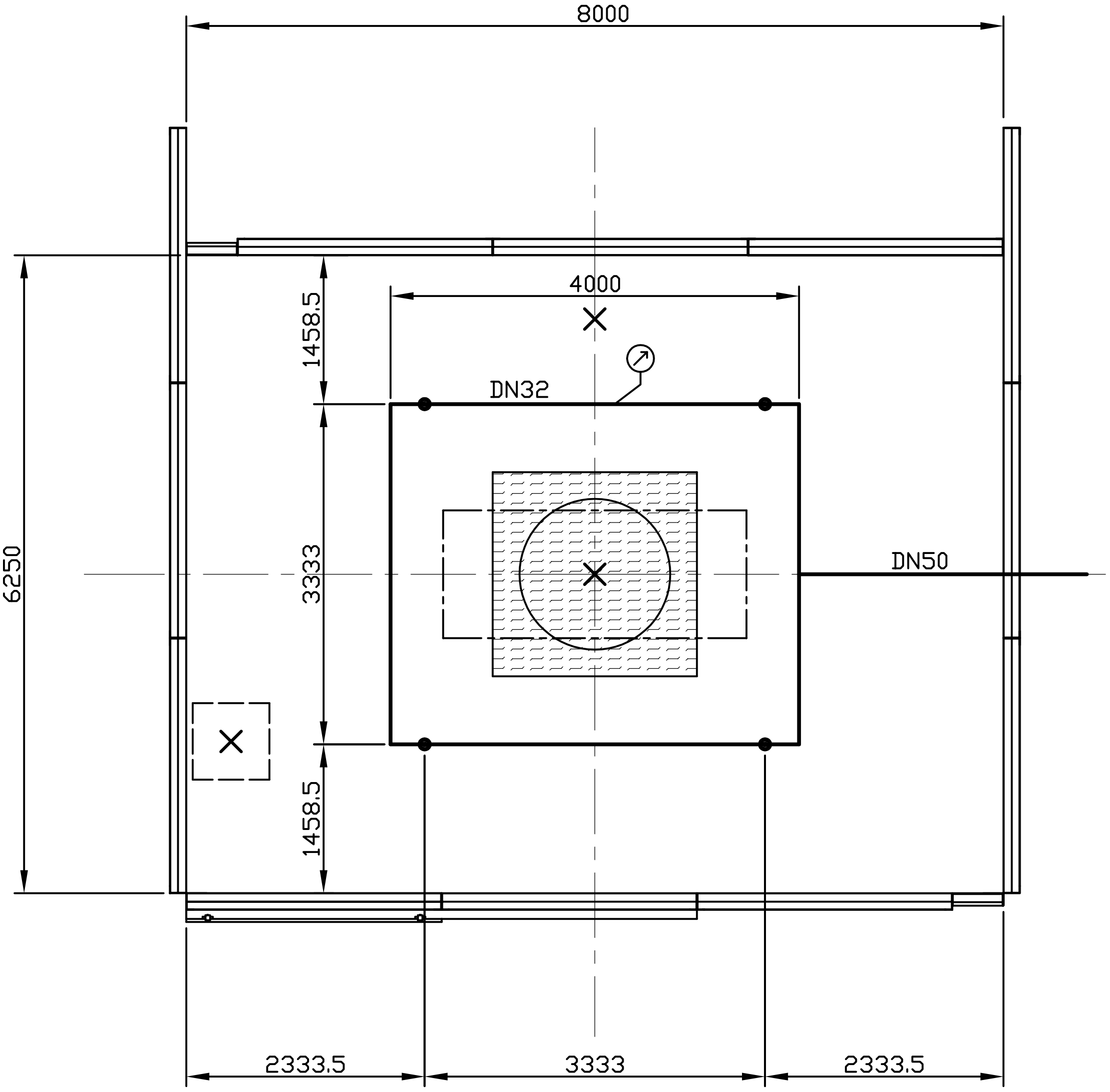
Enclosure No:	
Report No:	2003:29
Date: 2002-04-15	Rev. Date:
Scale: 1:75	Sign: MA



SP PROVNING · FORSKNING	**Steel module enclosure** Interior, top view With the high-pressure system	Enclosure No:	
		Report No:	2003:29
		Date: 2002-04-15	Rev. Date:
		Scale: 1:75	Sign: MA



SP PROVNING · FORSKNING	**Steel module enclosure** Interior, top view With the water spray and low-pressure systems	Enclosure No: Report No: BRs 6081 Date: 2003:29 / Rev. Date: Scale: 1:75 / Sign: MA



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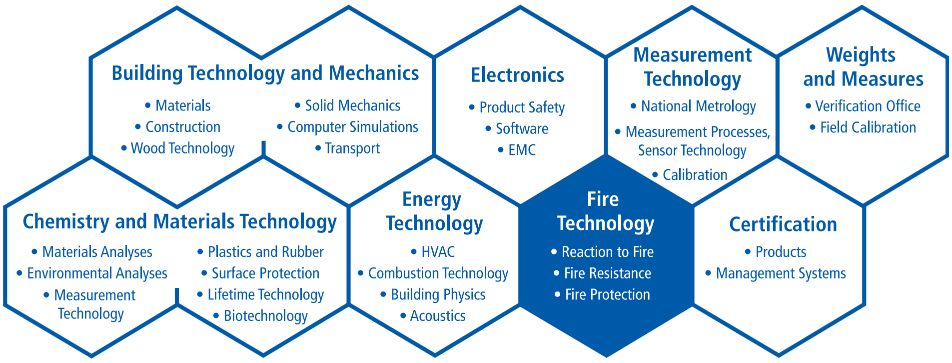

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