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Fire protection of weapon storage and water mist redundancy philosophies

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PWGSC Contract Number: W7707-125492/001/HAL
CSA: John A. Hiltz, Defence Scientist, 902-427-3425

Defence R&D Canada – Atlantic

Contract Report
DRDC Atlantic CR 2012-193
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Abstract

The FiST-project “New Technologies for Fire Suppression On Board Naval Craft”, is a tri-lateral research project under the Canada, the Netherlands, Sweden Cooperative Science and Technology MOU. The focus for the project is active firefighting on navy ships, with a special emphasis on how firefighting systems might perform in a damaged condition.

The results of a number of full scale fire tests run at SP Technical Research Institute of Sweden, December 2011-February 2012 are reported. The testing had two objectives. The first was to investigate redundancy solutions for fire suppression systems. To this end, the performance of a low pressure water mist system with reduced capacity and the performance of a redundant extinguishment system attached to a strength bulkhead were investigated. The results of the tests indicated that a low pressure system designed to handle a well-ventilated hydrocarbon fire scenario can suppress the same fire in a less ventilated space with a 50 % reduction in water supply. Further if the system is fed by pumps providing water at lower pressure e.g. the fire main, it still has the capacity to suppress a compartment fire. Testing of the bulkhead mounted system indicated that it could extinguish an obstructed diesel pool fire at water flow rates of 12-14 L/m^2/min provided nozzles that distributed the water spray over the entire test space were used. The second objective was to study the relevance of the weapon storage fire protection water delivery requirements found in Naval Ship Code (NSC) (24 mm/min) or Class DNV (32 mm/min) regulations. For the fire scenario studied, the results indicated that lower water flow rates were successful in keeping the temperature of a dummy torpedo below a ‘critical temperature’.

Résumé

Le projet FiST (Nouvelles technologies d’extinction des incendies sur des embarcations navales) est un projet de recherche trilatéral relevant du PE sur la coopération en science et en technologie conclu entre le Canada, les Pays-Bas et la Suède. Le projet est orienté principalement vers la lutte active contre les incendies à bord des navires de la marine, avec une attention spéciale portée à la performance éventuelle des systèmes de lutte contre les incendies endommagés.

Les résultats de certains essais en vraie grandeur menés à l’Institut de recherche technique SP de Suède, de décembre 2011 à février 2012, sont rapportés. Les mises à l’essai avaient deux (2) objectifs. Premièrement, ils visaient à analyser les solutions de redondance pour les systèmes d’extinction. À cette fin, la performance d’un système à brouillard d’eau à basse pression et débit réduit et la performance d’un système d’extinction redondant fixé à une cloison résistante ont été analysées. Les résultats des essais ont montré qu’un système à basse pression conçu pour éteindre un incendie d’hydrocarbures dans un endroit bien aéré pouvait éteindre un tel incendie dans un espace moins bien aéré avec deux (2) fois moins d’eau. De plus, si le système est alimenté en eau à une pression moindre, par exemple la canalisation principale d’incendie, il demeure tout de même capable d’éteindre un incendie dans un compartiment. La mise à l’essai du système monté sur cloison a révélé que ce dernier pouvait éteindre un incendie dans une cuvette de diesel obstruée, à des débits d’eau de 12 à 14 L/m^2/min, pour autant que l’on utilise la même lance que

celle ayant servi à projeter le jet d'eau dans l'espace d'essai. Le deuxième objectif des mises à l'essai était d'étudier la pertinence des exigences en matière d'alimentation en eau pour protection incendie des entrepôts d'armes prescrites par le Naval Ship Code (CNM) (accumulation d'eau de 24 mm/min) ou par les règlements de la classe DNV (accumulation d'eau de 32 mm/min). En ce qui concerne les scénarios d'incendie mis à l'essai, les résultats ont montré que des débits d'eau moindres permettaient de maintenir la température d'une torpille factice sous le seuil 'critique'.

Executive summary

Fire protection of weapon storage and water mist redundancy philosophies

Michael Rahm and Johan Lindstrom; DRDC Atlantic CR 2012-193; Defence R&D Canada – Atlantic; November 2012.

Introduction: The FiST project "New Technologies for Fire Suppression On Board Naval Craft", is a tri-lateral research project under the Canada, the Netherlands, Sweden Cooperative Science and Technology MOU. The focus for the project is active fire fighting on navy ships, with a special emphasis on how firefighting systems might perform in a damaged condition.

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Results: The results of the testing of the low pressure water mist system at reduced capacity indicated that a low pressure system designed to handle a well-ventilated hydrocarbon fire scenario can suppress the same fire in a less ventilated space with a 50 % reduction in water supply. Further if the system is fed by pumps providing water at lower pressure, e.g., the fire main, it still has the capacity to suppress a compartment fire. Testing of the bulkhead mounted system indicated that it could extinguish an obstructed diesel pool fire at water flow rates of 12-14 $L/m^2/min$ provided nozzles that distributed the water spray over the entire test space were used. For the fire scenario studied, the results of the weapon storage fire protection water delivery requirements testing indicated that lower water flow rates were successful in keeping the temperature of a dummy torpedo below a 'critical temperature'.

Significance: The performance of fire suppression systems on naval vessels is critical in ensuring that fires can be suppressed and extinguished and that the ship's functions can be recovered in the shortest period of time. The testing described in this report studied the efficacy of a low pressure water mist system that had lost 50% of its capacity. In addition, the concept of using a bulkhead mounted water spray system to carry out fire suppression following damage to the water mist system was studied. In the first instance, the scenario is representative of a damaged system and in the second the bulkhead mounted system is representative of a redundant (back-up) system. The testing of the magazine (weapon storage) fire protection system was carried to determine if the large volumes of water delivered by these systems is overly conservative.

Future plans: Testing of a damaged medium to high pressure water mist system is planned for the winter of 2012-13. The tests will investigate the effect of pipe ruptures (breaks and fragment damage) and damaged or inoperable nozzles on the residual efficacy of the system.

Sommaire

Fire protection of weapon storage and water mist redundancy philosophies

Michael Rahm and Johan Lindstrom; DRDC Atlantic CR 2012-193; R & D pour la défense Canada – Atlantique; novembre 2012.

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Résultats : Les résultats des essais menés sur le système à brouillard d’eau à basse pression ont montré qu’un système à basse pression conçu pour éteindre un incendie d’hydrocarbures dans un endroit bien aéré pouvait éteindre un tel incendie dans un espace moins bien aéré avec deux (2) fois moins d’eau. De plus, si le système est alimenté en eau à une pression moindre, par exemple la canalisation principale d’incendie, il demeure tout de même capable d’éteindre un incendie dans un compartiment. La mise à l’essai du système monté sur cloison a révélé que ce dernier pouvait éteindre un incendie dans une cuvette de diesel obstruée, à des débits d’eau de 12 à 14 L/m^2/min, pour autant que l’on utilise la même lance que celle ayant servi à projeter le jet d’eau dans l’espace d’essai. En ce qui concerne les scénarios d’incendie mis à l’essai, l’étude de la pertinence des exigences en matière d’approvisionnement des entrepôts d’armes en eau pour protection incendie a montré que des débits d’eau moindres permettaient de maintenir la température d’une torpille factice sous le seuil « critique ».

Importance : La performance des systèmes d’extinction sur les navires militaires est essentielle pour garantir l’extinction des feux et pour s’assurer que les fonctions du navire pourront être rétablies le plus rapidement possible. La mise à l’essai décrite dans le rapport visait l’analyse de l’efficacité d’un système à brouillard d’eau à basse pression dont le débit avait diminué de 50 %. De plus, la possibilité d’utiliser un système de pulvérisation d’eau monté sur cloison pour éteindre un incendie, dans l’éventualité où le système à brouillard d’eau serait endommagé, a été étudiée. Dans le premier scénario, un système est endommagé, et dans le second, un système monté sur cloison est utilisé en guise de système redondant (de secours). Les systèmes de protection incendie des magasins (entrepôts d’armes) ont été mis à l’essai afin de déterminer si les grands

volumes d’eau qu’ils fournissent sont excessifs (trop conservateurs) : c’était le cas pour les scénarios d’incendie étudiés.

Essais prévus : La mise à l’essai d’un système à brouillard d’eau à pression moyenne à élevée endommagé est prévue pour l’hiver 2012-2013. Les essais viseront à analyser l’effet des ruptures de tuyaux (dommages causés par les bris et la fragmentation) et des dommages causés aux lances (ou de leur non-fonctionnement) sur l’efficacité résiduelle du système.

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REPORT

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FIST

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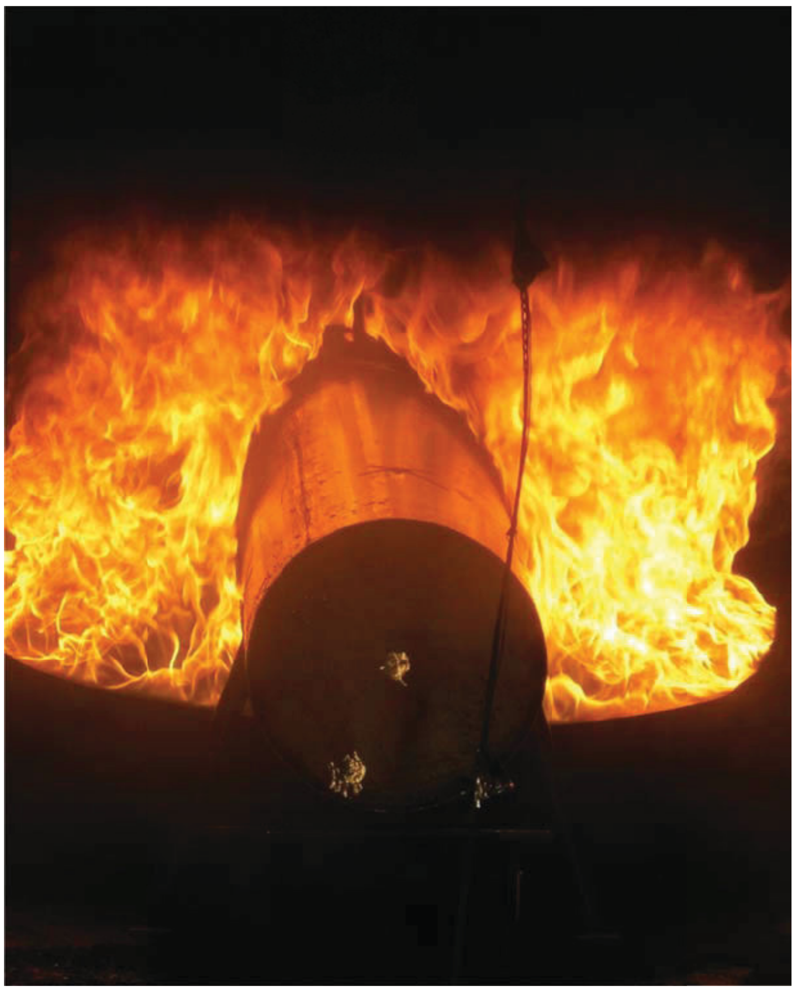
(1 appendix)



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Abstract

The FiST-project “New Technologies for Fire Suppression On Board Naval Craft”, is a tri-lateral (Canada, the Netherlands, Sweden) research project under the CAN/NLD/SWE Cooperative Science and Technology MOU. The focus for the project is active fire fighting on navy ships, with a special emphasis on how firefighting systems might perform in a damaged condition.

The results of a number of full scale fire tests run at SP Technical Research Institute of Sweden, December 2011-February 2012 are reported. The testing had two objectives. The first was to investigate redundancy solutions for fire suppression systems. To this end, the performanceof a low pressure water mist system with reduced capacity and the performance of a redundant extinguishment system attached to a strength bulkhead were investigated. The results of the tests indicated that a low pressure system designed to handle a well-ventilated hydrocarbon fire scenario can suppress the same fire in a less ventilated space with a 50 % reduction in water supply. Further if the system is fed by pumps providing water at lower pressure e.g. the fire main, it still has the capacity to suppress a compartment fire. Testing of the bulkhead mounted system indicated that it could extinguish an obstructed diesel pool fire at water flow rates of 12-14 L/m^2/min provided nozzles that distributed the water spray over the entire test space were used. The second objective was to study the relevance of the weapon storage fire protection water delivery requirements found in NSC (24 mm/min) or Class DNV (32 mm/min) regulations. For the fire scenario studied, the results indicated that lower water flow rates were successful in keeping the temperature of a dummy torpedo below a ‘critical temperature’.

List of contents

Introduction

The results of full scale fire tests run at SP Technical Research Institute of Sweden during late December 2011 and January-February 2012 are reported. The purpose of the tests was to investigate redundancy solutions for active fire fighting on board navy ships and to investigate the relevance of the very high water density requirements for ammunition storage found, for example, in the Naval Ship Code (NSC) or in Class regulations.

Two redundancy designs were investigated: the first where a two pump system covers all compartments equally, i.e. if one system is destroyed, each compartment still has 50 % of the active fire fighting system left, and the second where only nozzles mounted through strength bulkheads are used for fire fighting. The rationale behind the second design is that if an explosion totally destroys the fire fighting setup in a compartment, then bulkhead nozzles fed from an undamaged adjacent compartment protected by the strength bulkhead would still be functional.

All tests were conducted in a ~55 m^3 enclosure using a 0.8m x 2.0m door opening.

A low pressure water mist/water spray system was chosen in favour of a high pressure system. These included practical implications such as a possibility to use common water supplies, e.g. the fire main, and technical simplicity and lower cost.

Tests were made to define a suitable water density to use in the fire suppression tests. A number of different nozzles were also tested to identify a good candidate. Obviously the nozzles used for the standard fire fighting system and the bulkhead nozzles needed to have very different characteristics.

A hydrocarbon fire was deemed to be a suitable design fire. Such a fire could arise as a result of a weapon impact that resulted in leakage and ignition of various combustible fluids used on the ship. The water flow rate was adjusted to suppress and extinguish the fire in an open space, i.e. imitating a situation where decks and bulkheads were gone due to the explosion. This meant that there would be no enclosure effects, e.g. the fire being suppressed due to a lowered oxygen content in the space. The amount of water used therefore became somewhat higher than what is a traditional IMO standard; 6 mm/min (6 L/min-m^2) instead of 5 mm/min.

The ammunition storage investigation was based on using a “torpedo dummy”, a geometrical object that in shape and mass resembled a torpedo. The dummy was placed in, or close to, the hydrocarbon fire and the temperature of the dummy was measured at different locations as a function of the water flow from the nozzles. An important part of the FiST project is also to collect data to be used in later simulations and as part of this, temperature data was collected using a low mass, thin shelled torpedo dummy.

As part of the FiST-project SP Fire Technology was contracted to perform experiments in order to:

- Challenge the 32 mm/min requirements for fire protection of weapon storage
- Test the performance of a low pressure water mist system with reduced capacity
- Test the performance of a redundant extinguishment system attached to a high strength bulkhead.

The results of these tests are reported in this document.

Test compartment

The fire test compartment was 4.8m x 4.8m x 2.4m (L x W x H) with an opening of 0.8m x 2.0m (W x H). Figure 1 shows a detailed drawing of the test compartment and the placement of the torpedo dummy and fuel pan positions 1 and 2.

The test compartment walls had an outer framework of 45mm x 90mm wood studs. Promatect sheets (calcium silicate) were used to surface the walls of the room. The ceiling was constructed of steel beams, covered with Promatect sheets and then with insulation boards.

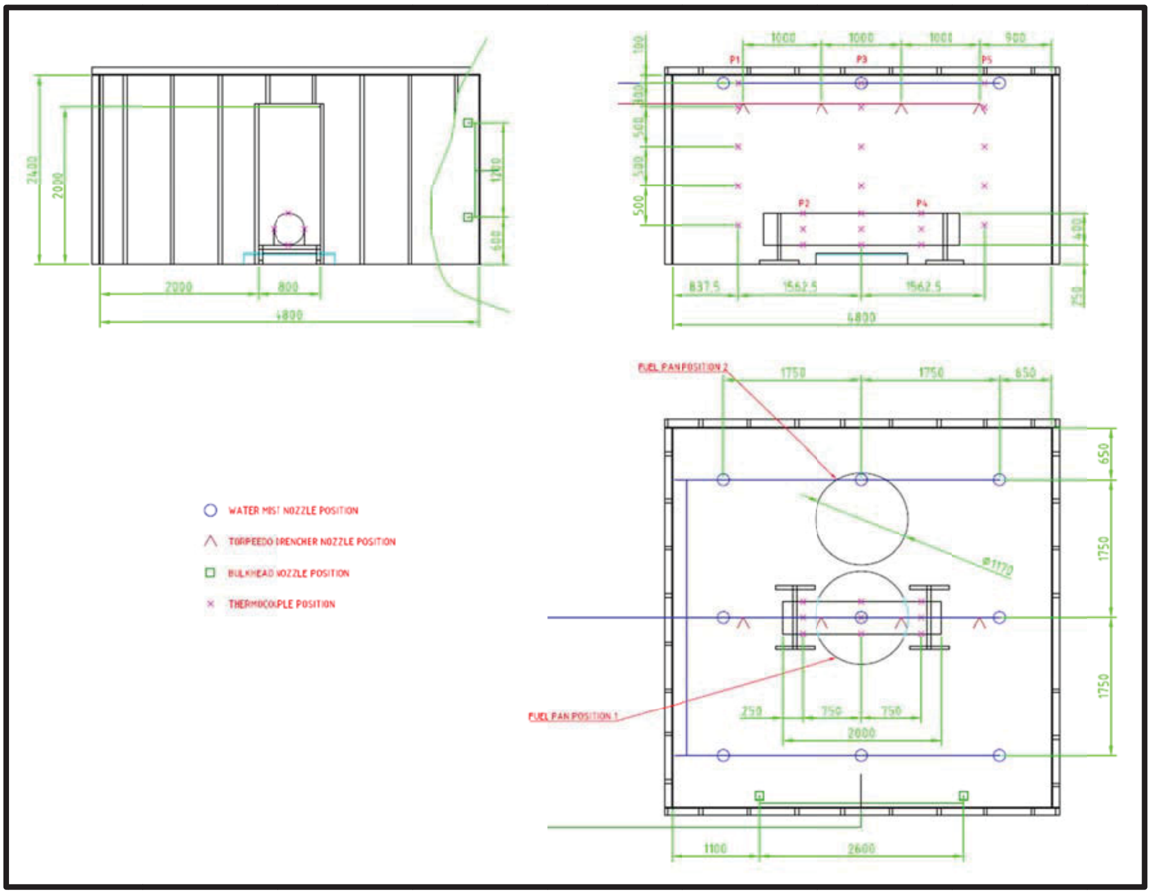

Figure 1 – Schematics of the test compartment.

Instrumentation

Figure 2 shows a side view of the test compartment. The five positions marked as P1-P5 in the view indicate the position of the measuring devices. P1 is closest to the door opening and P5 is in the back of the room. The positions are described below:

P1: A thermocouple tree with 0.5 mm type K thermocouples. The thermocouples were positioned 100, 400, 900, 1400 and 1900 mm below the ceiling.

P2: Four 0.5 mm type K thermocouples welded onto the outside of the dummy torpedo. Viewed from the door opening the thermocouples were placed on the top of the tube (12 o´clock), on the right side of the tube (3 o´clock), underneath the tube (6 o´clock) and on the left side of the tube (9 o´clock). P2 was used in tests 14-27 with the sand filled torpedo and tests 28-35 with the thin walled insulated tube.

P3: A thermocouple tree with 0.5 mm type K thermocouples. The thermocouples were positioned 100, 400, 900, and 1400 mm below the ceiling. In tests 14-27 and tests 28-35, there were also four 0.5 mm type K thermocouples welded onto the outside of the dummy torpedo. Viewed from the door opening the thermocouples were placed on the top of the tube (12 o´clock), on the right side of the tube (3 o´clock), underneath the tube (6 o´clock) and on the left side of the tube (9 o´clock). In tests14-27 there was a thermocouple taped on the inside bottom (6 o´clock) of the tube. Two thermocouples were also located at different distances into the sand used to fill the casing. One was placed half the radius of the casing from the bottom and the other was placed in the middle of the dummy torpedo.

P4: Four 0.5 mm type K thermocouples welded onto the outside of the tube. Viewed from the door opening the thermocouples were placed on the top of the tube (12 o´clock), on the right side of the tube (3 o´clock), underneath the tube (6 o´clock) and on the left side of the tube (9 o´clock). In test 14-27 there were also four 0.5 mm type K thermocouples welded on the inside at these positions. In test 28-35 there were four thermocouples taped on the inside of the steel tubes at these positions. P4 was only used in tests 14-27 with the sand filled torpedo and tests 28-35 with the thin walled insulated tube.

P5: A thermocouple tree with 0.5 mm type K thermocouples. The thermocouples were positioned 100, 400, 900, and 1400 mm below ceiling. In tests 14-27 and tests 28-35, P5 also contained four 0.5 mm type K thermocouples welded on the outside of the tube. Viewed from the door opening the thermocouples were placed on the top of the tube (12 o´clock), on the right side of the tube (3 o´clock), underneath the tube (6 o´clock) and on the left side of the tube (9 o´clock).

In addition to the measuring devices in position P1-P5, the following measuring devices were used in the test series:

- 1 mm sheathed thermocouple placed above the fuel surface to indicate if burning was taking place.
- Two O_2 analysers were placed close to P5 to monitor the oxygen level inside the compartment. The sampling pipes collected smoke at a distance of 900 mm and 1900 mm below the ceiling. The results for tests 7, 8 and 9 in the Appendix provide information on the response time for the oxygen monitors. In all Figures showing the oxygen level in the test space, the response time was not taken into account.
- A water pressure sensor was placed in the pipe system to monitor water pressure during each test.
- A water flow sensor was placed at the pump to monitor water flow (L/min) during each test.

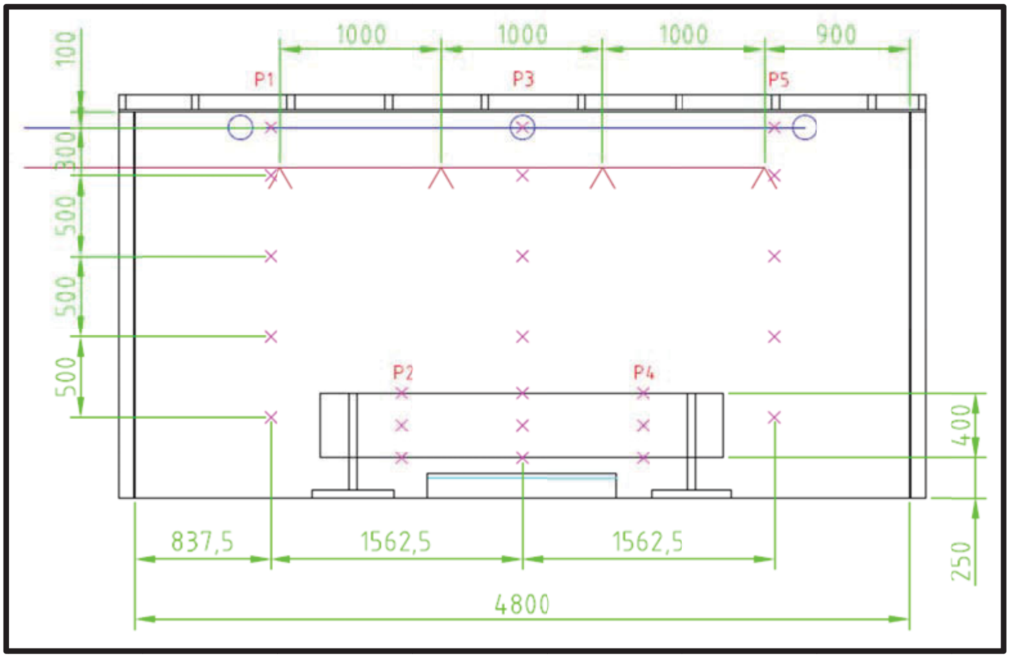

Figure 2 – Side view of the test compartment, showing positions P1 through P5

Fire scenarios

A diesel pool fire was selected as the design fire scenario.

Test equipment

Fuel pan

The fuel pan was a circular steel pan (Ø=1170 mm, A=1.08 m^2) with a 150 mm edge height. It was filled with water and 16 L of fuel was added for each test. This resulted in a15 mm thick layer of fuel on top of the water.

The water bed under the fuel layer was used for two reasons; to provide a flat, horizontal surface under the fuel and to achieve the desired freeboard in the pan. The pan was equipped with an overflow device to keep the freeboard constant at 25 mm. This prevented water from the fire protection system accumulating in the pan and causing it to overflow and spread the fuel on the floor.

During the tests the fuel surface was either fully exposed to the water spray or obstructed by pipes or calcium silica boards.

Diesel fuel (Shell city diesel) with a flashpoint of ~ 74°C was used for the fire tests.

To aid in starting the fire, approximately 0.5 L of heptane was gently pored over the diesel surface and ignited with a gas burner. A pre-burn time of 30 seconds was used for the majority of the tests before activation of the fire suppression systems.

Previous tests at SP Fire Technology indicated that the maximum heat release rate of a fully exposed diesel pool fire, A=1.08 m^2, was 1.3 MW

Obstructions

To achieve 50% obstruction of the circular fuel pan, six Spiro pipes (200 mm outside diameter) were placed 250 mm above the fuel surface as shown in Figure 3.

Figure 3 – Experimental set-up for the obstructed fuel pan fire.

Dummy torpedo

In tests 14-27 a steel (3mm thick) dummy torpedo was used. It is shown in Figure 4. The dummy was 200 cm long and 35 cm in diameter and weighed 65 kg. The tube was filled with sand. The total weight of the steel tube and sand was 371 kg. These dimensions and the use of sand as ballast were chosen to have a torpedo/ missile replica that was as close to a "real" torpedo in material properties as possible.

The diameter of the dummy was chosen to be 35 cm as the Harpoon and the Exocet missiles and the Mark 46 torpedo are 35 cm in diameter. Some torpedoes have an aluminium alloy body, but the most common have plain steel. Although a 3 mm thick steel casing is thinner than that commonly used in ordnance, the 3 mm steel will allow heat to pass more rapidly from the exterior to the interior of the case. The thermal conductivities of explosives range from 0.25-0.50 W/mK. Dry sand has a thermal conductivity of from 0.15-0.25 W/mK (www.engineeringtoolbox.com).While this is a little lower than the value for explosives, it is in the same range.

Figure 5 shows the dummy torpedo during one of the fire tests.

Figure 4 - Dummy torpedo in position directly over the fuel pan.

Figure 5 - Dummy torpedo during test with a 100% obstructed fuel pan in the position away from the dummy torpedo.

Thin walled insulated tube for AST-measurements

A different dummy torpedo was used in tests 28-35. The dummy was a 200 cm long and 40 cm in diameter Spiro tube. The tube was filled with ceramic insulation to reduce heat transfer from the tube. This was done to allow the dummy to be used to measure the adiabatic surface temperature (AST) of the tube, in a manner similar to a plate thermometer. The results from these tests will be used as input values in computer simulations. The computer simulations will be used to estimate temperatures in materials other than steel or for steel casing of different thicknesses. Figure 6 shows the thin walled insulated tube before one of the tests. Figure 7 shows the insulated tube during one test.

Figure 6 – The thin walled insulated tube used for adiabatic surface temperature (AST)-measurements

Figure 7 - Thin walled insulated tube used for AST-measurements during a test with the fuel pan in position 1

Water mist/water spray systems

Low pressure water mist/water spray system

In Figure 1 and Figure 2 the low pressure water mist/water spray system is indicated by the blue lines. Figure 8 shows how it was mounted at the ceiling. The incoming pipes were 1.5 inch in diameter, and the three longitudinal pipes were 1 inch in diameter. The nozzles and technical data for them are shown in Figure 9.

Figure 8 - Low pressure water mist/water spray system.

Low pressure water mist system: • Nozzles: BETE TF8-170 • K-factor: 5.93 • Pressure: 10 bar • Spacing: 1.75 m	

Figure 9 - BETE TF8-170 low pressure water mist nozzle.

Bulkhead nozzle systems

The bulkhead nozzle system is shown in Figure 10. The nozzles and technical data for them are shown in Figure 11. The horizontal pipes were 1.5 inch and the vertical pipes were 1 inch in diameter. The vertical distance between nozzles was 1.2 m and the horizontal distance was 2.5 m. Three alternative concepts were tested; alternative 1had four BETE TW20-180-nozzles, alternative 2 had two BETE NC0706K nozzles mounted in the upper positions on the bulkhead and two BETE TW20-180-nozzles mounted in the lower positions on the bulkhead, alternative 3 had four BETE NC0706K-nozzles.

Figure 10 - Bulkhead nozzle system in the magazine test space .

Alternative 1: • Nozzles: BETE TW20-180 • K-factor: 37.6 • Spray angle: 180° • Pressure: 5.4 bar • Vertical spacing: 1.2 m • Horizontal spacing: 2.6 m • Total flow rate: 320 L/min • Nominal discharge density (if evenly distributed in the compartment): 13.9 L/m2*min	
Alternative 2: • Nozzles: BETE NC0706K/TW20-180 • K-factor: 32/37.6 • Spray angle: 30°/180° • Pressure: 5.4 bar • Vertical spacing: 1.2 m • Horizontal spacing: 2.6 m • Total flow rate: 300 L/min • Nominal discharge density: 13.0 L/m2*min	 
Alternative 3: • Nozzles: BETE NC0706K • K-factor: 32 • Spray angle: 30° • Pressure: 5.4 bar • Vertical spacing: 1.2 m • Horizontal spacing: 2.6 m • Total flow rate: 280 L/min • Nominal discharge density: 12.2 L/m2*min	

Figure 11 – Nozzles used for alternative 1, 2 and 3 bulkhead water mist systems.

Weapon drencher systems:

In Figure 1 and Figure 2 the weapon drencher system is shown by the red lines. Figure 12 shows how the system was mounted underneath the water mist/water spray centrum line. The nozzles and system parameters for the 32, 10 and 5 mm/min tests are shown in Figure 13. The drencher pipe was 1 inch in diameter.

Figure 12 – Magazine space weapon drencher system.

<table>
<tr><td>Alternative 1, 32 mm/min:

• Nozzles: LECHLER 460.928
• K-factor: 15.2
• Pressure: 10 bar
• Spacing: 1.0 m</td><td></td></tr>
<tr><td>Alternative 2, 10 mm/min:

• Nozzles: LECHLER 460.728
• K-factor: 4.8
• Pressure: 10 bar
• Spacing: 1.0 m</td><td></td></tr>
<tr><td>Alternative 3, 5 mm/min:

• Nozzles: LECHLER 460.608
• K-factor: 2.4
• Pressure: 10 bar
• Spacing: 1.0 m</td><td></td></tr>
</table>

Figure 13 - Alternative 1, 2 and 3 weapon drencher system using LECHLER 460.928, 460.728 and 460.608 nozzles.

Performance criteria

Damaged water mist system

No definite performance criteria was selected for the damaged water mist system. The time to extinguishment and the time to reduce the gas temperatures to less than 80°C were used to evaluate the performance of the damaged systems.

Undamaged water mist system

The performance criteria for the undamaged water mist system were:

- Extinguish a non-obstructed diesel pool fire in a well-ventilated environment in ~120 seconds.
- Suppress an obstructed diesel pool fire in a well-ventilated environment in less than 1 minute where suppression is defined as:
  - Reduction of heat radiation to a level 20% of the maximum measured heat radiation in a free-burning test or maximum 4.5 kW/m^2.
  - The difference between the temperature of a plate thermocouple one meter distance from the diesel pool fire and the ambient gas temperature is reduced to a maximum 20% of a free-burning test.

Weapon protection system

The following performance criteria were used to evaluate the different systems used for weapon protection.

- Maximum surface temperature of dummy torpedo must not exceed 200 °C.
- 60 seconds after activation of the system, the maximum surface temperature of the dummy torpedo must not exceed 150 °C.

This was based on the assumption that 200 °C is the critical temperature for a fast heating phase and that 150 °C is the critical temperature for a slow heating phase.

The criteria were assumed to be conservative since the surface temperature was measured. In a real application the critical temperature is the temperature of the high explosive inside the steel shell.

Test programme

The tests carried out in this report are listed below. The protocols and graphs of results for each tests are presented in Appendix 1.

Test No	Description
1	50% water mist system, 10 bar and 80s pre-burn time
2	50% water mist system, 10 bar, 80s pre-burn time, 50% obstructed
3	50% water mist system, 10 bar, 30s pre-burn time, 50% obstructed
4	Bulkhead nozzles alternative 1, 50% obstructed
5	Bulkhead nozzles alternative 2, 50% obstructed
6	Bulkhead nozzles alternative 3, 50% obstructed
7	Water distribution test with drencher system 32 mm/min
8	Water distribution test with drencher system 10 mm/min
9	Water distribution test with drencher system 5 mm/min
10	Water mist system, 10 bar and 30s pre-burn time
11	Water mist system, 5 bar and 30s pre-burn time
12	Water mist system, 5 bar, 50% obstructed, 30s pre-burn time
13	Water mist system, 10 bar, 50 % obstructed, 30s pre-burn time
14	Sand filled torpedo dummy, free-burning reference test, fuel pan pos 1
15	Sand filled torpedo dummy, water mist system (6 mm/min)
16	Sand filled torpedo dummy, drencher system 32 mm/min
17	Sand filled torpedo dummy, drencher system 10 mm/min
18	Sand filled torpedo dummy, drencher system 5 mm/min + water mist
19	Sand filled torpedo dummy, drencher system 5 mm/min + water mist, fuel pan pos 2, obstructed
20	Sand filled torpedo dummy, drencher system 32 mm/min, fuel pan pos 2, obstructed
21	Sand filled torpedo dummy, drencher system 32 mm/min, fuel pan pos 2, obstructed
22	Sand filled torpedo dummy, drencher system 32 mm/min, fuel pan pos 2, obstructed
23	Sand filled torpedo dummy, drencher system 32 mm/min, fuel pan pos 2, obstructed
24	Sand filled torpedo dummy, drencher system 10 mm/min, fuel pan pos 2
25	Sand filled torpedo dummy, drencher system 10 mm/min, fuel pan pos 2
26	Sand filled torpedo dummy, drencher system 5 mm/min + water mist, fuel pan pos 2
27	Sand filled torpedo dummy, free-burning reference test, fuel pan pos 2
28	Thin walled torpedo, water mist system, fuel pan pos 1
29	Thin walled torpedo, drencher system 32 mm/min, fuel pan pos 1
30	Thin walled torpedo, drencher system 10 mm/min, fuel pan pos 1
31	Thin walled torpedo, water mist system, fuel pan pos 2
32	Thin walled torpedo, drencher system 10 mm/min, fuel pan pos 2
33	Thin walled torpedo, drencher system 32 mm/min, fuel pan pos 2
34	Thin walled torpedo, free-burning reference test, fuel pan pos 1
35	Thin walled torpedo, free-burning reference test, fuel pan pos 2
36	50% water mist system, 10 bar and 30s pre-burn time
37	Free-burning reference test, fuel pan pos 1

Results

Damaged system

The following damage scenarios were tested:

- Reduced number of nozzles:
  These tests were performed based on the assumption that the water mist system in the space was fed by two pipes. One of these pipes was considered to be damaged resulting in four nozzles instead of nine with a spacing of 3.5 m (instead of 1.75 m). In the summary below (Table 1) these tests are denominated “50% WMS nozzles”.
- Reduced pressure:
  These tests were performed based on the assumption that either the piping was damaged or that the fire main was used as a redundant water source. Both of these scenarios resulted in reduced system pressure. In these tests the pressure was 5 bar instead of 10 bar.

In the first tests a pre-burn time of 80 seconds was used. After this pre-burn time the smoke layer was 1 m above the floor and the fire was extinguished instantly when the extinguishment system was activated and mixed the gases in the compartment. To avoid this a pre-burn time of 30 seconds was selected for the remainder of the tests.

A summary of the results of the tests is presented in Table 1 and gas temperatures in the centre of the compartment are presented in Figure 14.

Table 1 – Summary of results for damaged water mist systems.

Test no	Description of setup	Time (after activation) to temp <80°C [s]	Time (after activation) to extinguishment [s]	O_2 concentration at extinguishment [vol%]
1	50% WMS nozzles, 80 s pre-burn time, no obstruction Full pressure (10 bar)	80	10	Not measured
2	50% WMS nozzles, 80 s pre-burn time, 50 % obstruction Full pressure (10 bar)	58	10	Not measured
3	50% WMS nozzles, 30 s pre-burn time, 50% obstruction, Full pressure (10 bar)	30	Did not extinguish	Not measured
11	100% WMS nozzles, 30 s pre-burn time, no obstruction, Reduced pressure (5 bar)	26	251	18.7 (lowest measured value: 18.2)
12	100% WMS nozzles, 30 s pre-burn time, 50% obstruction, Reduced pressure (5 bar)	142	Did not extinguish	- (lowest measured value: 16.0)
36	50% WMS nozzles, 30 s pre-burn time, no obstruction Full pressure (10 bar)	25	28	18.8 (lowest measured value: 18.5)
37	Free burning	-	-	(lowest measured value: 8.8)

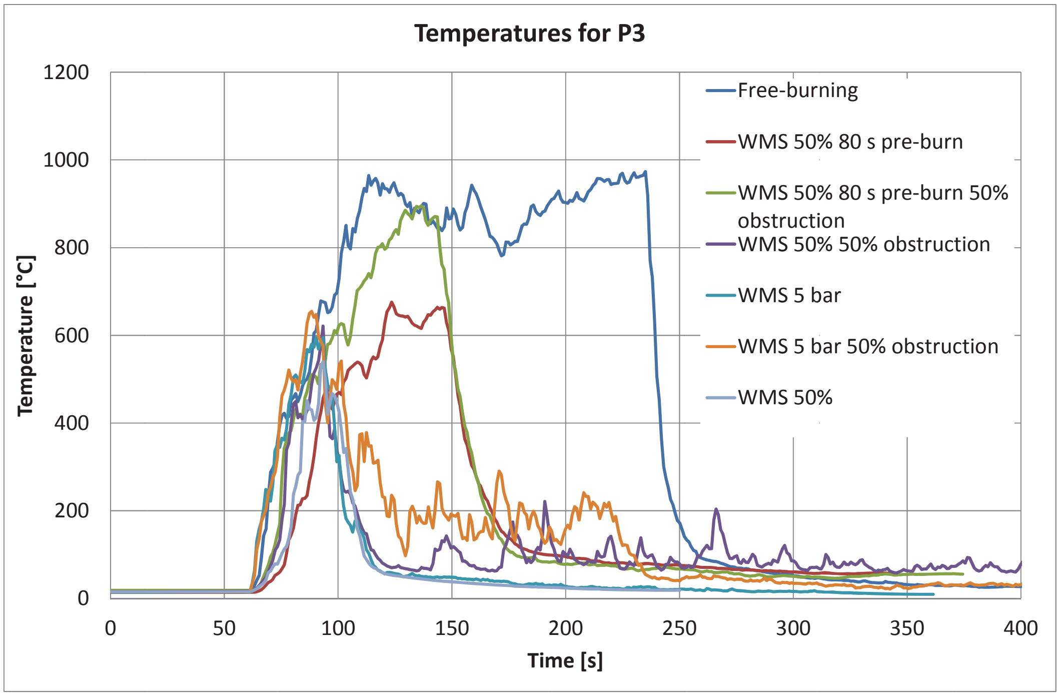

Figure 14 – Room centre thermocouple tree temperatures (average temperature 1 m below the ceiling) for free-burning and damaged system scenarios.

Non-damaged system

A series of tests was performed with non-damaged systems as reference for the damaged systems scenarios.

A summary of the results is presented in Table 2 and gas temperatures in the centre of the compartment are plotted in Figure 15.

Table 2 - Summary of results for non-damaged water mist systems.

Test no	Description of setup	Time (after activation) to temp <80°C [s]	Time (after activation) to extinguishment [s]	O_2 concentration at extinguishment [vol%]
10	100% WMS nozzles, 30 s pre-burn time, no obstruction Full pressure (10 bar)	20	150	18.8 (lowest measured value: 18.8)
13	100% WMS nozzles, 30 s pre-burn time, 50 % obstruction Full pressure (10 bar)	35	202	18.9 (lowest measured value: 18.1)
37	Free burning	-	-	(lowest measured value: 8.8)

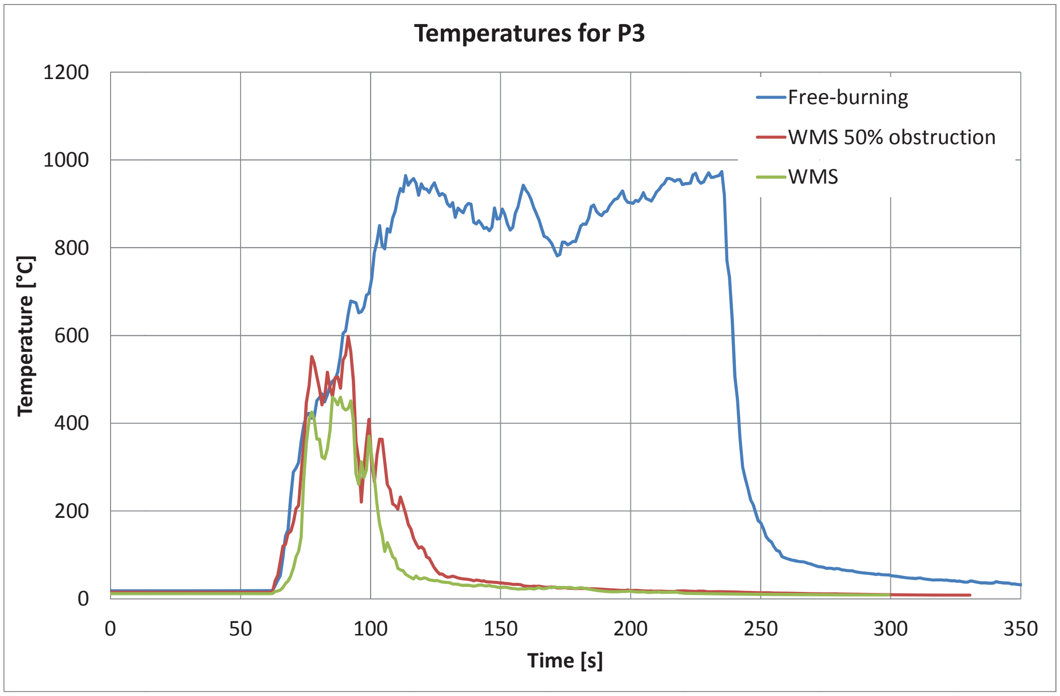

Figure 15 – Room centre thermocouple tree temperatures (average temperature 1 m below the ceiling) for free-burning and non-damaged water mist system scenarios

Bulkhead nozzles

The use of water spray nozzles mounted to high strength bulkheads was also investigated. These bulkheads are less likely to sustain damage from a blast and therefore the nozzles mounted on them can provide fire protection even if the primary fire protection system is destroyed by the blast.

A summary of the results of these tests is presented in Table 3 and gas temperatures in the centre of the compartment are plotted in Figure 16.

In test no 4 (alternative 1) it was observed that the water spray did not cover the entire compartment. The range of the water spray from the BETE TW20-180-nozzles was estimated to about 2.5 m compared to the compartment´s width that was 4.8 m.

Table 3 - Summary of results for bulkhead nozzles.

Test no	Description of setup	Time (after activation) to temp <80°C [s]	Time (after activation) to extinguishment [s]	O_2 concentration at extinguishment [vol%]
4	System alternative 1 30 s pre-burn time, 50% obstruction Total flow: 320 L/min	139	228	Not measured
5	System alternative 2 30 s pre-burn time, 50% obstruction Total flow: 300 L/min	18	152	19.5 (lowest measured value: 17.4)
6	System alternative 3 30 s pre-burn time, 50% obstruction Total flow: 280 L/min	25	65	18.2 (lowest measured value: 18.2)
37	Free burning	-	-	(lowest measured value: 8.8)

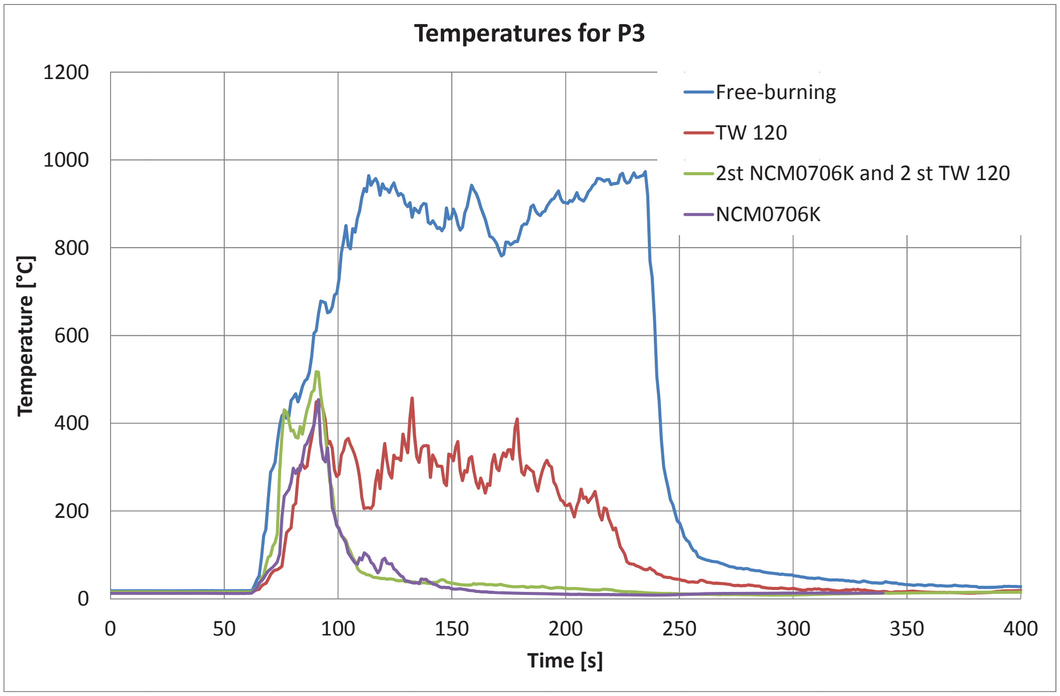

Figure 16 - Room centre thermocouple tree temperatures (average temperature 1 m below the ceiling) for free-burning and bulkhead mounted water mist nozzle scenarios.

Sand filled dummy torpedo

A series of tests were performed to evaluate the amount of water needed to prevent a weapon like a missile or a torpedo from heating to the point of cook-off during a fire in a magazine space. Fuel pan positions, water spray systems and obstructions were varied during the testing.

The following fuel pan positions were used:

- Position 1 - The fuel pan was directly below the dummy torpedo with a vertical distance of 50 mm between steel shell and fuel surface.
- Position 2 - The fuel pan was beside the dummy torpedo with a vertical distance of 50 mm between steel shell and fuel surface, and a horizontal distance of 0 or 250 mm (normally 0 mm, in some tests 250 mm, this is noted in the test protocols in Appendix 1) between fuel pan and the dummy torpedo.

The following water spray systems were used:

- The water mist system (~6 L/m^2/min)
- The water mist system + drencher (5 L/m^2/min)
- Drencher (10 L/m^2/min)
- Drencher (32 L/m^2/min)

A summary of the results is presented in Table 4 and the maximum steel surface temperatures are plotted in Figure 17 and Figure 18.

For these fire scenarios all systems applying more than 10 L/m^2/min fulfilled the performance criteria for cooling of the sand filled dummy torpedo.

Table 4 - Summary of results sand filled torpedo dummy.

Test no	Description of setup	Peak surface temperature [°C]	Peak surface temperature > 1 min after activation [°C]	Time (after activation) to extinguishment [s]
14	Free burning Fuel pan position 1 Non obstructed	550*	-	-
15	WMS, 6 L/m^2/min Fuel pan position 1 Obstructed by torpedo dummy	203	203	Did not extinguish
16	Drencher 32 L/m^2/min Fuel pan position 1 Obstructed by torpedo dummy	128	39	24
17	Drencher 10 L/m^2/min Fuel pan position 1 Obstructed by torpedo dummy	138	89	45
18	WMS + Drencher 5 L/m^2/min Fuel pan position 1 Obstructed by torpedo dummy	148	92	53
19	WMS + Drencher 5 L/m^2/min Fuel pan position 2 100% obstruction	150	81	Did not extinguish
20	Drencher 32 L/m^2/min Fuel pan position 2 100% obstruction**	113	35	27
24	Drencher 10 L/m^2/min Fuel pan position 2 Non obstructed	65	38	160
25	Drencher 10 L/m^2/min Fuel pan position 2 100% obstruction	162	82	Did not extinguish
26	WMS + Drencher 5 L/m^2/min Fuel pan position 2 100% obstruction	151	105	Did not extinguish
27	Free burning Fuel pan position 2 Non obstructed	604*	-	-

*when the test was stopped, the temperature was still rising.
**four tests (test 20 – 23) were run with similar setups trying to shield the fuel surface from the water spray to avoid fast extinguishment, test 20 resulted in the highest temperatures and is considered the worst case.

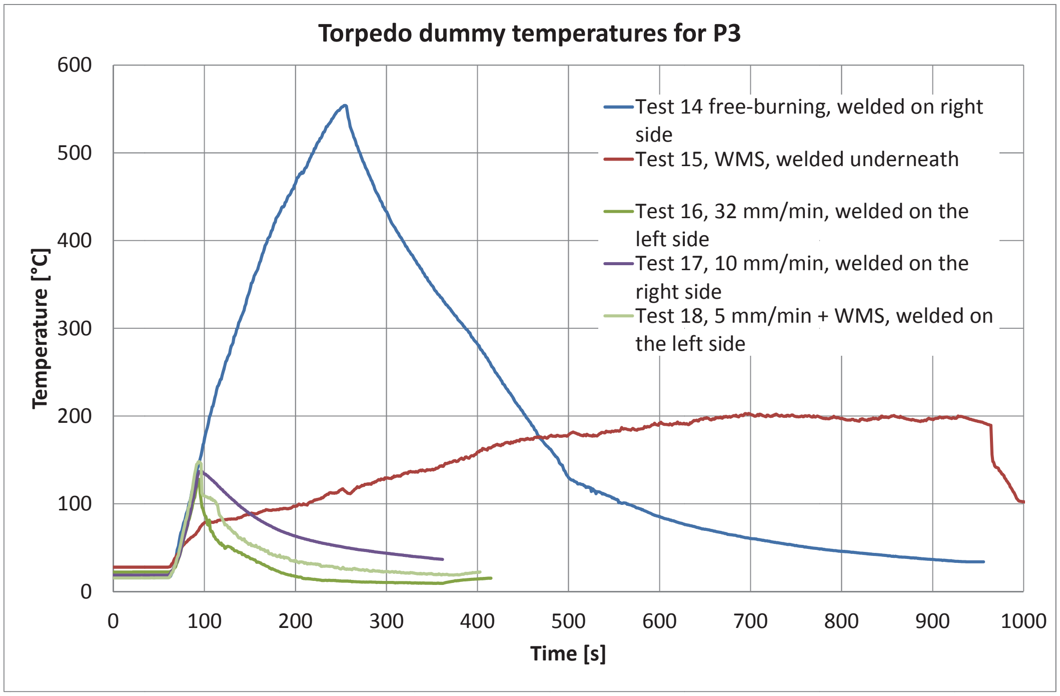

Figure 17 –Dummy torpedo temperatures with fuel pan in position 1 (under the dummy torpedo).

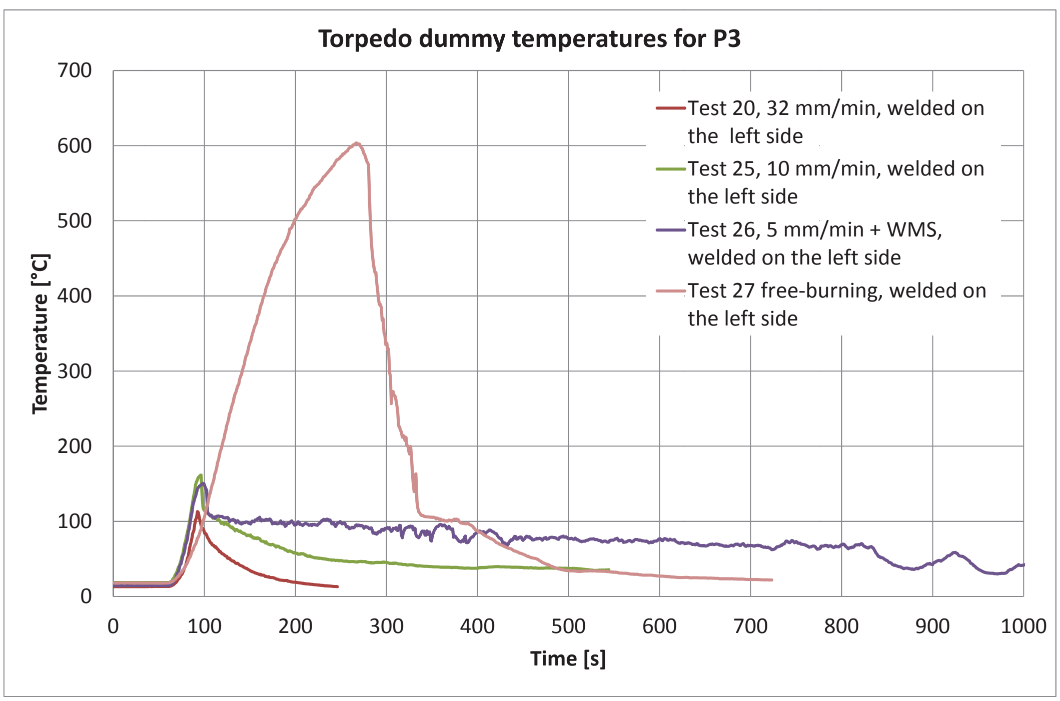

Figure 18 - Torpedo dummy temperatures with fuel pan in position 2 (beside the dummy torpedo).

Thin walled, insulated pipe

A series of tests were performed to collect data to be used as input for simulations to estimate temperatures in weapons with thermal properties different from the sand filled dummy torpedo. Fuel pan positions, water spray systems and obstructions were varied as indicated below.

The following fuel pan positions were used:

- Position 1 - The fuel pan was directly below the dummy torpedo with a vertical distance of 50 mm between steel shell and fuel surface.
- Position 2 - The fuel pan was beside the dummy torpedo with a vertical distance of 50 mm between steel shell and fuel surface. and a horizontal distance of 0 or 250 mm (normally 0 mm, in some tests 250 mm, this is noted in the test protocols in Appendix 1) between fuel pan and the torpedo dummy.

The following water spray systems were used:

- The water mist system (~6 L/m^2 /min)
- The water mist system + drencher (5 L/m^2/min)
- Drencher (10 L/m^2/min)
- Drencher (32 L/m^2/min)

A summary of the results is presented in5 and the maximum steel surface temperatures are plotted in Figure 19 and Figure 20.

Table 5 - Summary of results thin walled, insulated pipe.

Test no	Description of setup	Peak surface temperature [°C]	Time (after activation) to extinguishment [min:s]
28	WMS, 6 L/m^2/min Fuel pan position 1 Obstructed by dummy torpedo	493	Did not extinguish
29	Drencher 32 L/m^2/min Fuel pan position 1 Obstructed by dummy torpedo	484	0:20
30	Drencher 10 L/m^2/min Fuel pan position 1 Obstructed by dummy torpedo	460	0:32
31	WMS, 6 L/m^2/min Fuel pan position 2 Non obstructed	242	1:08
32	Drencher 10 L/m^2/min Fuel pan position 2 Non obstructed	128*	10:17
33	Drencher 32 L/m^2/min Fuel pan position 2 Non obstructed	206	0:48
34	Free burning Fuel pan position 1 Obstructed by dummy torpedo	859	-
35	Free burning Fuel pan position 2 Non obstructed	816	

* low temperature probably due to wet thermocouple.

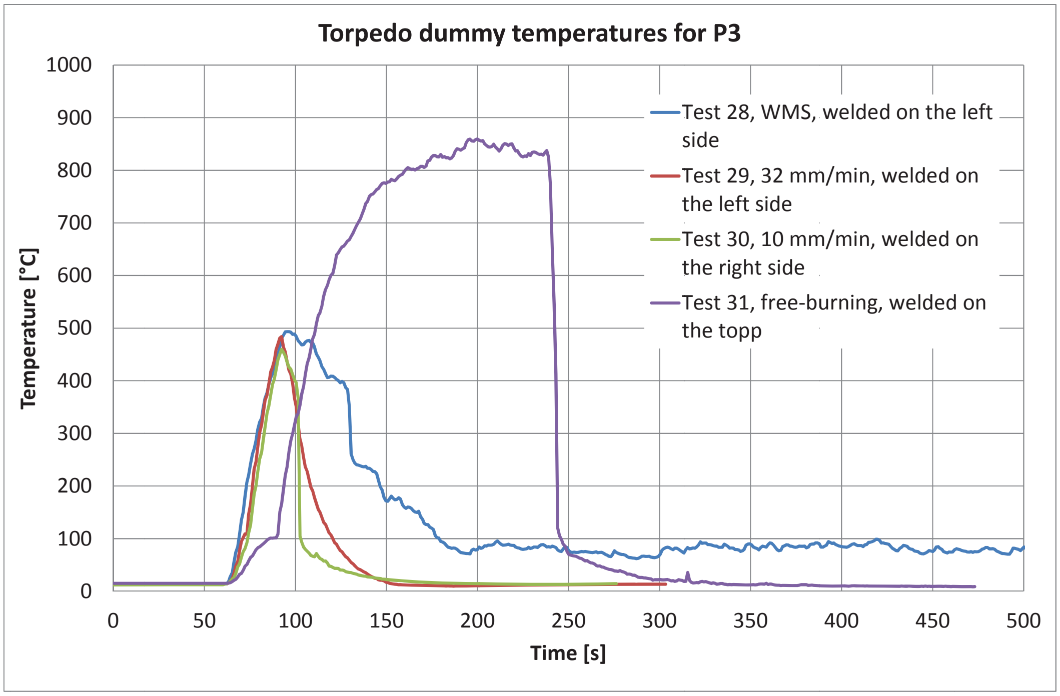

Figure 19 – Thin walled dummy torpedo temperatures with fuel pan in position 1 (under the dummy torpedo).

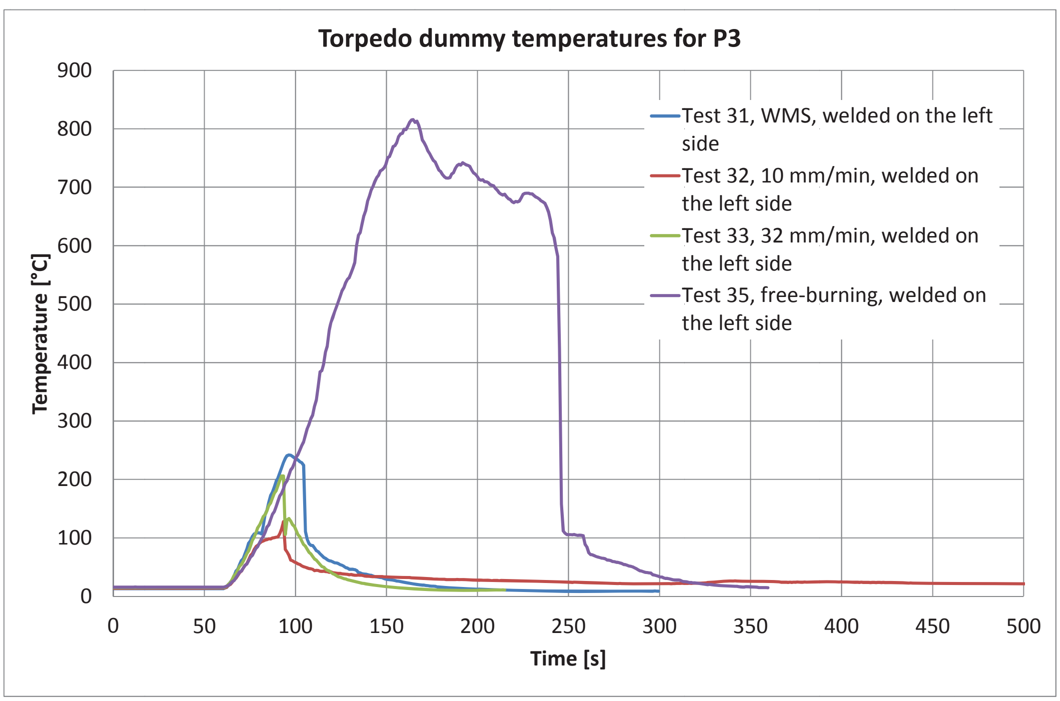

Figure 20 - Thin walled dummy torpedo temperatures with fuel pan in position 2 (beside the torpedo dummy)

Conclusion

Redundancy tests of a low pressure water mist/water spray system have been conducted at SP Fire Technology. The results of the tests indicate that a low pressure system designed to handle a well-ventilated hydrocarbon fire scenario can suppress the same fire in a less ventilated space with a 50 % reduction in water supply. This implies that the suggested redundancy design using two separate pumps, each supplying water to 50 % of the nozzles in an enclosure, would be an acceptable fire risk control measure. Further if the system is fed by pumps providing water at lower pressure e.g. the fire main, it still has the capacity to suppress a compartment fire.

The results of the tests using bulkhead nozzles indicated the potential for fire suppression using nozzles mounted on walls in the enclosure. This is interesting as it suggests a more radical way to design the fire fighting system on board ships to provide a higher degree of redundancy-safety. The higher degree of redundancy arises from the fact that the system is fed from another compartment that might remain intact after an explosion has destroyed the primary system. The tests showed that a water discharge density of 12-14 L/m^2/min is sufficient to extinguish an obstructed diesel pool fire in an ventilated compartment provided that the nozzle configuration distributes the water spray over the entire protected area. The next step would be to create installation guidelines. To do this, further research/testing should focus on optimizing the required water discharge density and analysing water spray distribution of nozzles that might be used in the system.

The results of the tests investigating appropriate water densities for ammunition stores drencher/fire suppression systems using the “torpedo dummy” indicated that, for the fire scenario studied, a much lower volume flow rate of water than stated in specifications was sufficient to keep the “torpedo dummy” below critical temperatures. If the design fire is a diesel pool fire and if the temperature criteria used in these tests are applicable, a drencher system providing a water discharge density of 10 L/m^2/min was found to be sufficient for ammunition store protection.

SP Technical Research Institute of Sweden
Fire Technology - Fire Dynamics

Performed by | Examined by

Michael Rahm, Johan Lindström | Tommy Hertzberg

Appendix

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Appendix 1

Test protocol

Test: 1

Date: 2012-01-26

Test engineer: Michael Rahm, Johan Lindström

Type of test	50% water mist system, 10 bar and 80s pre-burn
Pool fire size (Ø in mm)	1170
Position of pool fire	1
Obstruction (% of pool area)	
Amount of diesel (L)	15
Height of freeboard (mm)	25
Water mist nozzle	BETE TF8-170 (four nozzles)
Bulkhead nozzle	
Drencher nozzle	
Distance from nozzle to pool area	
Pressure (bar)	10
Water flow (L/min)	76-78
Notes:	
Time (s)	
0	Start data acquisition program and video camera
60	Ignition
140	Activation of water mist system
150	No visible flames (probably extinguished). A lot of smoke. No visibility inside the test room.
300	The water mist system was stopped
	The smoke height was about 90 cm from the floor when the system activated.

Appendix 1

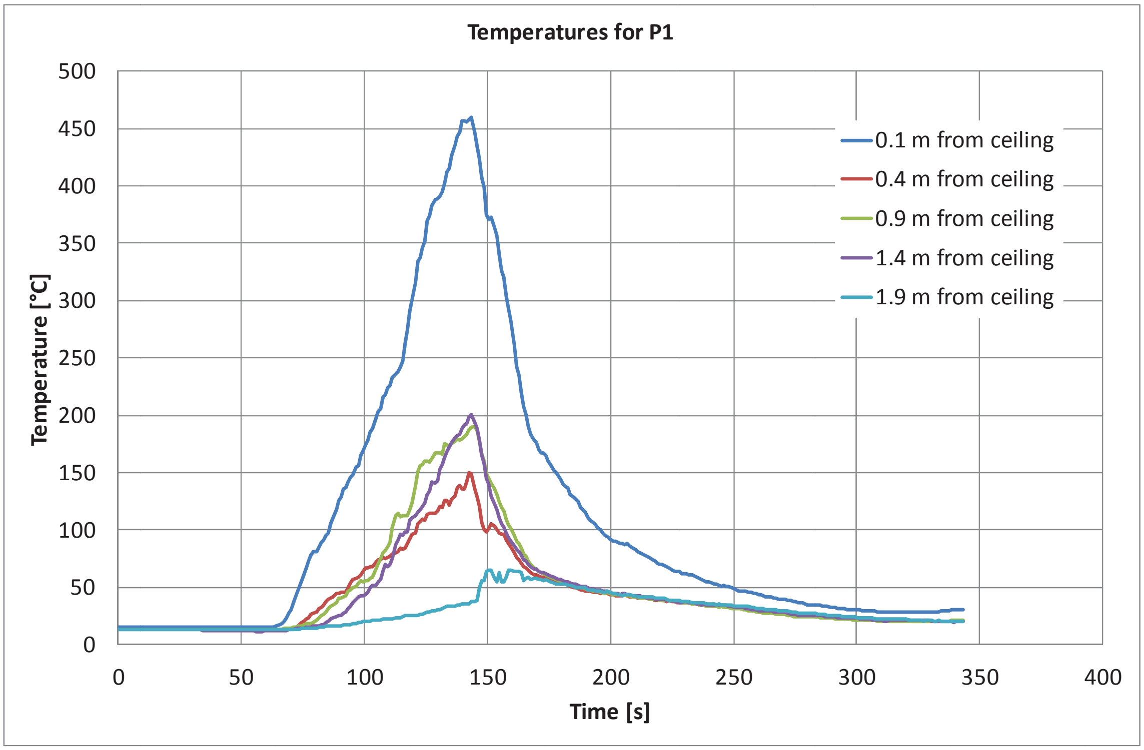

Figure 21. Test 1, Temperatures for thermocouple tree at P1

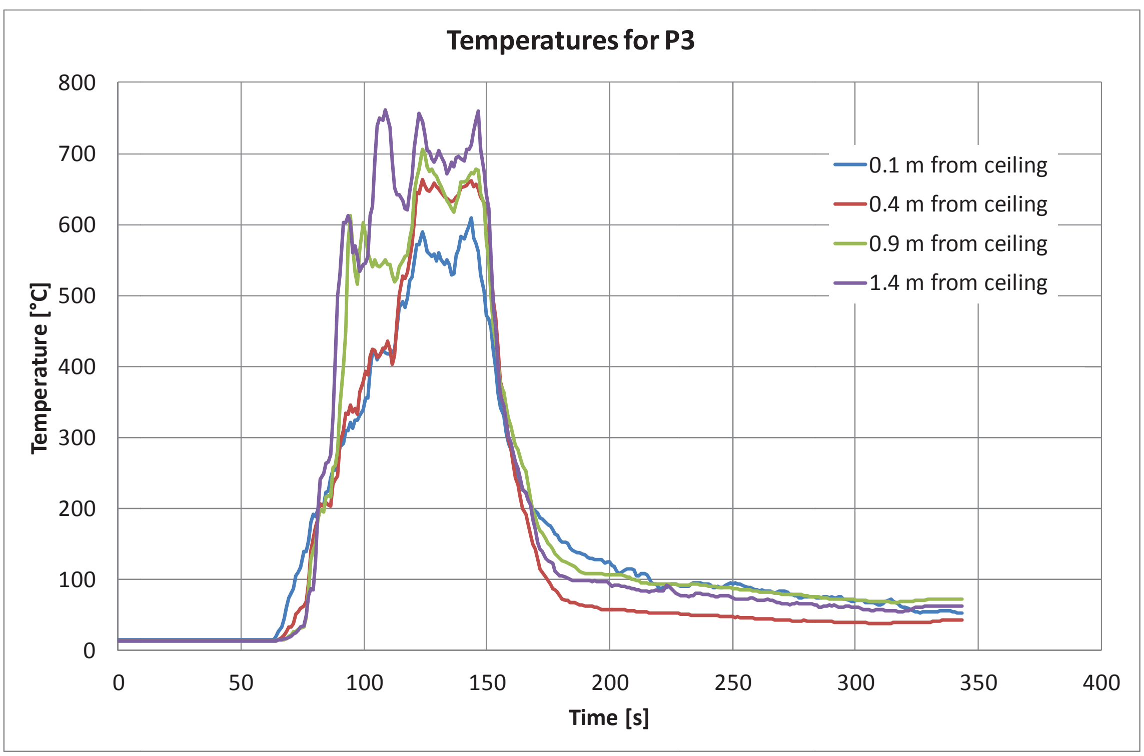

Figure 22. Test 1, Temperatures for P3

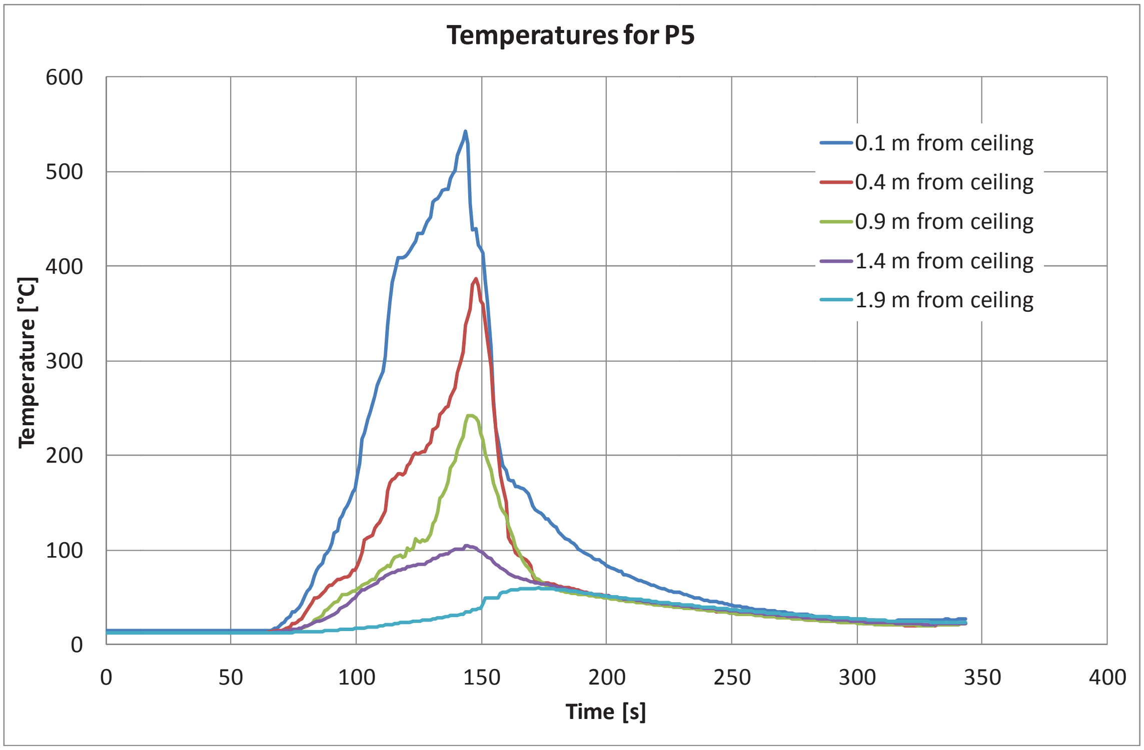

Figure 23. Test 1, Temperatures for P5

Appendix 1

Test protocol

Test: 2

Date: 2012-01-26

Test engineer: Michael Rahm, Johan Lindström

Type of test	50% water mist system, 10 bar, 80s pre-burn time, 50% obstructed
Pool fire size (Ø in mm)	1170
Position of pool fire	1
Obstruction (% of pool area)	50
Amount of diesel (L)	10
Height of freeboard (mm)	25
Water mist nozzle	BETE TF8-170 (four nozzles)
Bulkhead nozzle	
Drencher nozzle	
Distance from nozzle to pool area	
Pressure (bar)	10
Water flow (L/min)	76-77
Notes:	
Time (s)	
0	Start measuring program and video camera
60	Ignition
140	Activation of water mist system
150	No visible flames (probably extinguished). A lot of smoke. No visibility inside the test room.
300	The water mist system was stopped
	The smoke height was about 90 cm from the floor when the system activated.

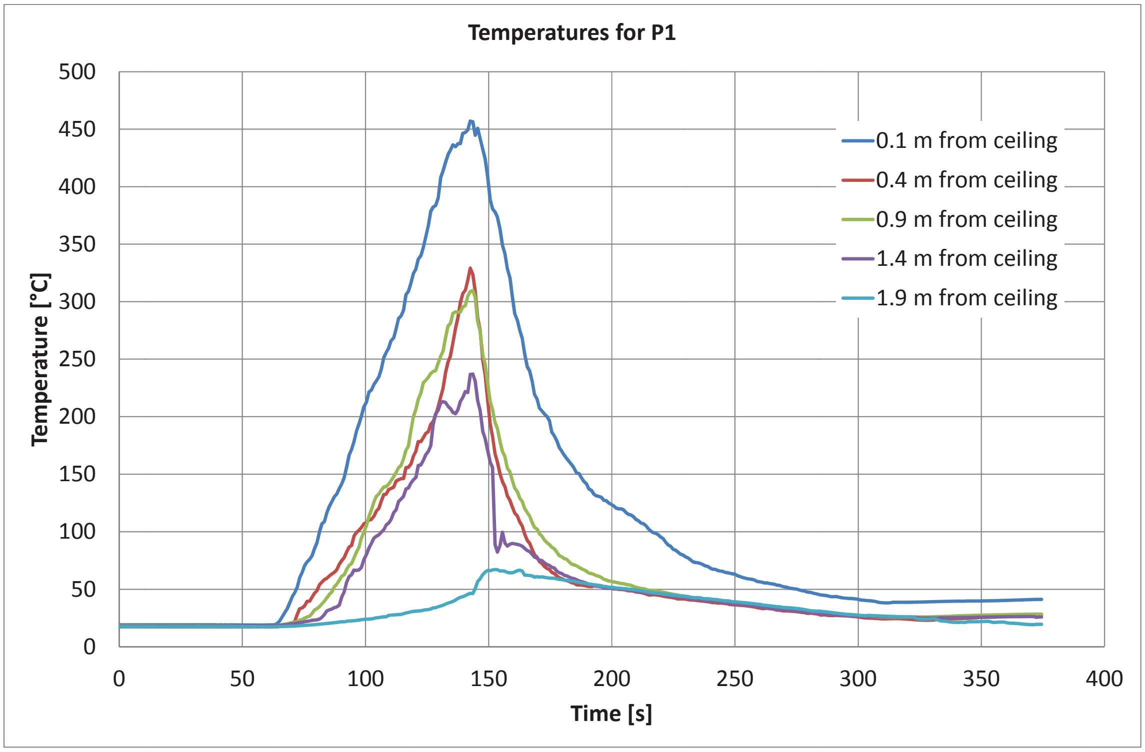

Figure 24. Test 2, Temperatures for P1

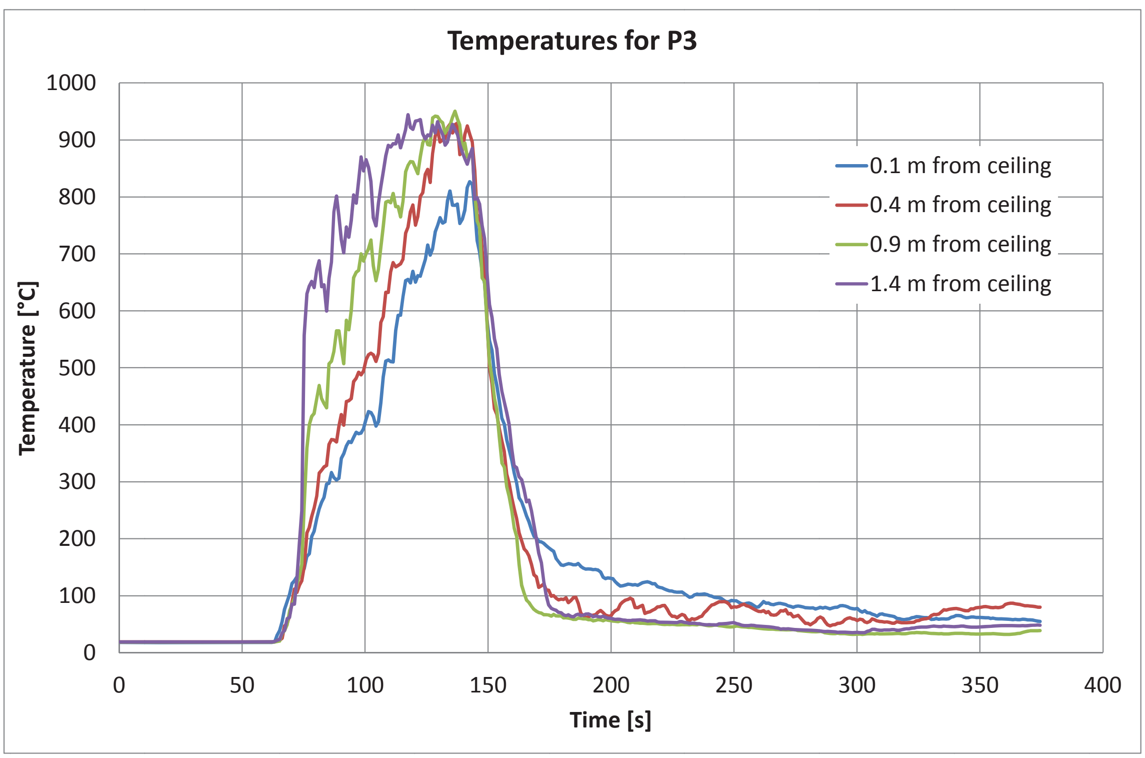

Figure 25. Test 2, Temperatures for P3

Appendix 1

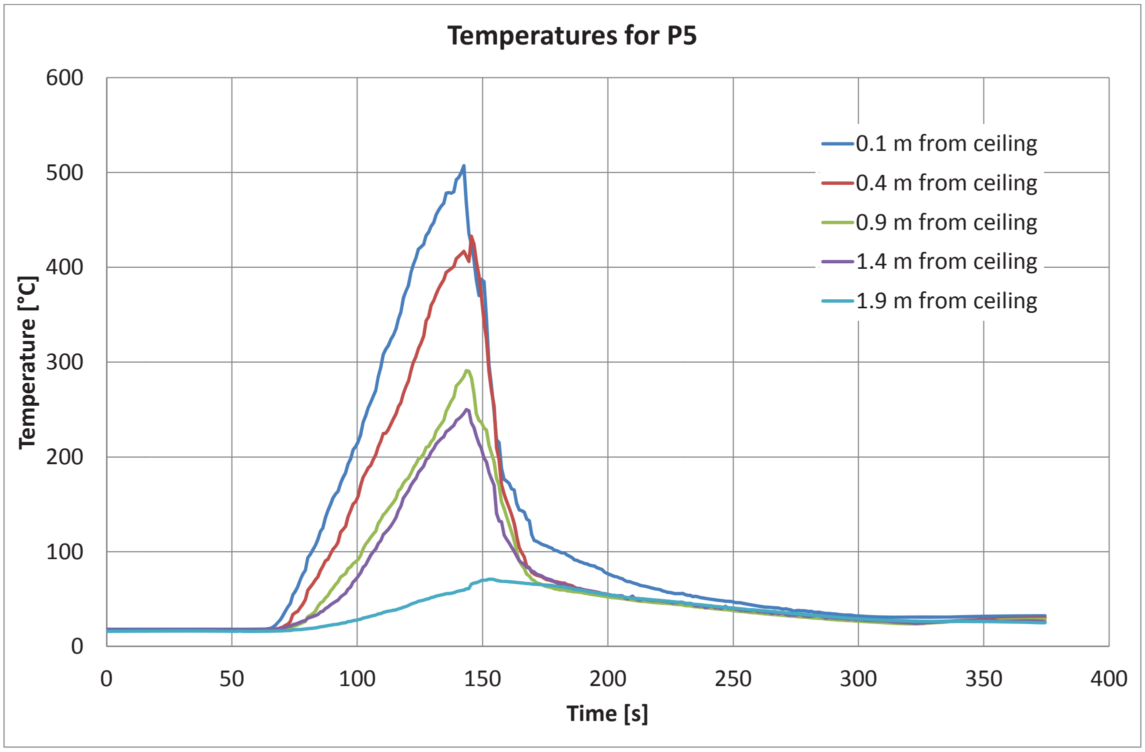

Figure 26. Test 2, Temperatures for P5

Appendix 1

Test protocol

Test: 3

Date: 2012-01-26

Test engineer: Michael Rahm, Johan Lindström

Type of test	50% water mist system, 10 bar, 30s pre-burn time, 50% obstructed
Pool fire size (Ø in mm)	1170
Position of pool fire	1
Obstruction (% of pool area)	50
Amount of diesel (L)	15
Height of freeboard (mm)	25
Water mist nozzle	BETE TF8-170 (four nozzles)
Bulkhead nozzle	
Drencher nozzle	
Distance from nozzle to pool area	
Pressure (bar)	10
Water flow (L/min)	76-77
Notes:	
Time (s)	
0	Start measuring program and video camera
60	Ignition
90	Activation of water mist system
115	Suppressed fire (approximately 1.5 m high flames)
420	The water mist system was stopped
440	Extinguishes the fire with foam system

Appendix 1

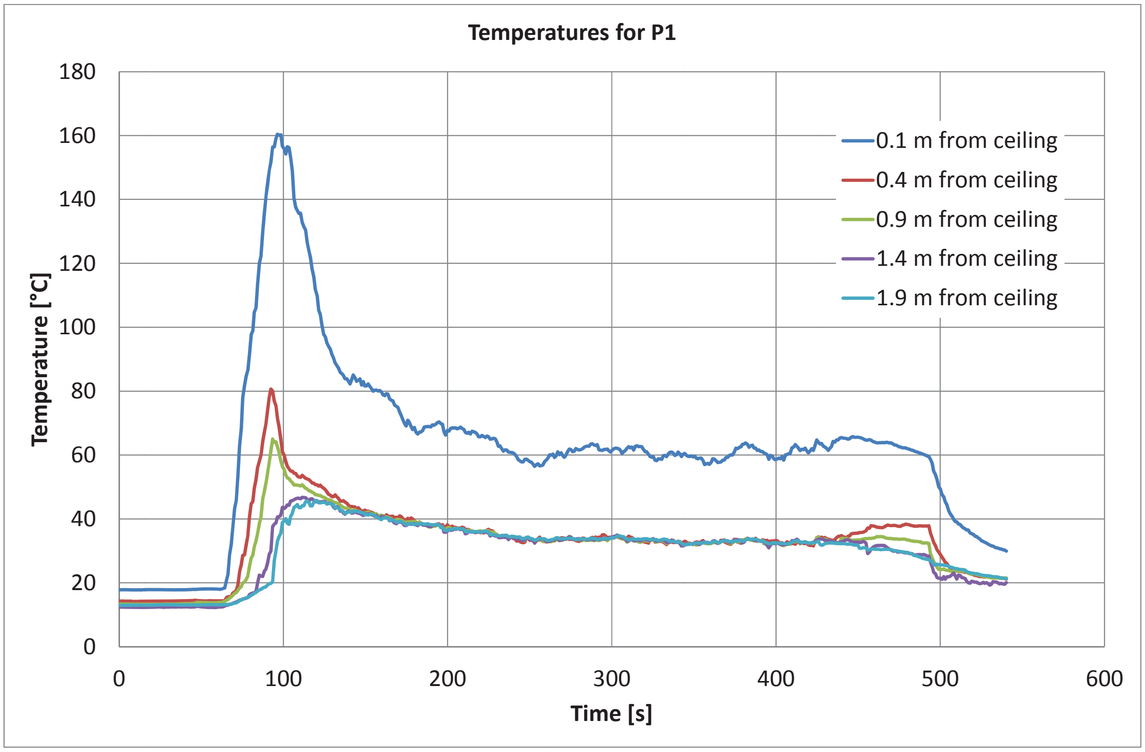

Figure 27. Test 3, Temperatures for P1

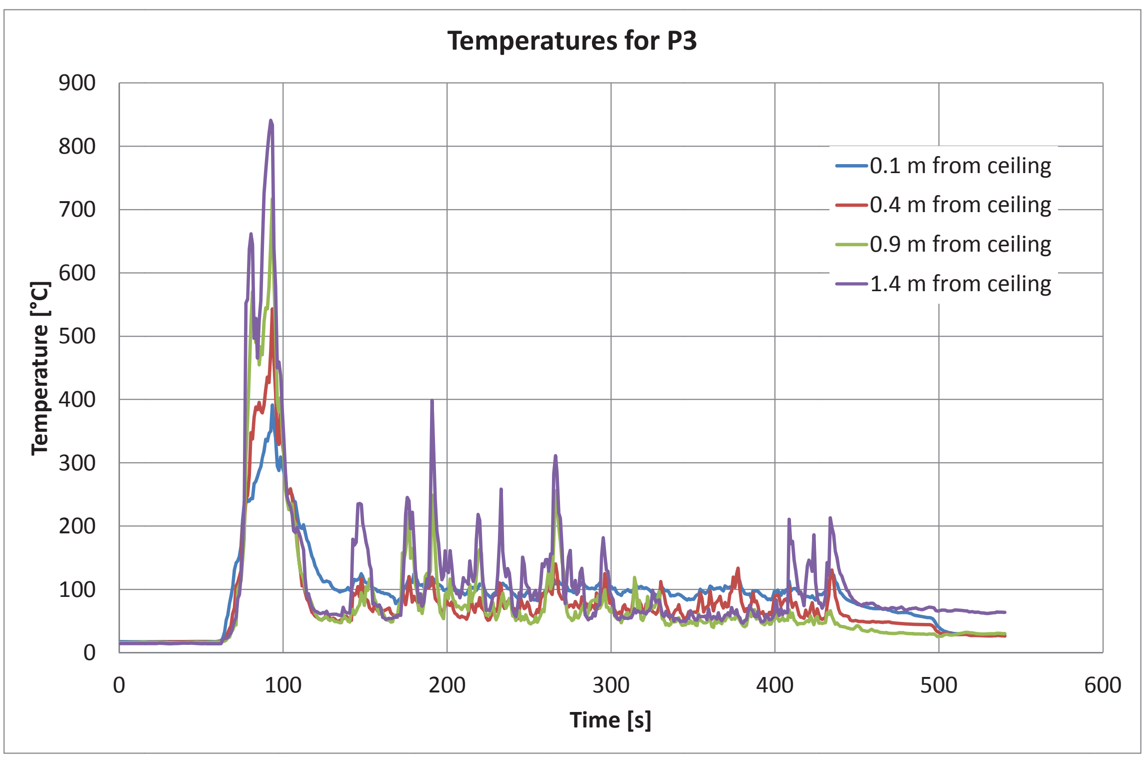

Figure 28. Test 3, Temperatures for P3

Appendix 1

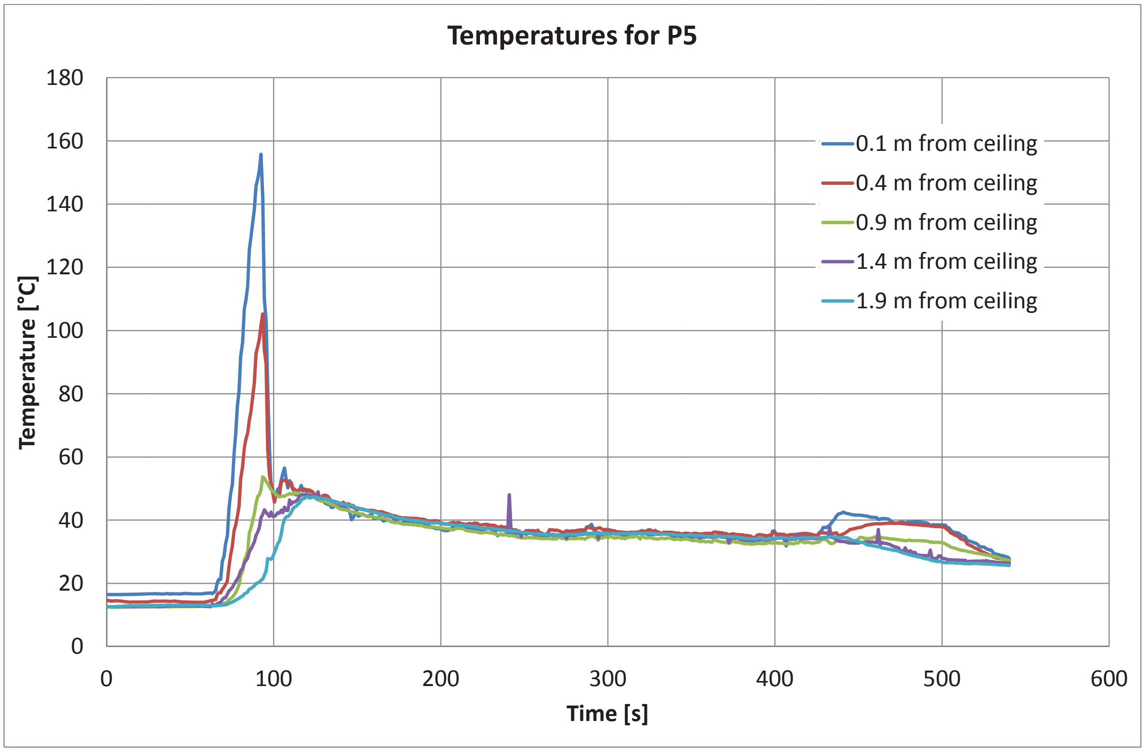

Figure 29. Test 3, Temperatures for P5

Test protocol

Test: 4

Date: 2012-01-27

Test engineer: Michael Rahm, Johan Lindström

Type of test	Bulkhead nozzles, 50% obstructed
Pool fire size (Ø in mm)	1170
Position of pool fire	1
Obstruction (% of pool area)	50
Amount of diesel (L)	15
Height of freeboard (mm)	25
Water mist nozzle	
Bulkhead nozzle	BETE TW20-180
Drencher nozzle	
Distance from nozzle to pool area	2.4m
Pressure (bar)	5.4
Water flow (L/min)	320
Notes:	
Time (s)	
0	Start measuring program and video camera
60	Ignition
90	Activation of the bulkhead system
220	Suppressed fire (approximately 1.5 m high flames), smoke all the way down to the floor
240	Small flames around the edge of the pool area
318	The fire was extinguished
370	Stops the water to the bulkhead nozzles

Appendix 1

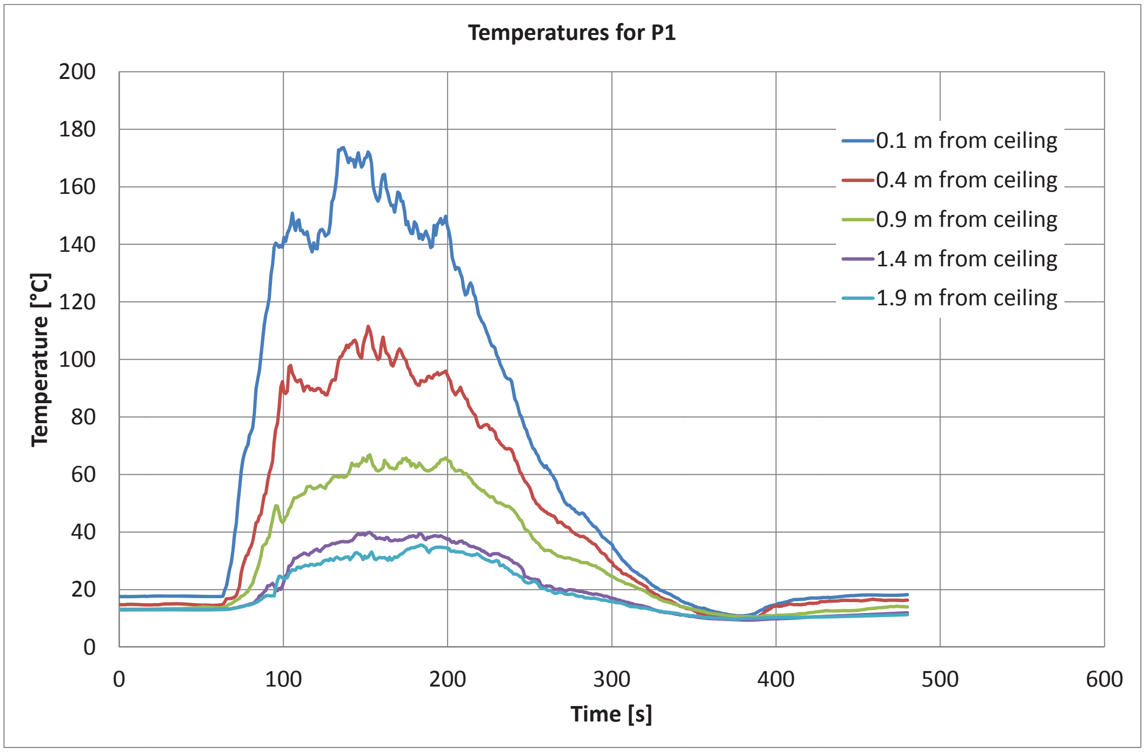

Figure 30. Test 4, Temperatures for P1

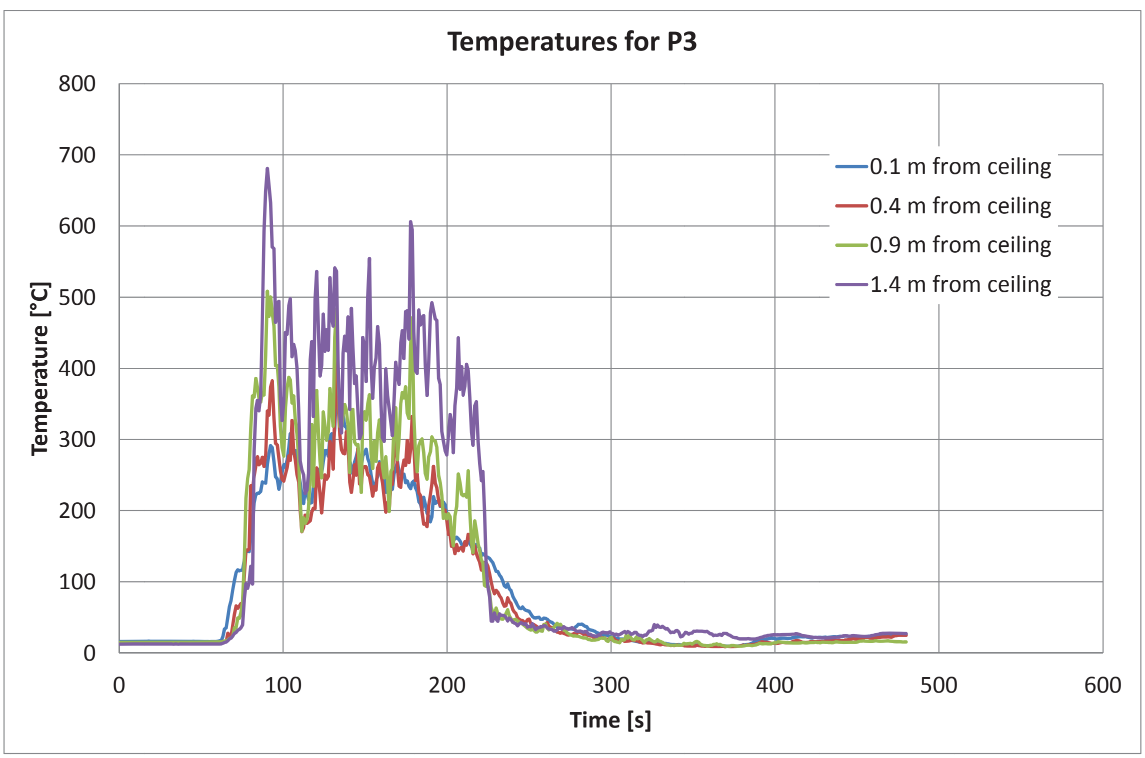

Figure 31. Test 4, Temperatures for P3

Appendix 1

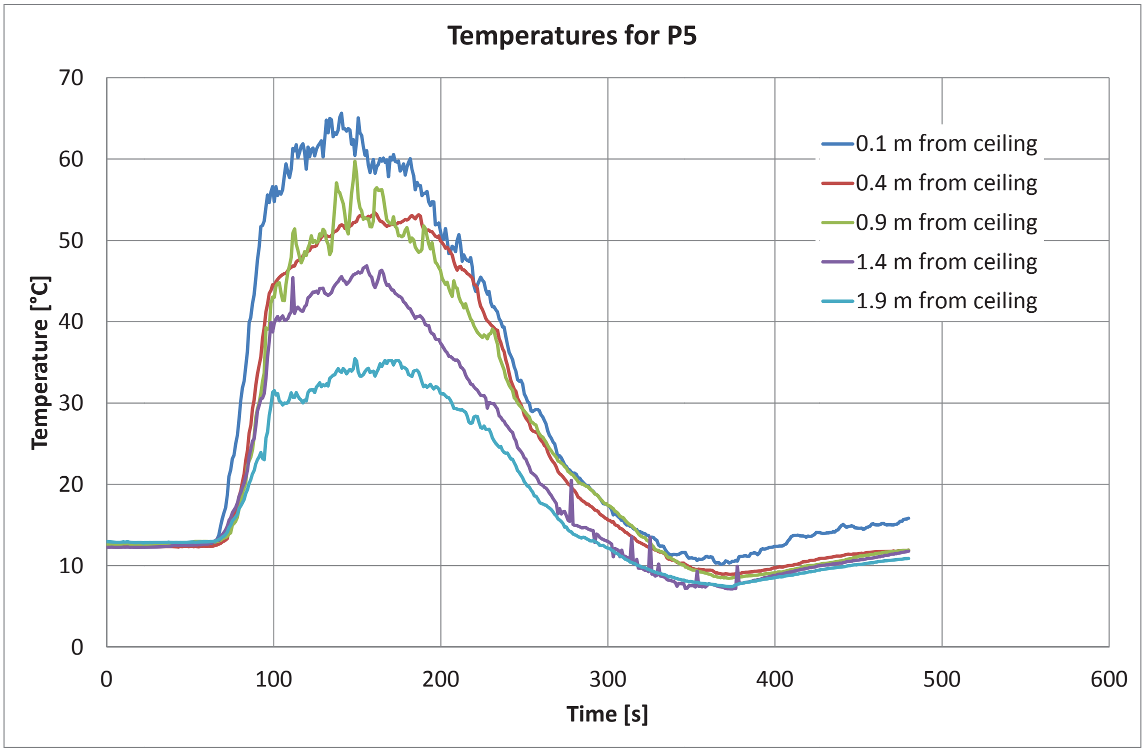

Figure 32. Test 4, Temperatures for P5

Appendix 1

Test protocol

Test: 5

Date: 2012-01-27

Test engineer: Michael Rahm, Johan Lindström

Type of test	Bulkhead nozzles, 50% obstructed
Pool fire size (Ø in mm)	1170
Position of pool fire	1
Obstruction (% of pool area)	50
Amount of diesel (L)	15
Height of freeboard (mm)	25
Water mist nozzle	
Bulkhead nozzle	Two BETE TW20-180 on the under row and two BETE NCM0706K on the upper row
Drencher nozzle	
Distance from nozzle to pool area	2.4m
Pressure (bar)	5.2
Water flow (L/min)	295-300
Notes:	
Time (s)	
0	Start measuring program and video camera
60	Ignition
90	Activation of the bulkhead system
100	Suppressed fire (approximately 1.5 m high flames)
195	Small flames around the edge of the pool area
242	The fire was extinguished
300	Stops the water to the bulkhead nozzles

Appendix 1

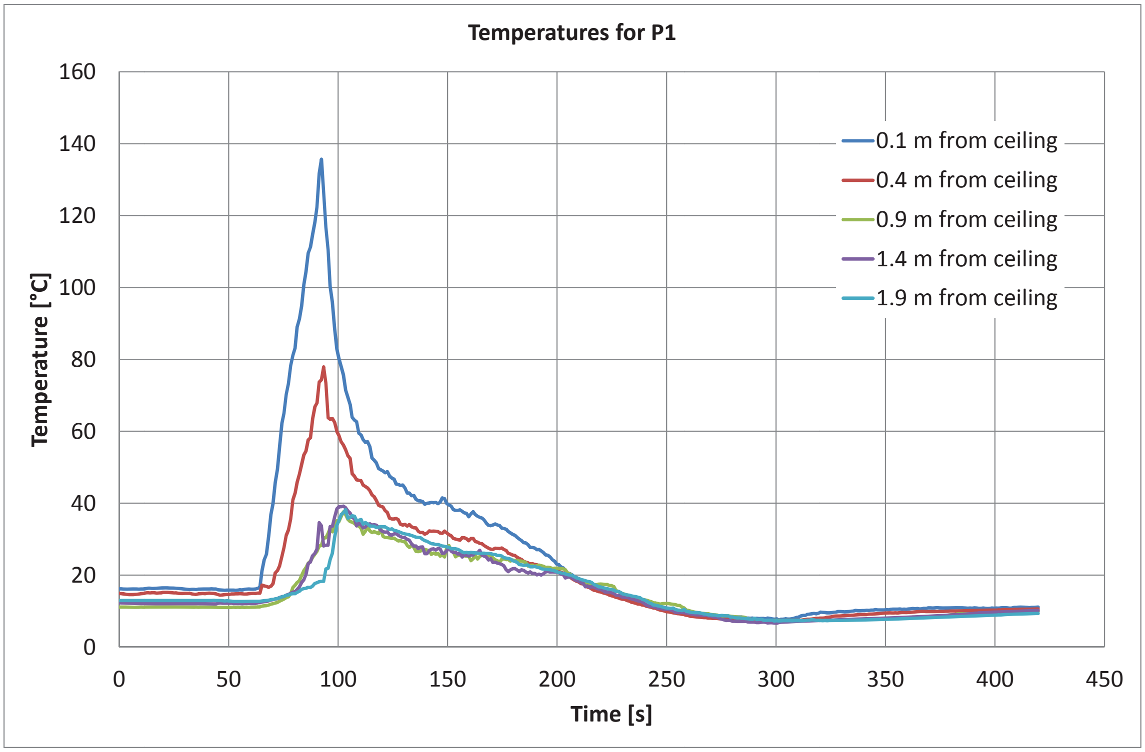

Figure 33. Test 5, Temperatures for P1

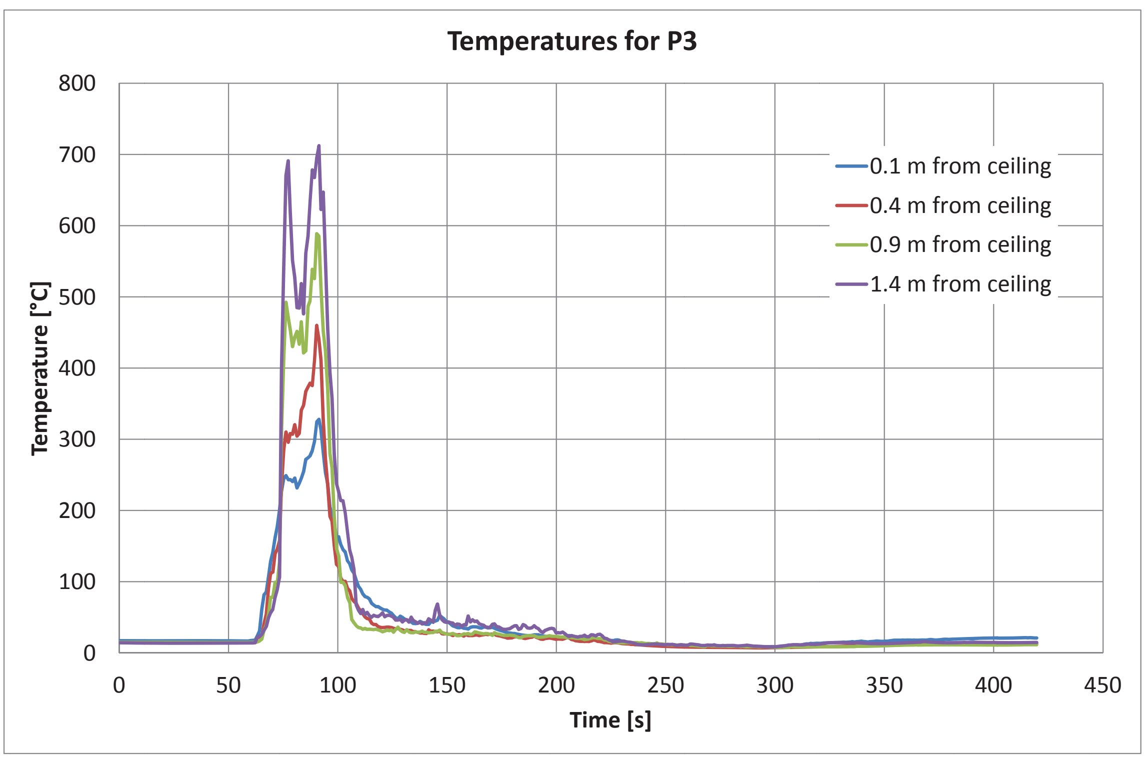

Figure 34. Test 5, Temperatures for P3

Appendix 1

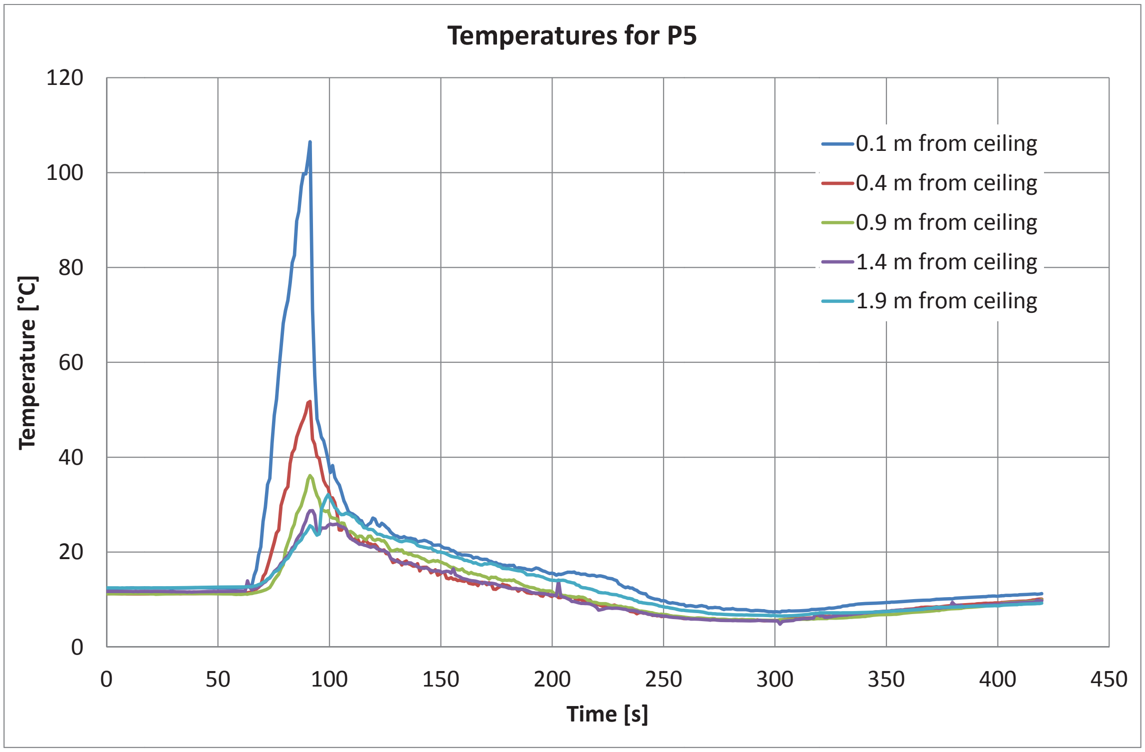

Figure 35. Test 5, Temperatures for P5

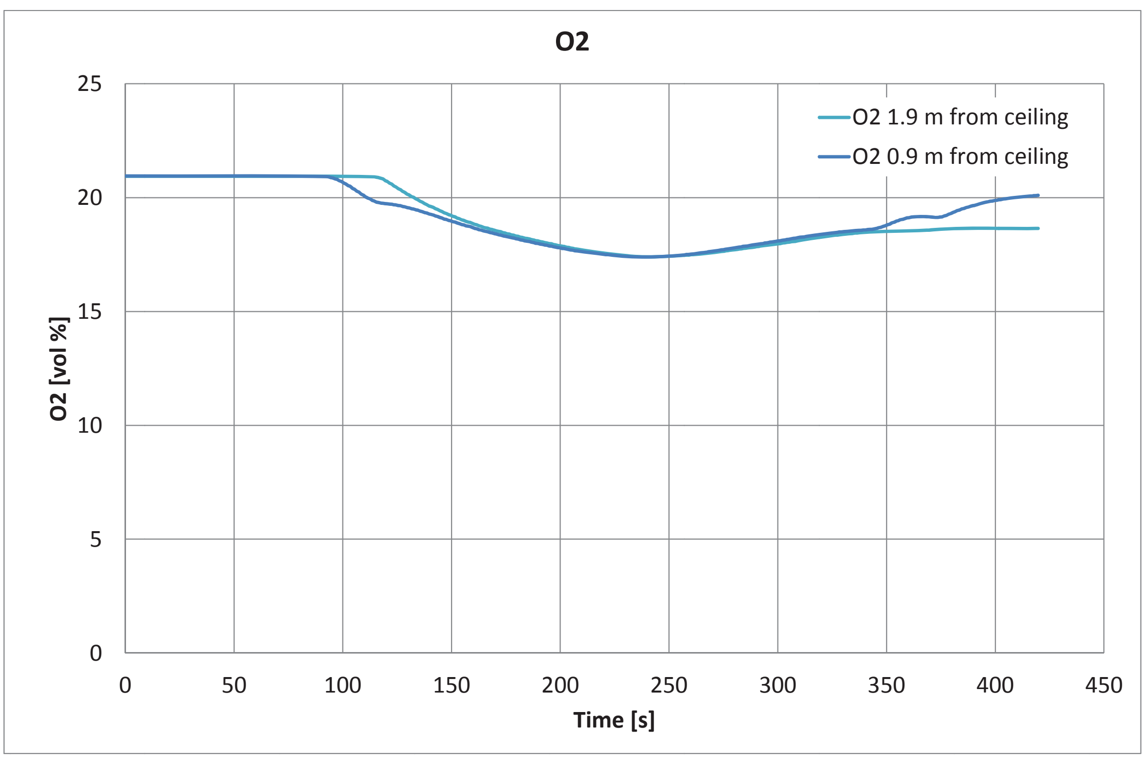

Figure 36. Test 5, O2 level. Not time-adjusted

Appendix 1

Test protocol

Test: 6

Date: 2012-01-27

Test engineer: Michael Rahm, Johan Lindström

Type of test	Bulkhead nozzles, 50% obstructed
Pool fire size (Ø in mm)	1170
Position of pool fire	1
Obstruction (% of pool area)	50
Amount of diesel (L)	15
Height of freeboard (mm)	25
Water mist nozzle	
Bulkhead nozzle	BETE NCM0706K
Drencher nozzle	
Distance from nozzle to pool area	2.4m
Pressure (bar)	5.2
Water flow (L/min)	279
Notes:	
Time (s)	
0	Start measuring program and video camera
60	Ignition
90	Activation of the bulkhead system
102	Suppressed fire (approximately 1.5 m high flames)
125	Small flames around the edge of the pool area
155	The fire was extinguished
240	Stops the water to the bulkhead nozzles

Appendix 1

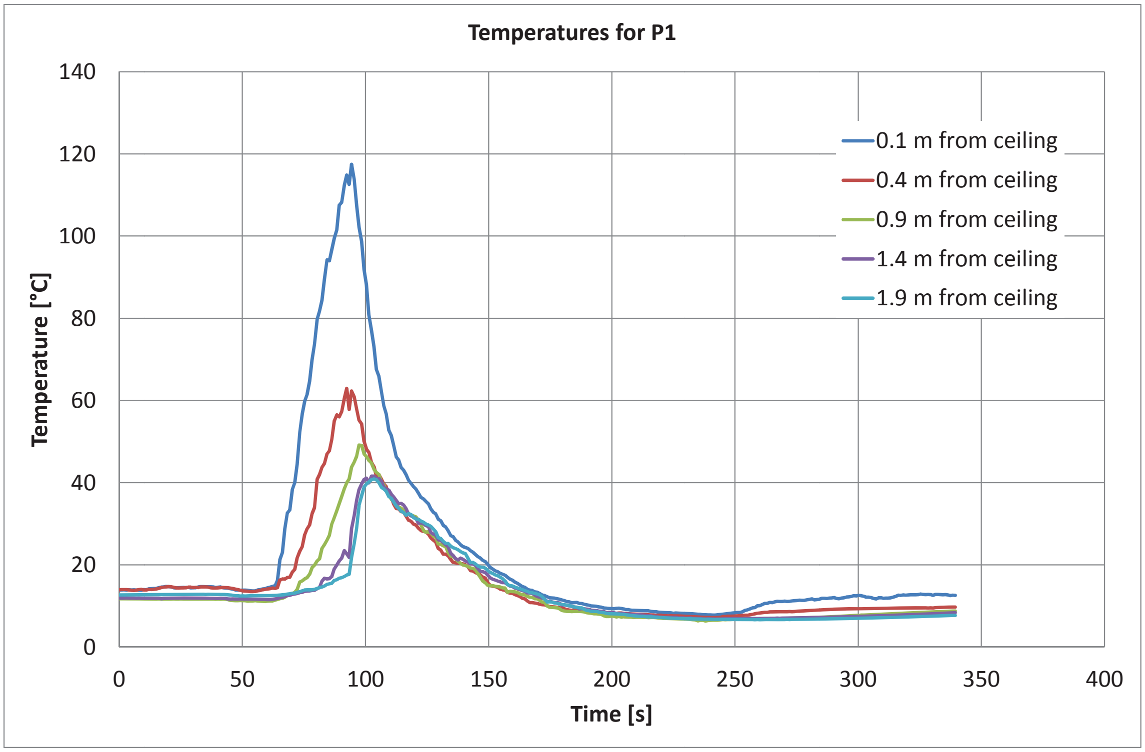

Figure 37. Test 6, Temperatures for P1

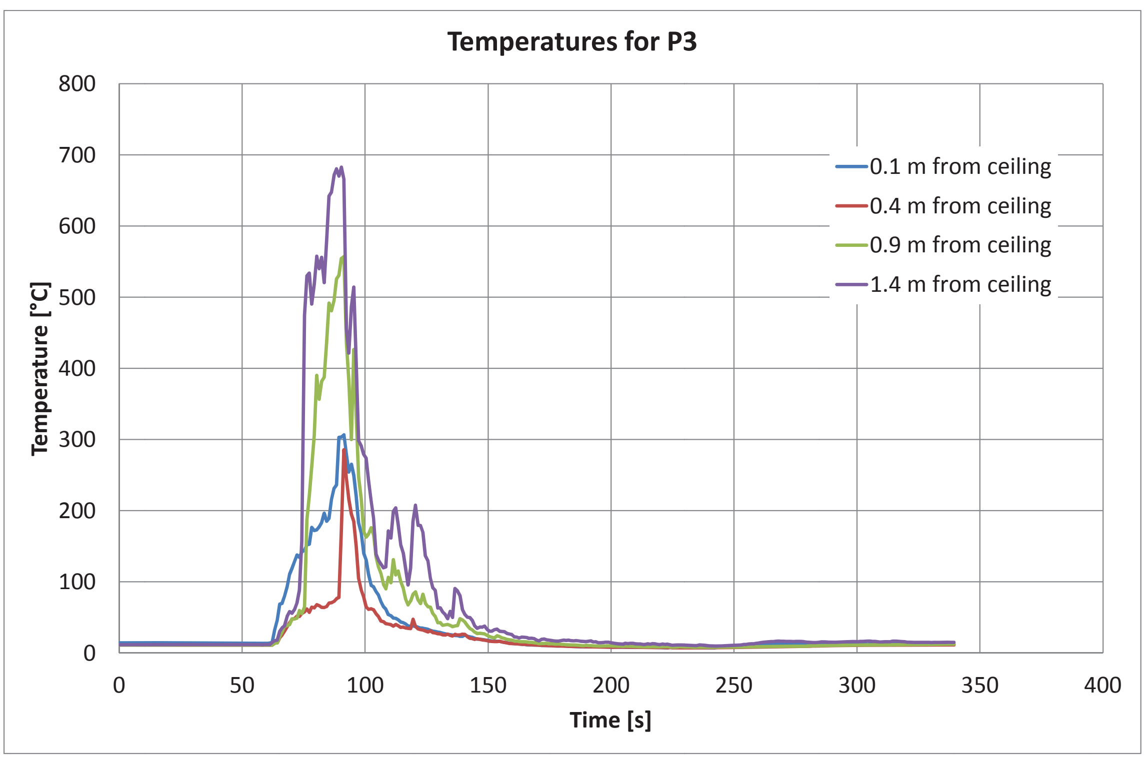

Figure 38. Test 6, Temperatures for P3

Appendix 1

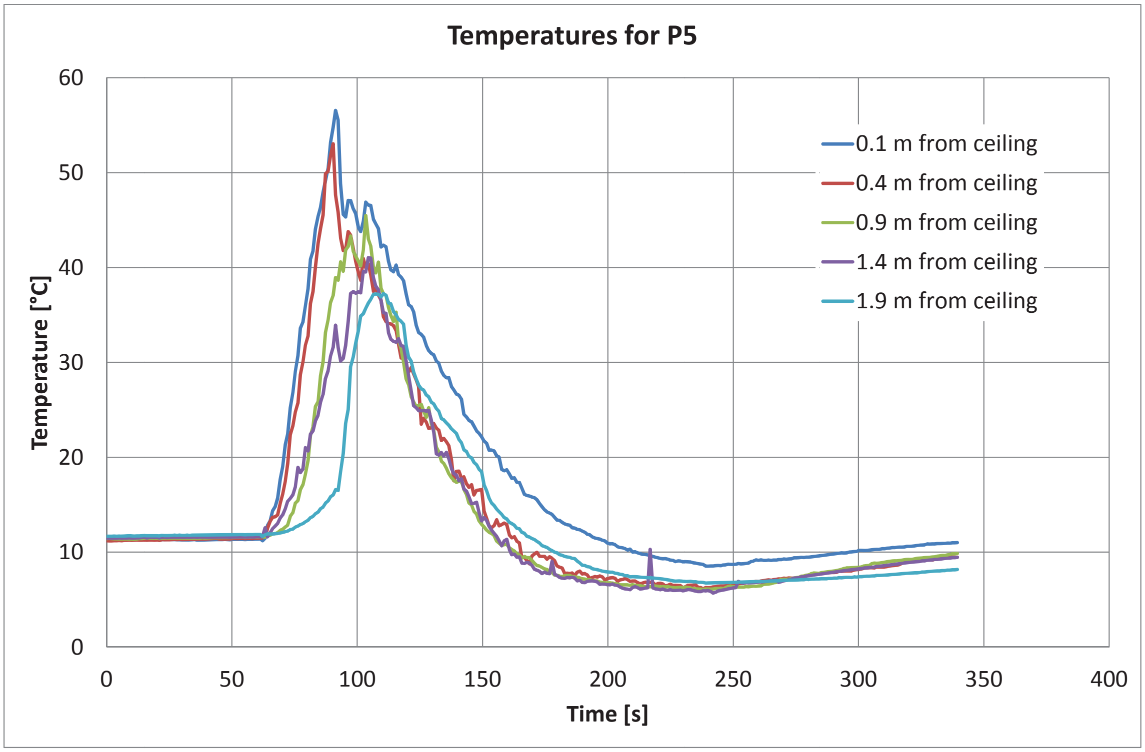

Figure 39. Test 6, Temperatures for P5

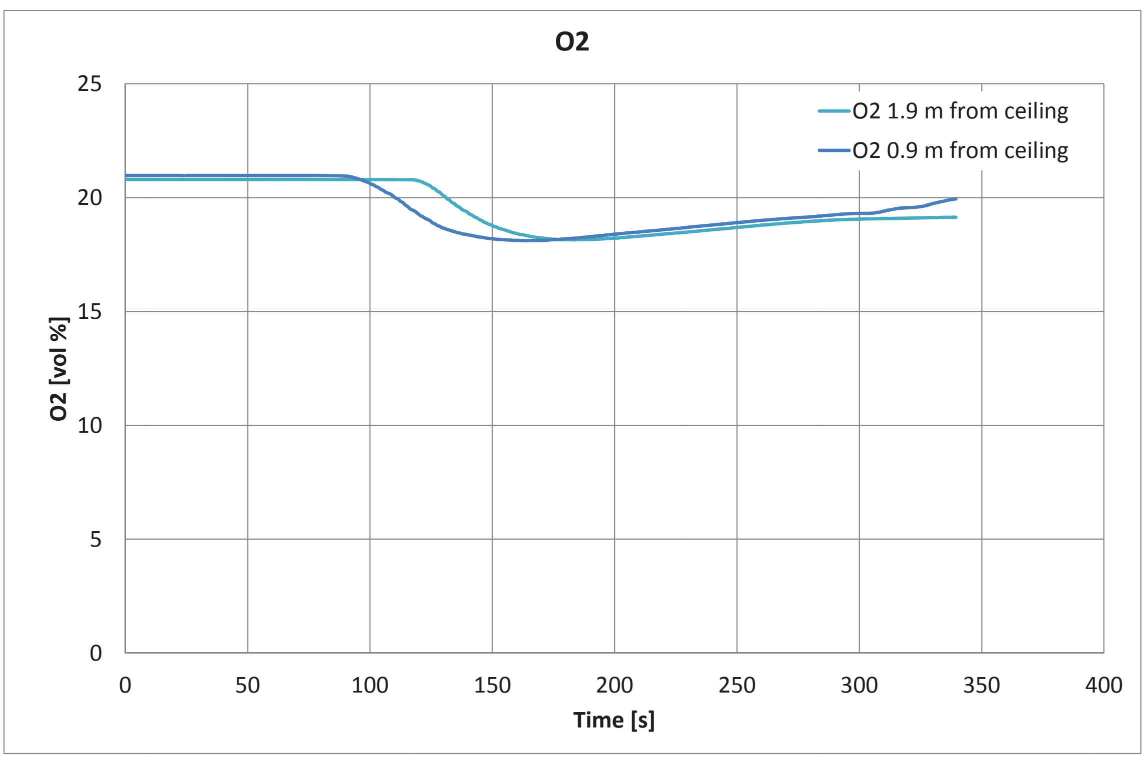

Figure 40. Test 6, O2 level. Not time-adjusted

Appendix 1

Test protocol

Test: 7, Response time for the O_2 measurements – test 1

Date: 2012-02-03

Test engineer: Michael Rahm, Johan Lindström

Type of test	Response time for the O_2 measurements – test 1
Pool fire size (Ø in mm)	
Position of pool fire	
Obstruction (% of pool area)	
Amount of diesel (L)	
Height of freeboard (mm)	
Water mist nozzle	
Bulkhead nozzle	
Drencher nozzle	
Distance from nozzle to pool area	
Pressure (bar)	
Water flow (L/min)	
Notes:	
	The tested O_2 measurement has its analyzing position at P5 1900 mm from ceiling.
Time (s)	
0	Start measuring program
60	Applying N_2
90	Manually reading a start of reaction time for the instrument
147	The measuring is stopped

Test protocol

Test: 8, Response time for the O_2 measurements – test 2

Date: 2012-02-03

Test engineer: Michael Rahm, Johan Lindström

Type of test	Response time for the O_2 measurements – test 2
Pool fire size (Ø in mm)	
Position of pool fire	
Obstruction (% of pool area)	
Amount of diesel (L)	
Height of freeboard (mm)	
Water mist nozzle	
Bulkhead nozzle	
Drencher nozzle	
Distance from nozzle to pool area	
Pressure (bar)	
Water flow (L/min)	
Notes:	
	The tested O_2 measurement has its analyzing position at P5 900 mm from ceiling.
Time (s)	
0	Start measuring program
60	Applying N_2
180	Manually reading a start of reaction time for the instrument. A valve was closed. That's why the response time was so delayed.
304	The measuring is stopped

Appendix 1

Test protocol

Test: 9, Response time for the O_2 measurements – test 3

Date: 2012-02-03

Test engineer: Michael Rahm, Johan Lindström

Type of test	Response time for the O_2 measurements – test 3
Pool fire size (Ø in mm)	
Position of pool fire	
Obstruction (% of pool area)	
Amount of diesel (L)	
Height of freeboard (mm)	
Water mist nozzle	
Bulkhead nozzle	
Drencher nozzle	
Distance from nozzle to pool area	
Pressure (bar)	
Water flow (L/min)	
Notes:	
	The tested O_2 measurement has its analyzing position at P5 900 mm from ceiling.
Time (s)	
0	Start measuring program
60	Applying N_2
85	Manually reading a start of reaction time for the instrument
126	The measuring is stopped

Test protocol

Test: 10

Date: 2012-01-31

Test engineer: Michael Rahm, Johan Lindström

Type of test	Water mist system
Pool fire size (Ø in mm)	1170
Position of pool fire	1
Obstruction (% of pool area)	
Amount of diesel (L)	15
Height of freeboard (mm)	25
Water mist nozzle	BETE TF8-170
Bulkhead nozzle	
Drencher nozzle	
Distance from nozzle to pool area	
Pressure (bar)	10
Water flow (L/min)	169
Notes:	
Time (s)	
0	Start measuring program and video camera
60	Ignition
90	Activation of water mist system
100	Suppressed fire (approximately 1.5 m high flames)
110	Small flames around the edge of the pool area.
240	The fire was extinguished
300	The water mist system was stopped

Appendix 1

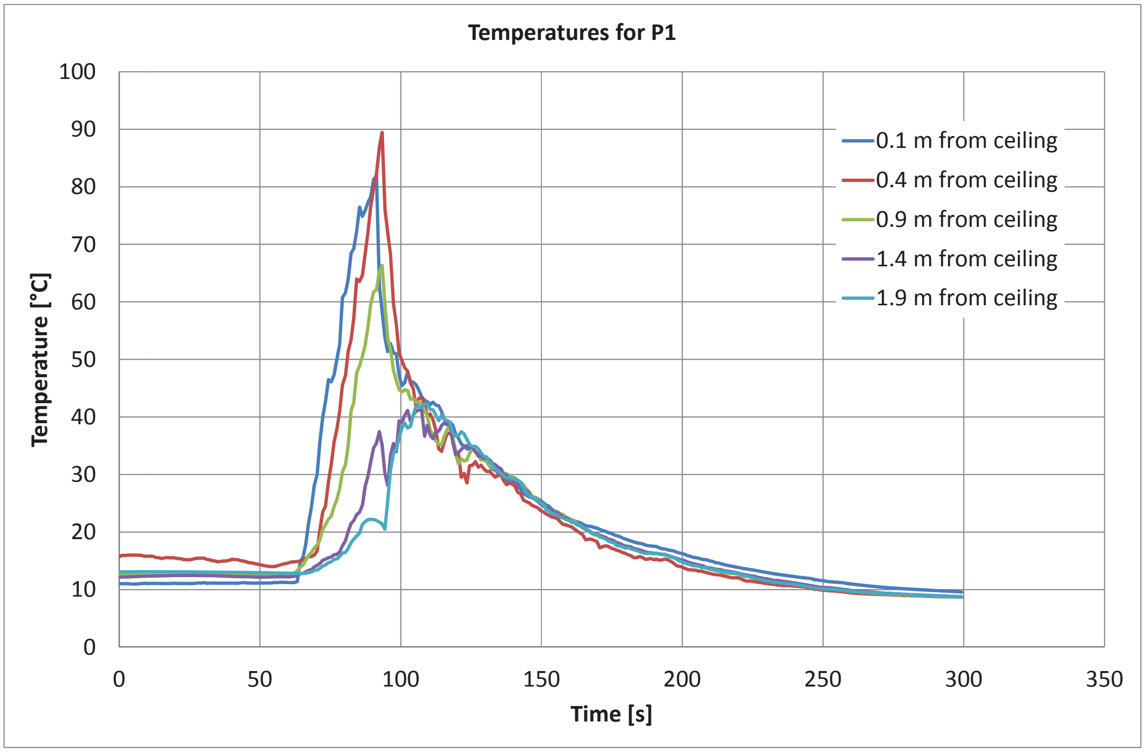

Figure 41. Test 10, Temperatures for P1

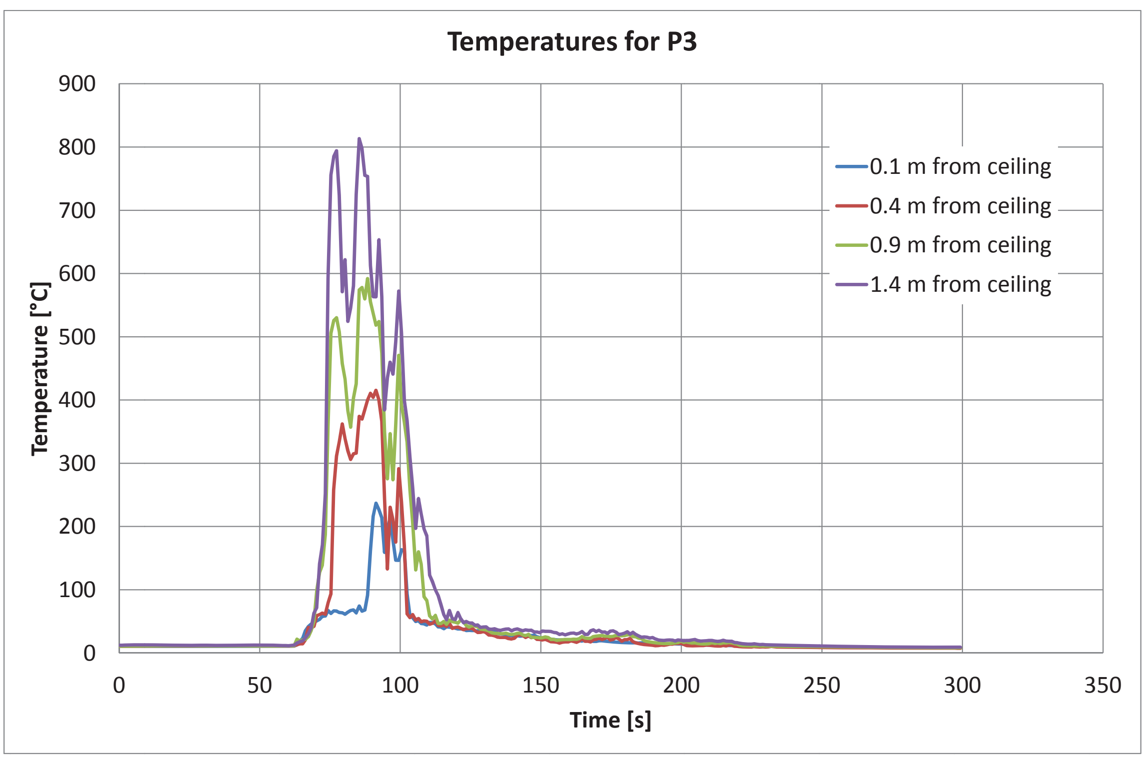

Figure 42. Test 10, Temperatures for P3

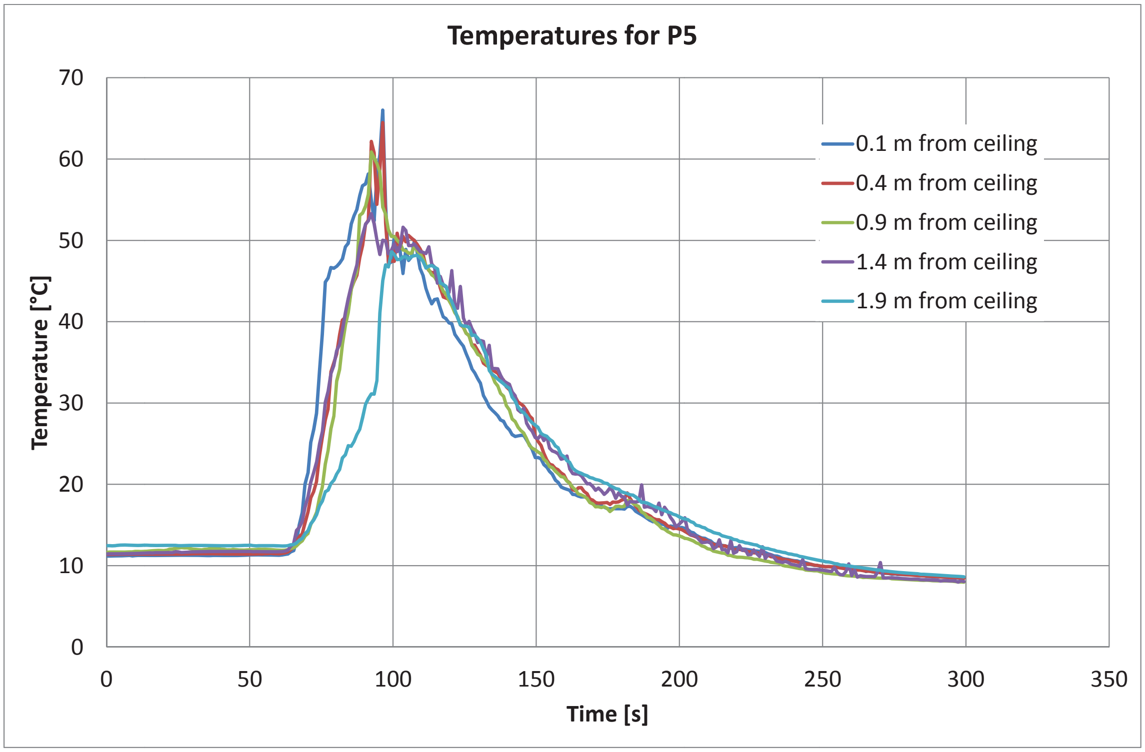

Figure 43. Test 10, Temperatures for P5

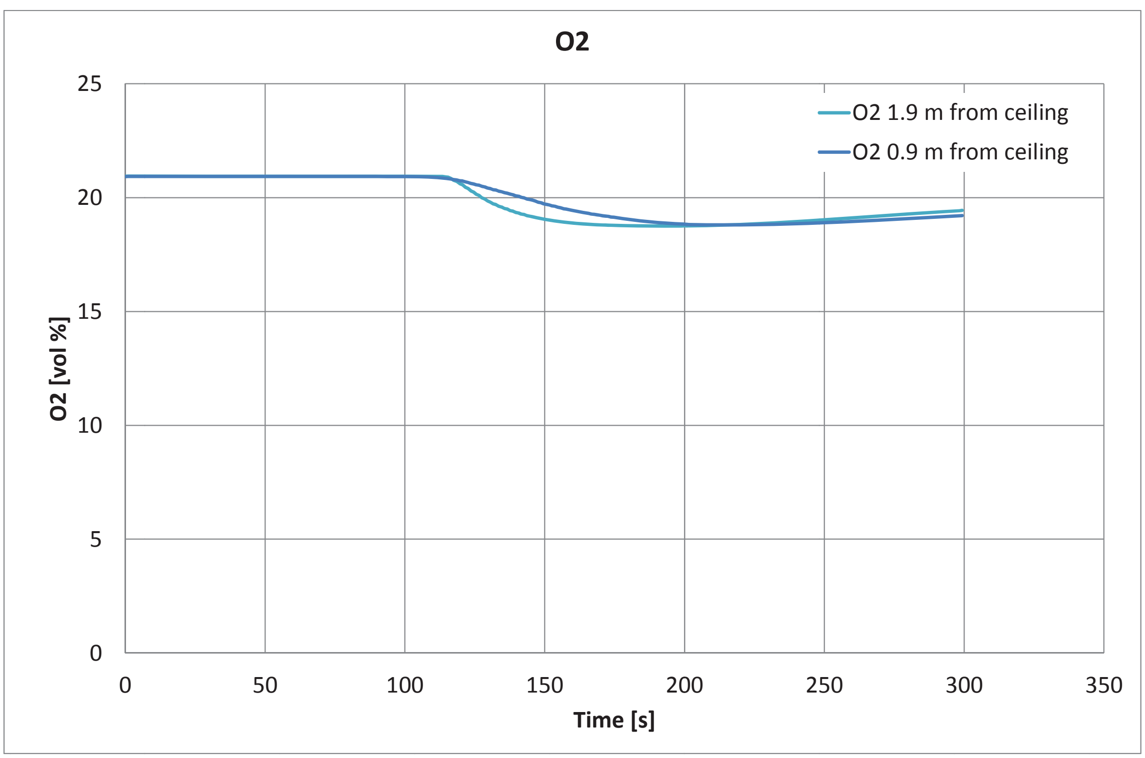

Figure 44. Test 10, O2 level. Not time-adjusted

Test protocol

Test: 11

Date: 2012-01-31

Test engineer: Michael Rahm, Johan Lindström

Type of test	Water mist system at 5 bar
Pool fire size (Ø in mm)	1170
Position of pool fire	1
Obstruction (% of pool area)	
Amount of diesel (L)	10
Height of freeboard (mm)	25
Water mist nozzle	BETE TF8-170
Bulkhead nozzle	
Drencher nozzle	
Distance from nozzle to pool area	
Pressure (bar)	5
Water flow (L/min)	120
Notes:	
Time (s)	
0	Start measuring program and video camera
60	Ignition
90	Activation of water mist system
95	Suppressed fire (approximately 1.5 m high flames)
100	Small flames around the edge of the pool area.
341	The fire was extinguished
360	The water mist system was stopped

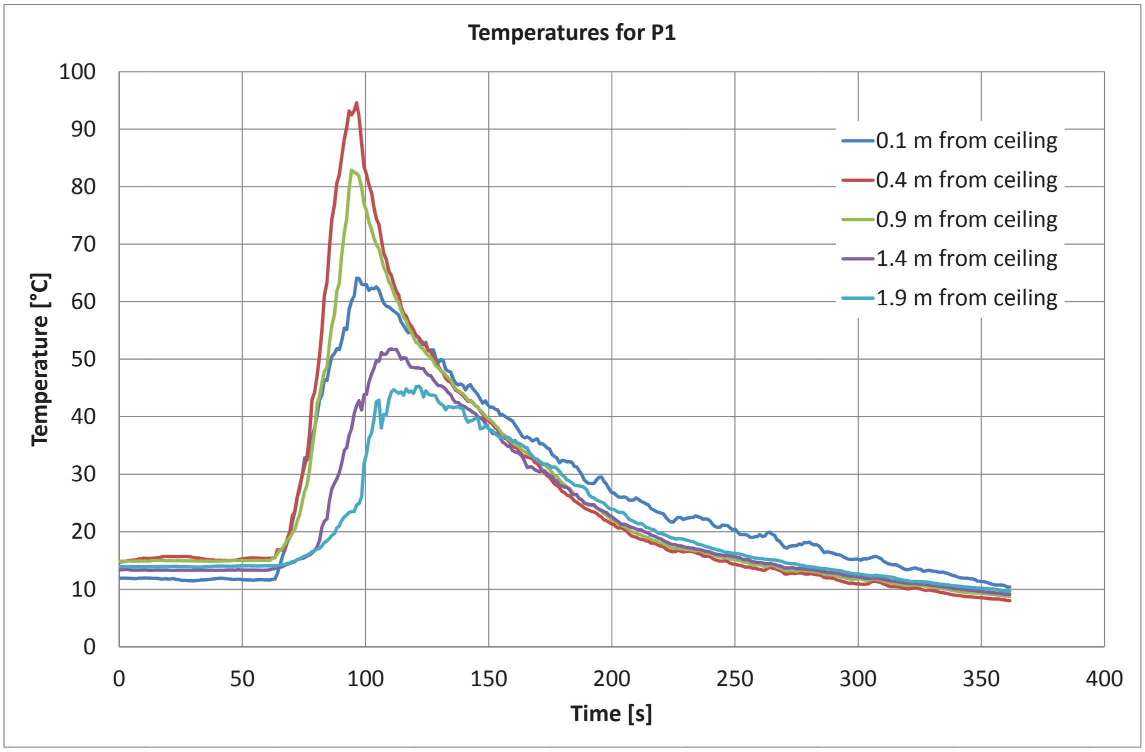

Figure 45. Test 11, Temperatures for P1

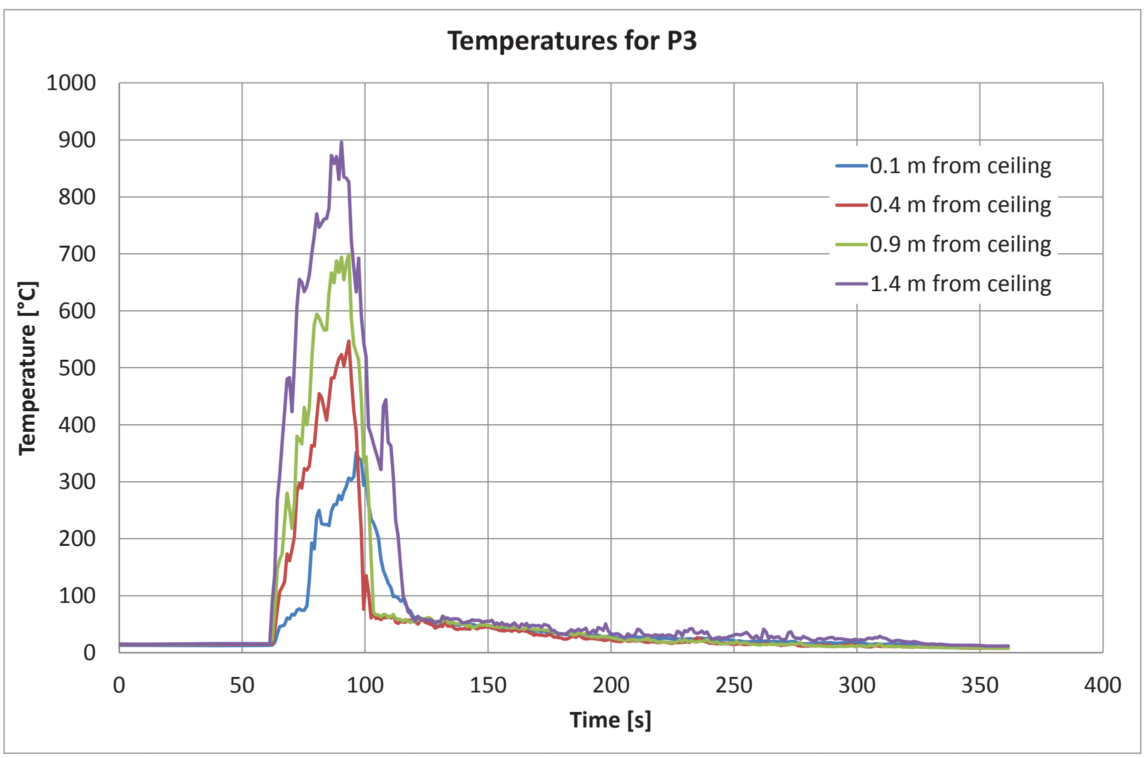

Figure 46. Test 11, Temperatures for P3

Appendix 1

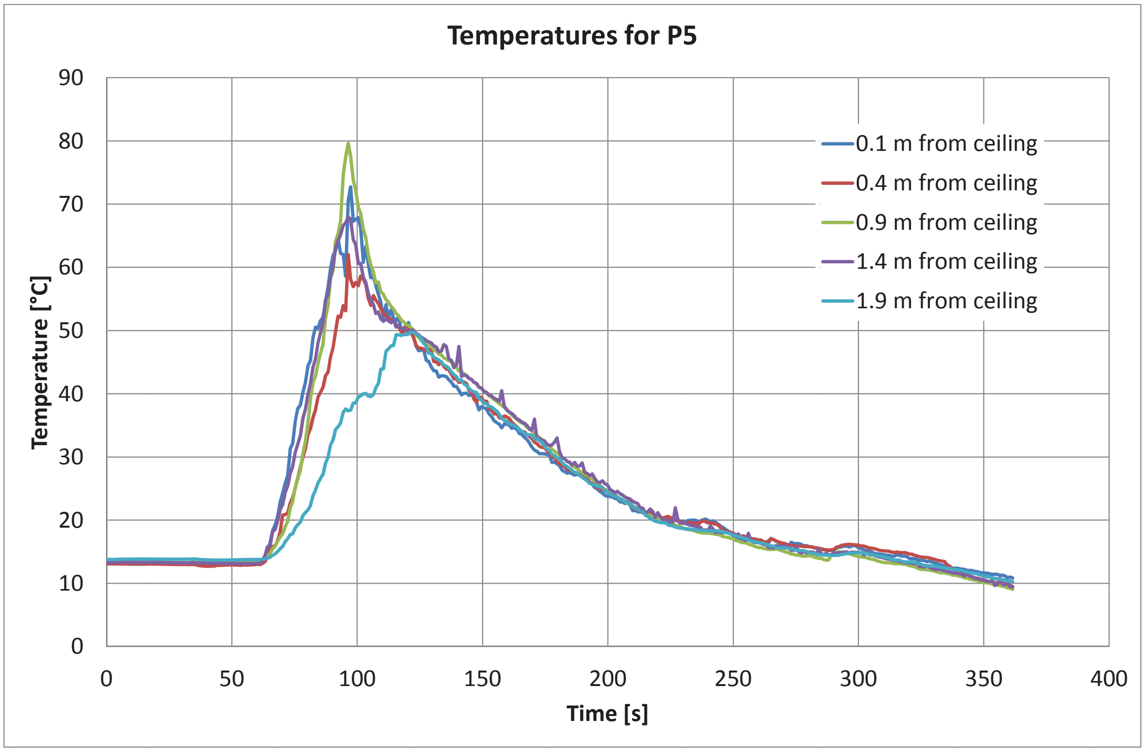

Figure 47. Test 11, Temperatures for P5

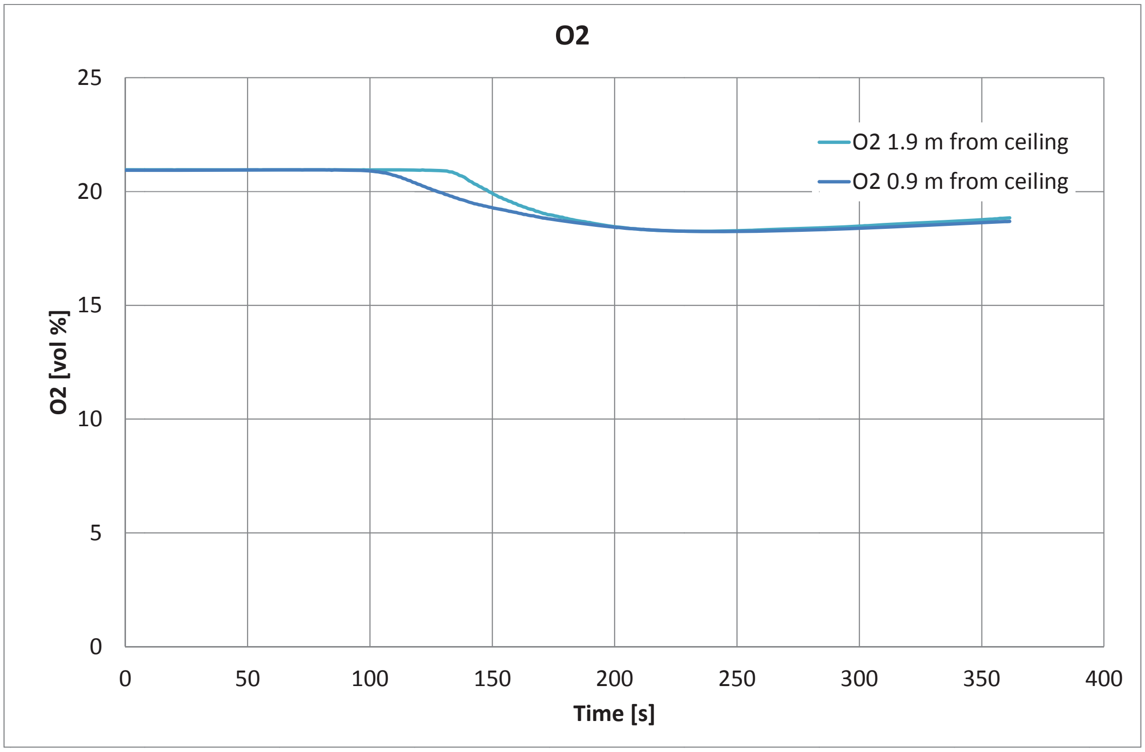

Figure 48. Test 11, O2 level. Not time-adjusted

Test protocol

Test: 12

Date: 2012-01-31

Test engineer: Michael Rahm, Johan Lindström

Type of test	Water mist system at 5 bar, 50% obstructed
Pool fire size (Ø in mm)	1170
Position of pool fire	1
Obstruction (% of pool area)	50
Amount of diesel (L)	10
Height of freeboard (mm)	25
Water mist nozzle	BETE TF8-170
Bulkhead nozzle	
Drencher nozzle	
Distance from nozzle to pool area	
Pressure (bar)	5
Water flow (L/min)	120
Notes:	
Time (s)	
0	Start measuring program and video camera
60	Ignition
90	Activation of water mist system
180	Suppressed fire (approximately 1.5 m high flames)
230	Small flames around the edge of the pool area.
300	16% oxygen and a lot of smoke
510	Start the pump to raise the pressure to 10 bar
540	The pressure was established at 10 bar
630	No big visible difference
730	Extinguish with foam

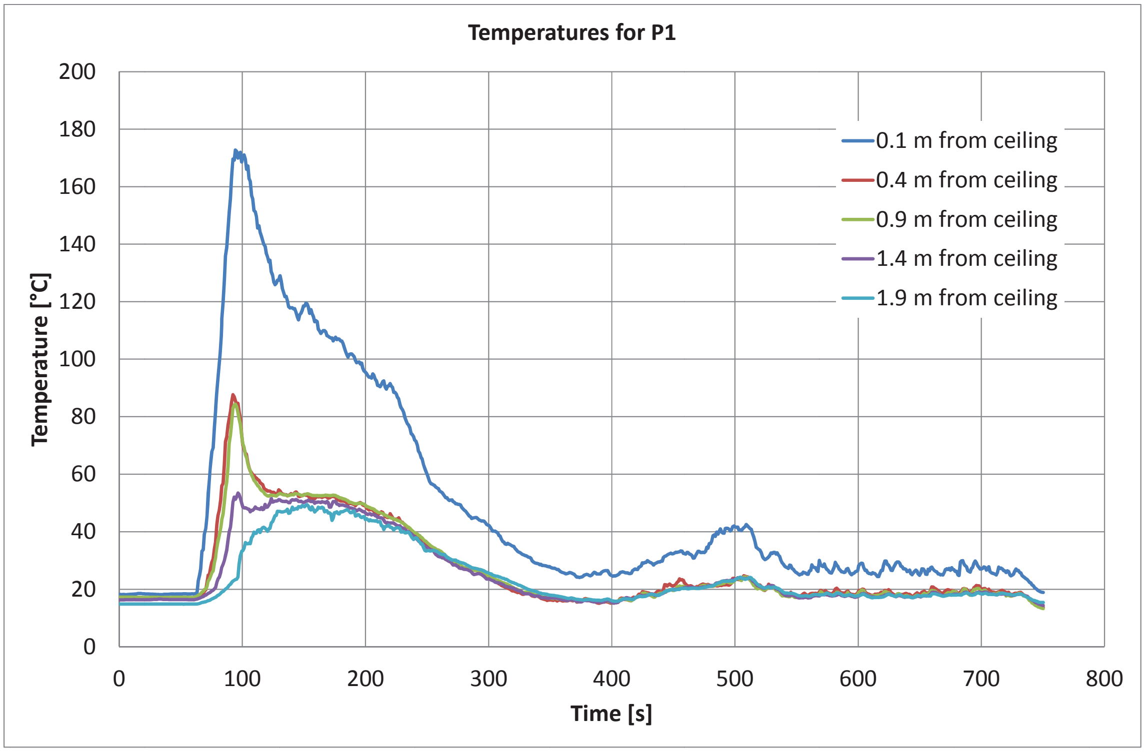

Figure 49. Test 12, Temperatures for P1

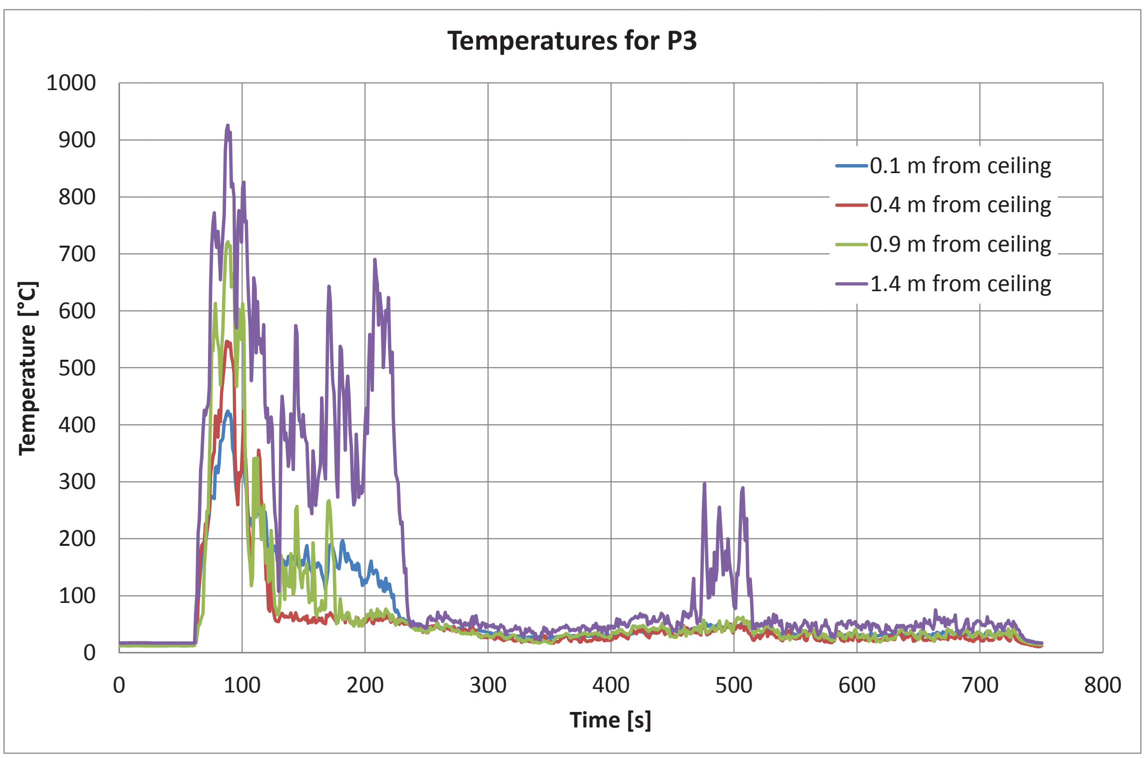

Figure 50. Test 12, Temperatures for P3

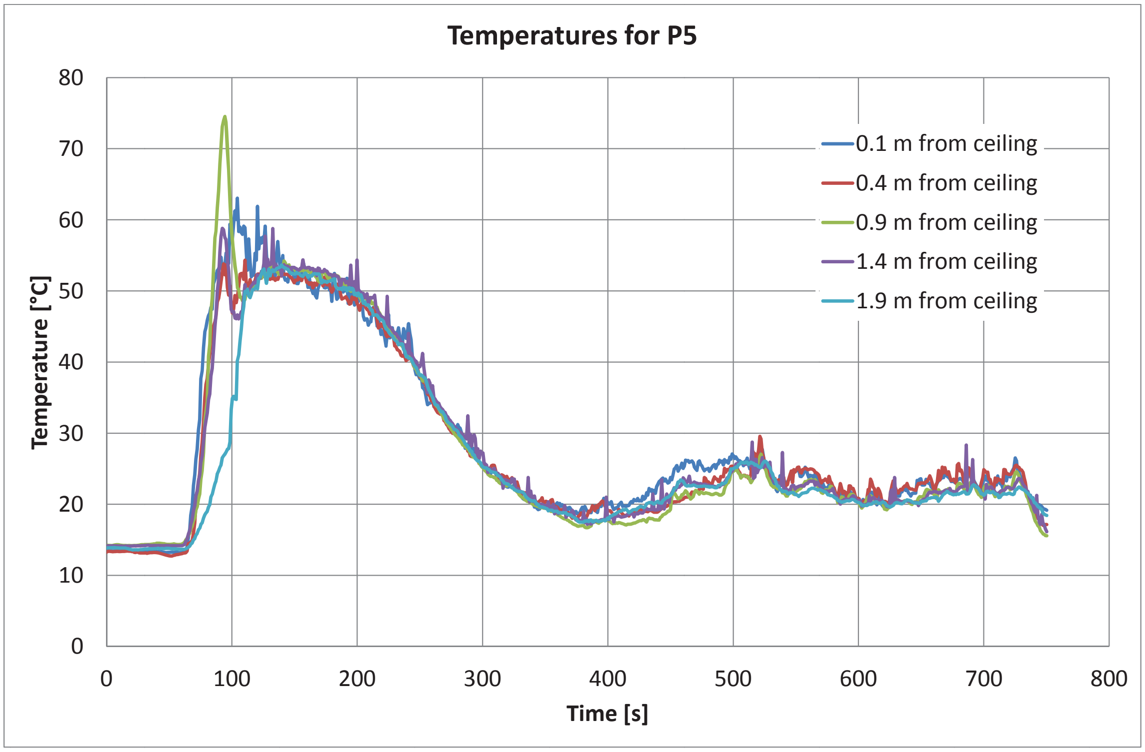

Figure 51. Test 12, Temperatures for P5

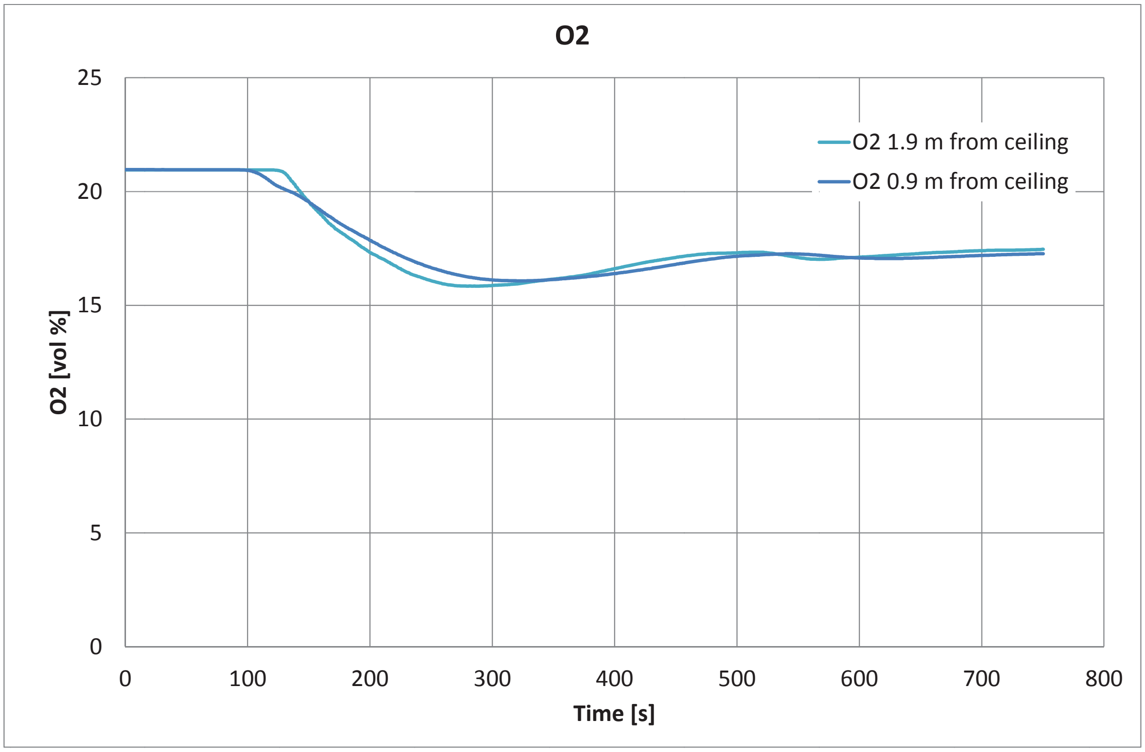

Figure 52. Test 12, O2 level. Not time-adjusted

Appendix 1

Test protocol

Test: 13

Date: 2012-01-31

Test engineer: Michael Rahm, Johan Lindström

Type of test	Water mist system, 10 bar, 50 % obstructed
Pool fire size (Ø in mm)	1170
Position of pool fire	1
Obstruction (% of pool area)	50
Amount of diesel (L)	15
Height of freeboard (mm)	25
Water mist nozzle	BETE TF8-170
Bulkhead nozzle	
Drencher nozzle	
Distance from nozzle to pool area	
Pressure (bar)	10
Water flow (L/min)	170
Notes:	
Time (s)	
0	Start measuring program and video camera
60	Ignition
90	Activation of water mist system
100	Suppressed fire (approximately 1.5 m high flames)
120	Small flames around the edge of the pool area. A lot of smoke
292	The fire was extinguished
330	The water mist system was stopped

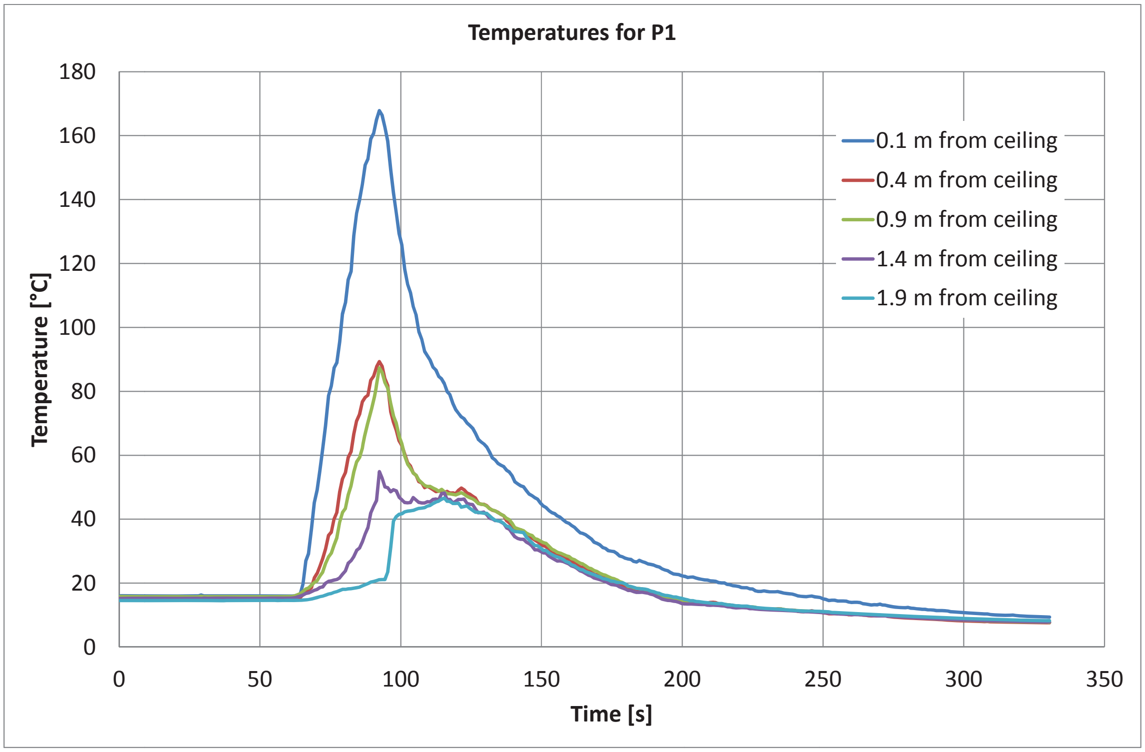

Figure 53. Test 13, Temperatures for P1

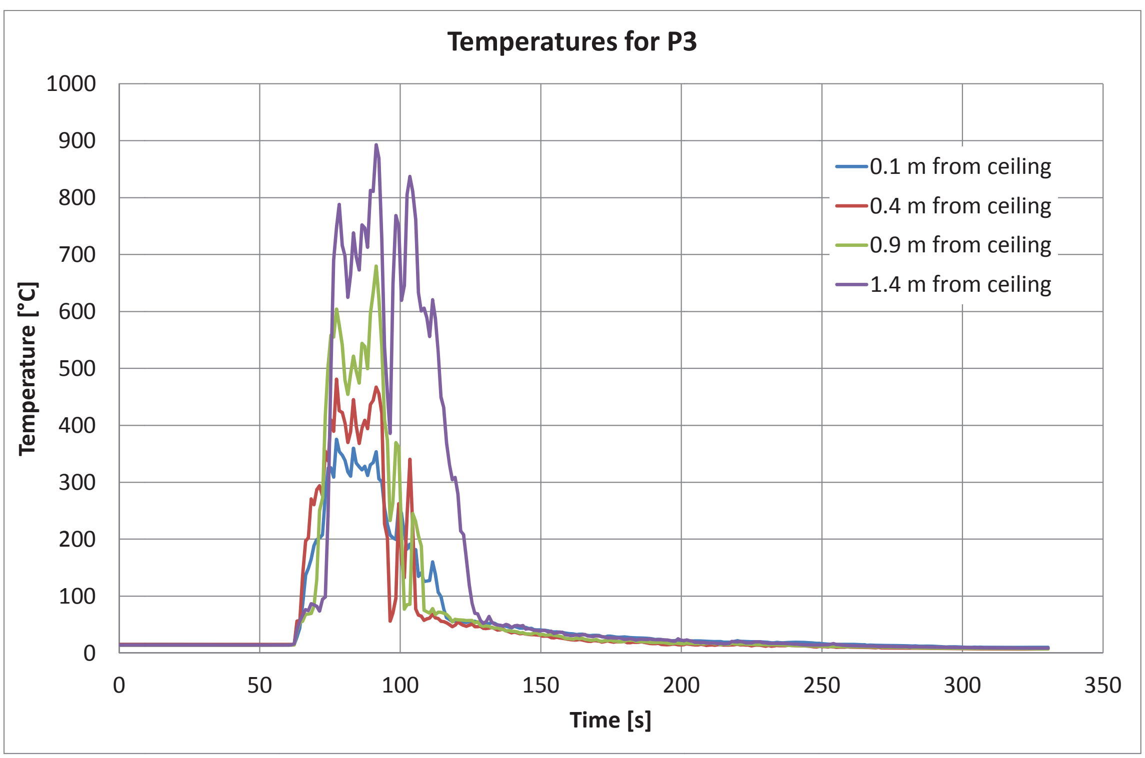

Figure 54. Test 13, Temperatures for P3

Appendix 1

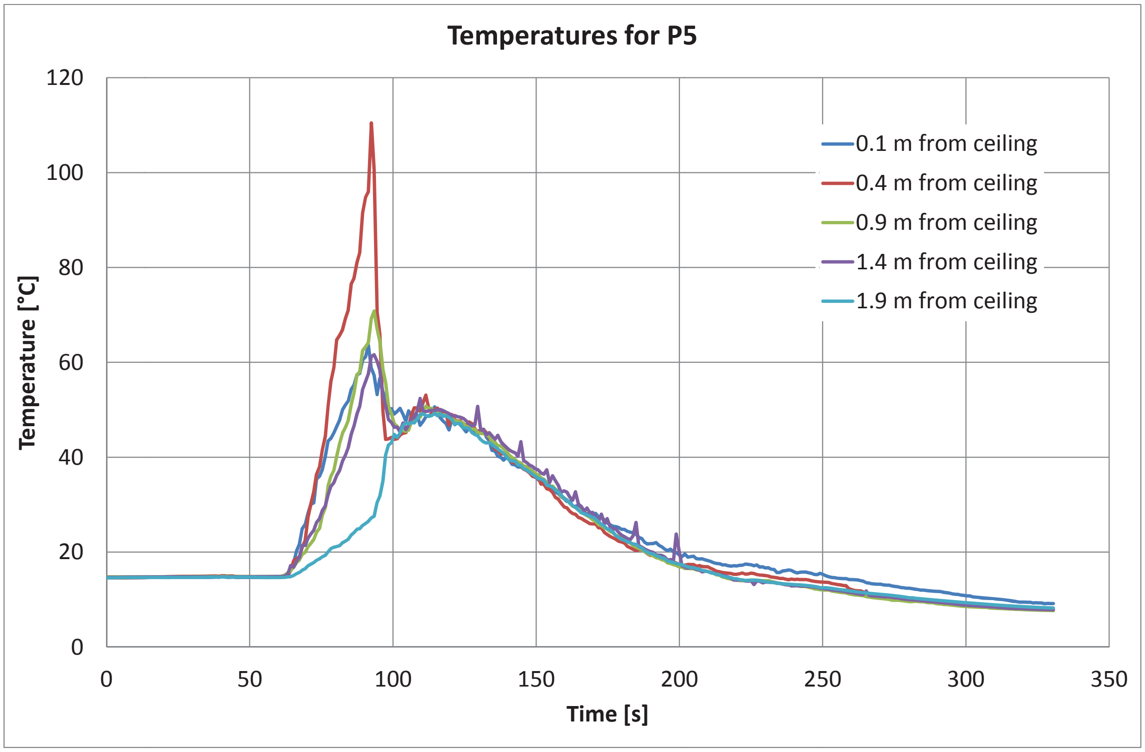

Figure 55. Test 13, Temperatures for P5

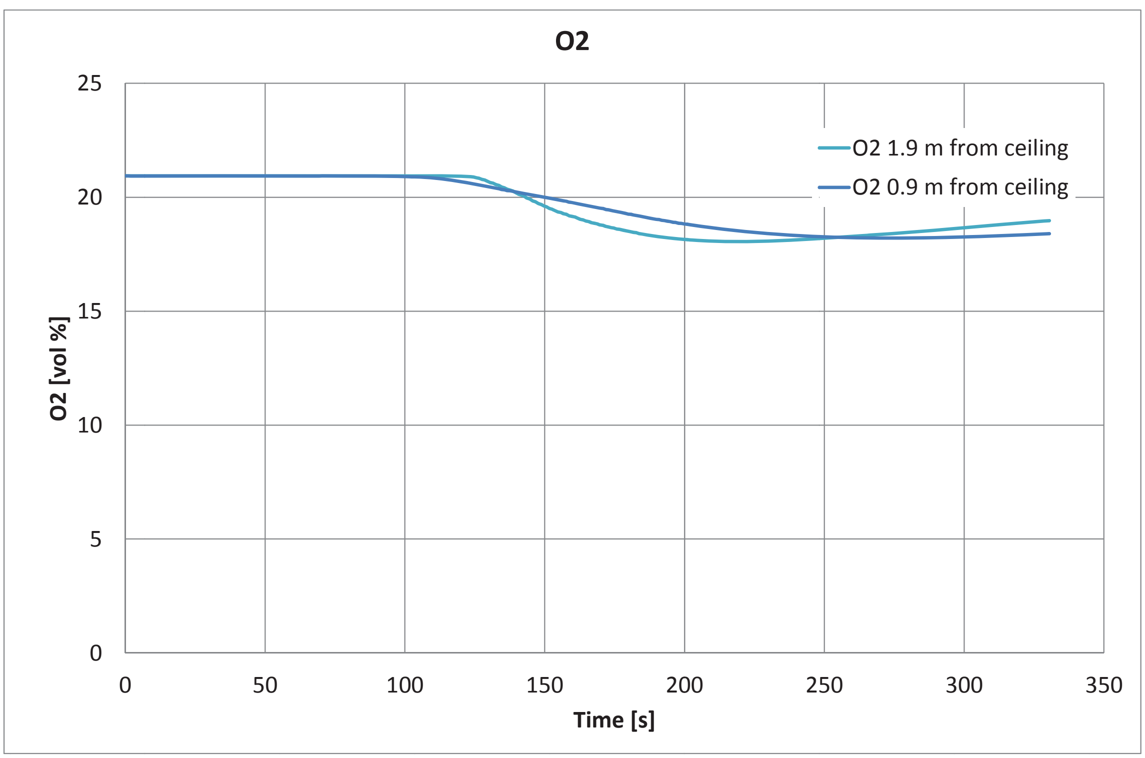

Figure 56. Test 13, O2 level. Not time-adjusted

Appendix 1

Test protocol

Test: 14

Date: 2012-02-01

Test engineer: Michael Rahm, Johan Lindström

Type of test	Sand torpedo, free-burn
Pool fire size (Ø in mm)	1170
Position of pool fire	1
Obstruction (% of pool area)	Torpedo, placed 50mm above pool surface
Amount of diesel (L)	15
Height of freeboard (mm)	25
Water mist nozzle	BETE TF8-170 used to extinguish the fire when needed.
Bulkhead nozzle	
Drencher nozzle	
Distance from nozzle to pool area	
Pressure (bar)	10
Water flow (L/min)	169
Notes:	
Time (s)	
0	Start measuring program and video camera
60	Ignition
254	Activation of water mist system
256	The fire was extinguished

Appendix 1

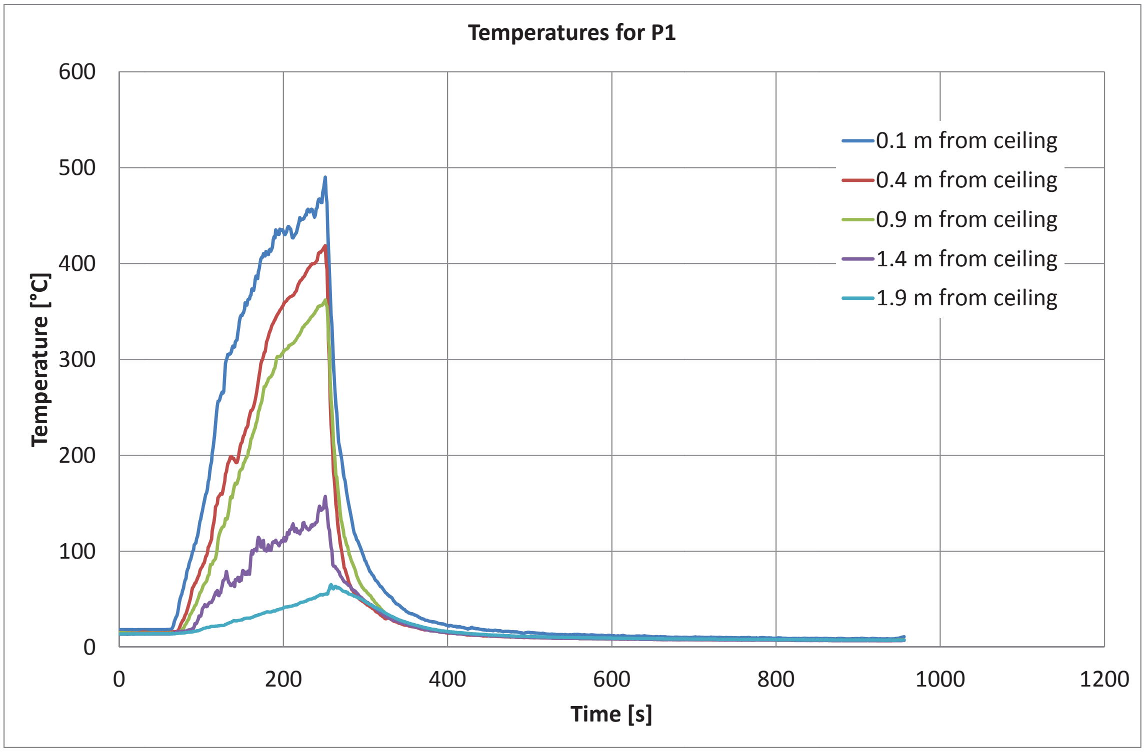

Figure 57. Test 14, Temperatures for P1

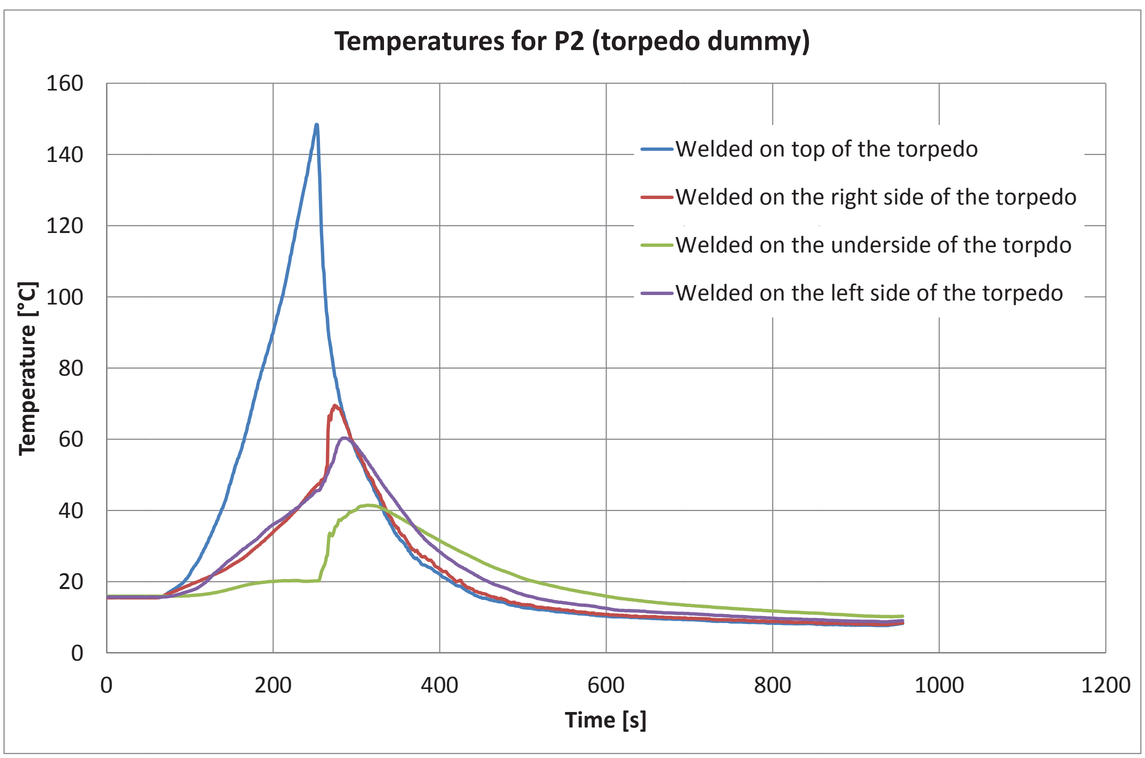

Figure 58. Test 14, Temperatures for P2 (dummy torpedo)

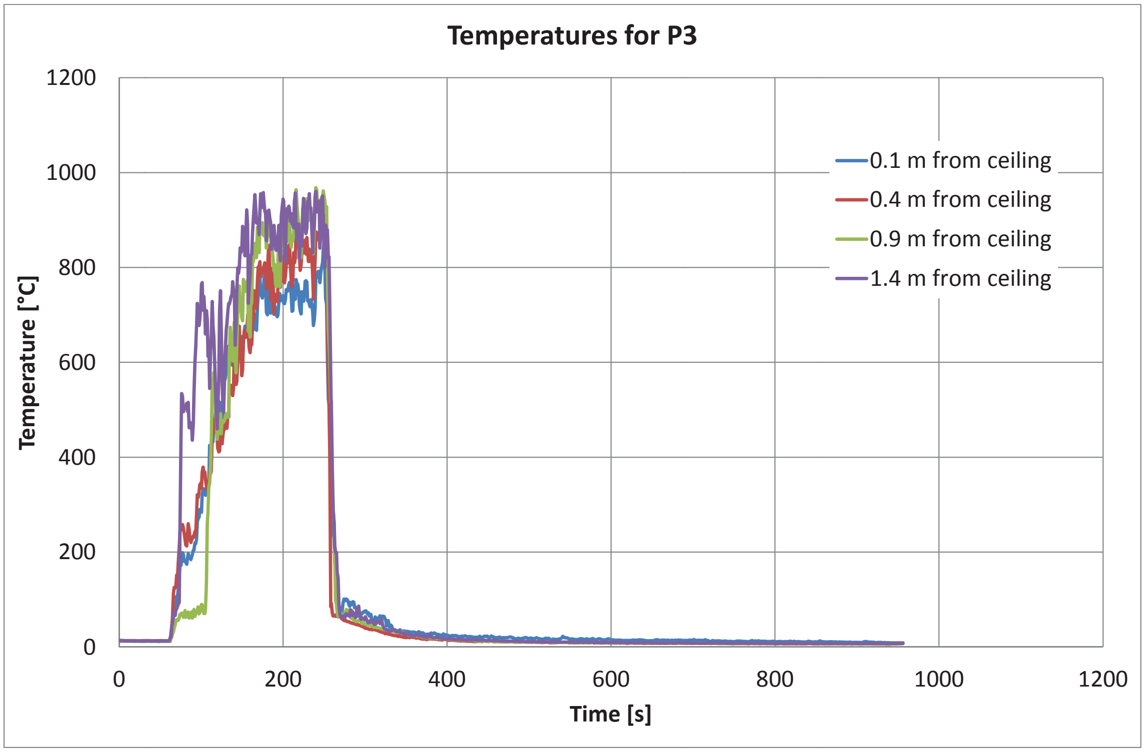

Figure 59. Test 14, Temperatures for P3

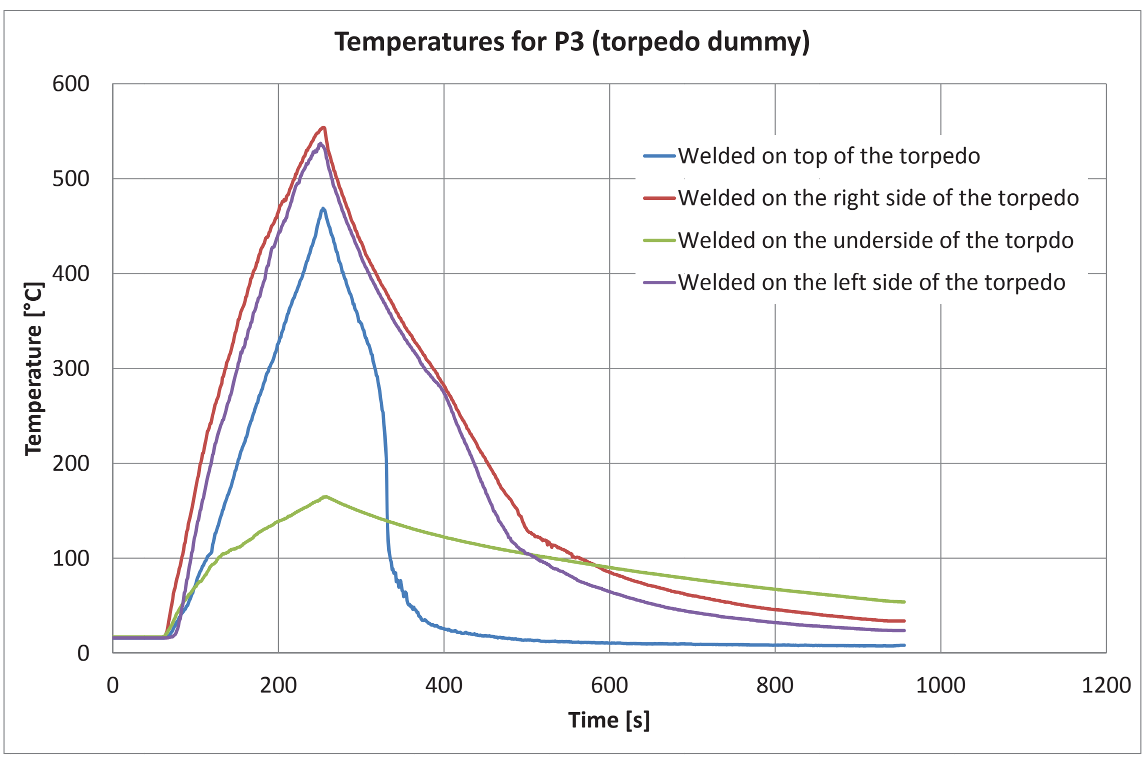

Figure 60. Test 14, Temperatures for P3 (dummy torpedo)

Appendix 1

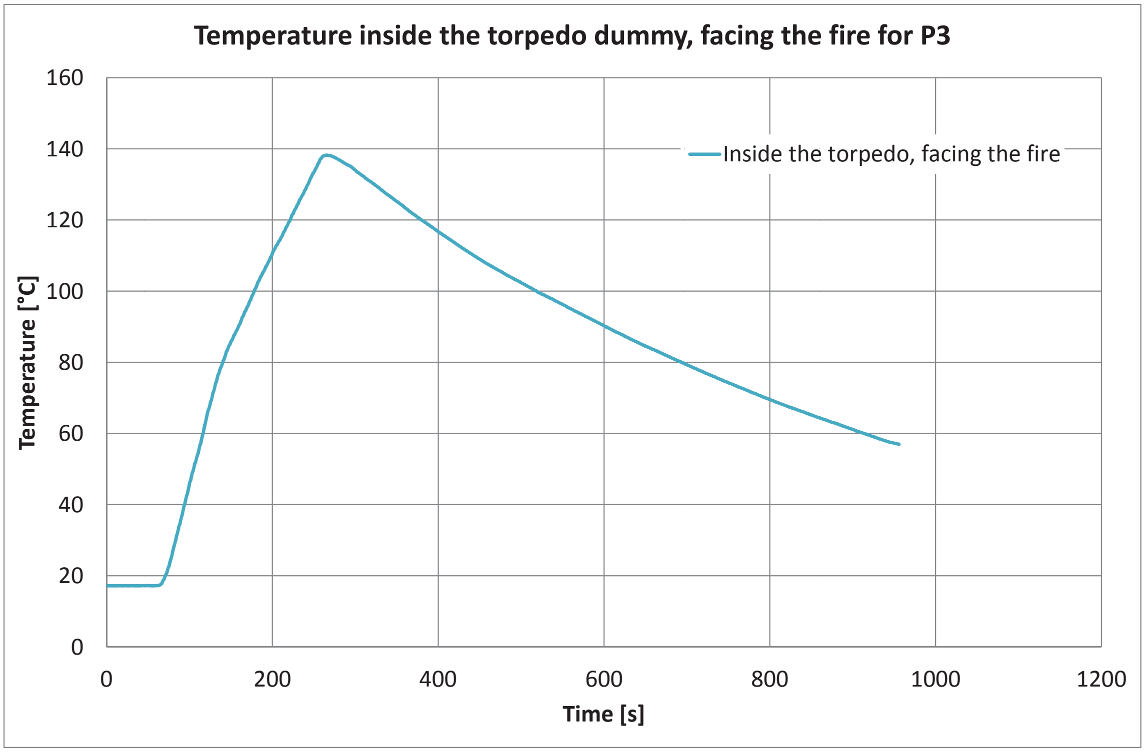

Figure 61. Test 14, Temperatures inside the torpedo dummy, facing the fire for P3

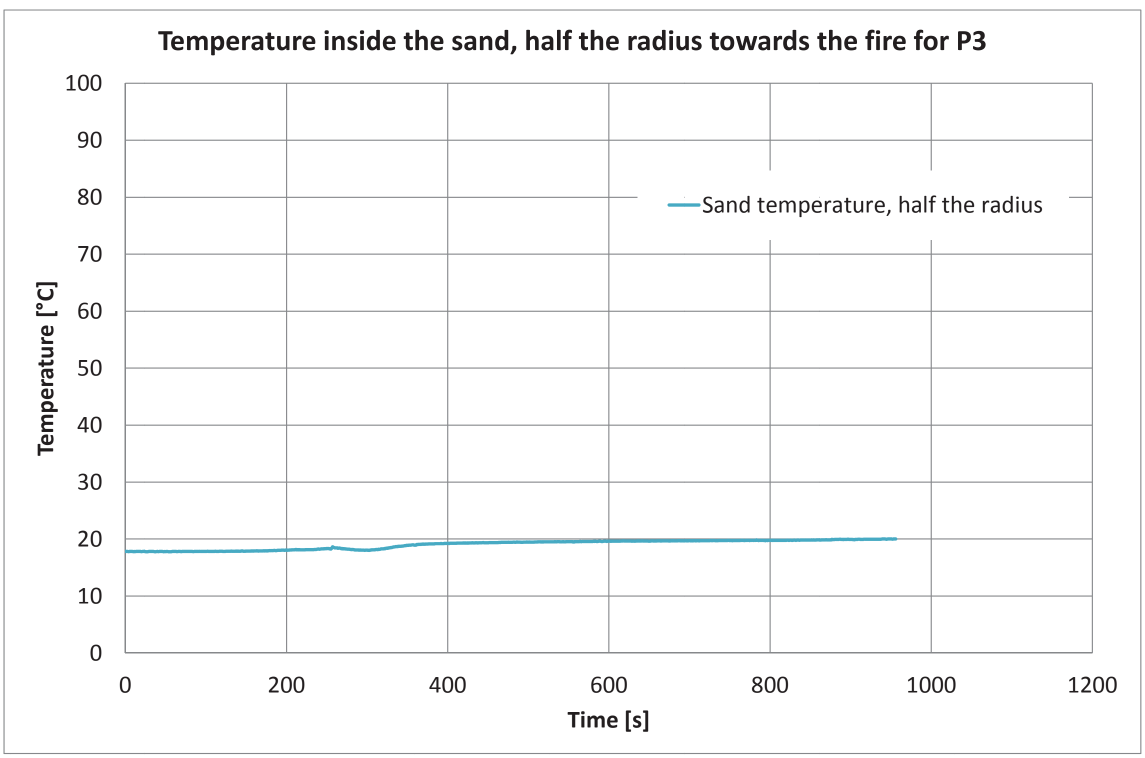

Figure 62. test 14, Temperatures inside the sand, half the radius towards the fire for P3

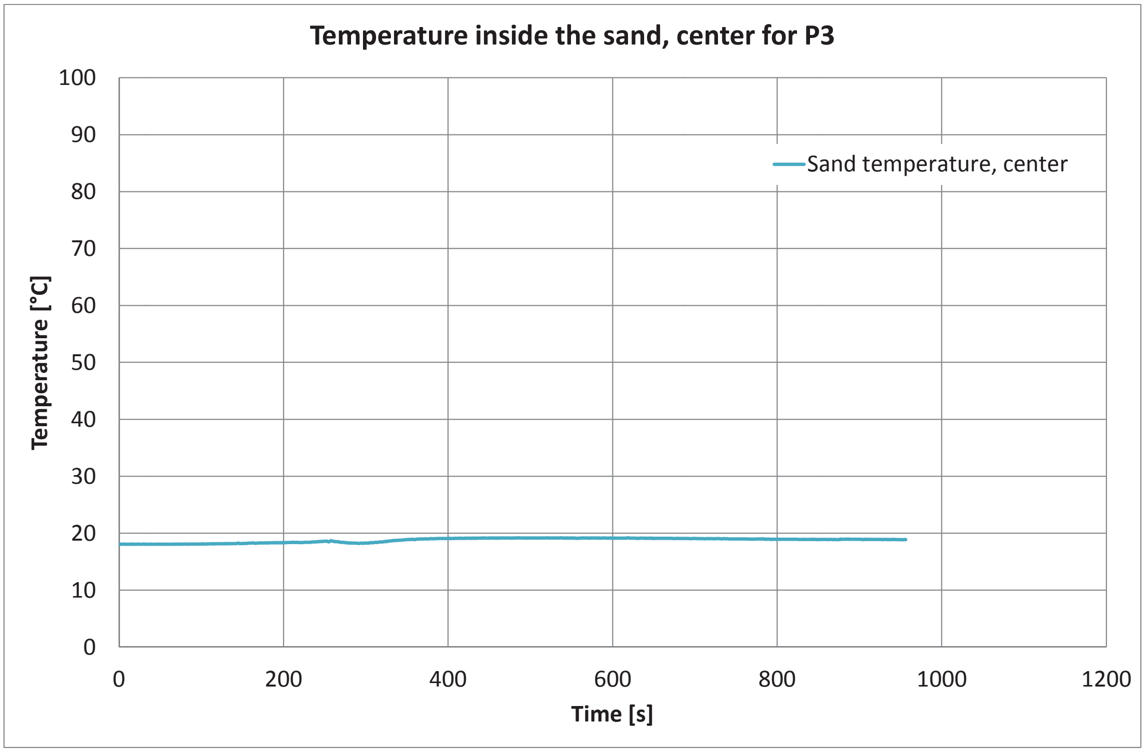

Figure 63. Test 14, Temperatures inside the sand, center for P3

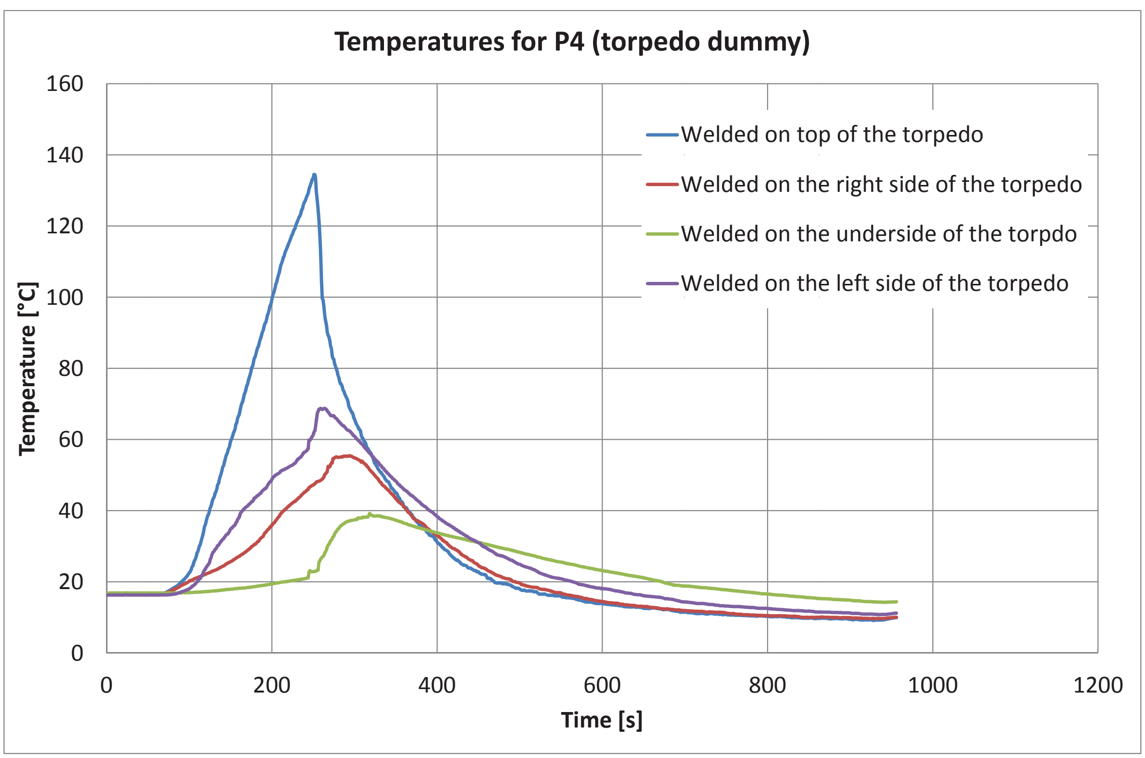

Figure 64. Test 14, Temperatures for P4 (dummy torpedo)

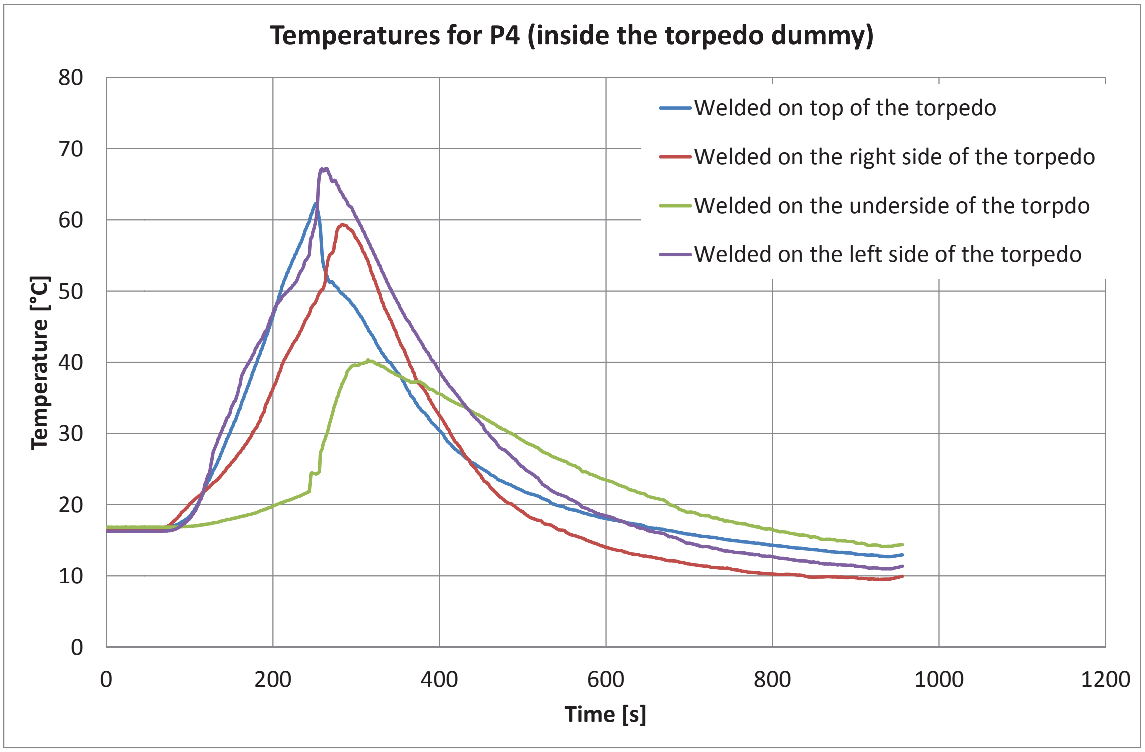

Figure 65. Test 14, Temperatures for P4 (inside the dummy torpedo)

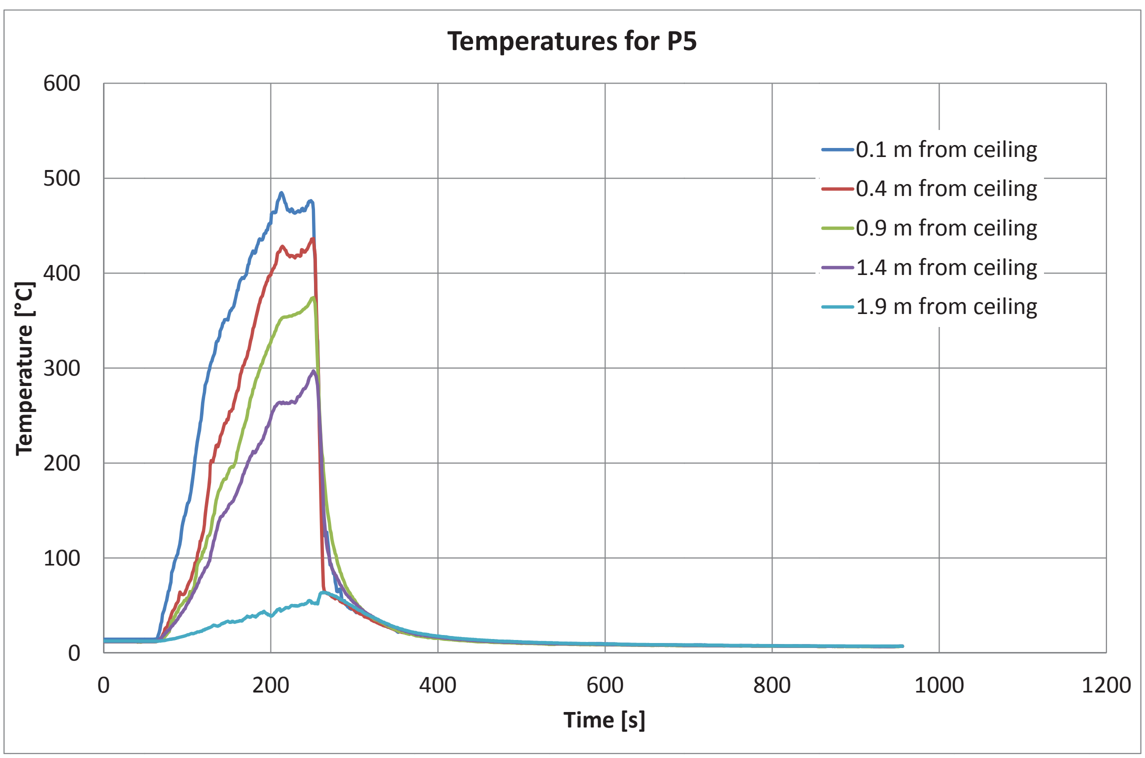

Figure 66. Test 14, Temperatures for P5

Appendix 1

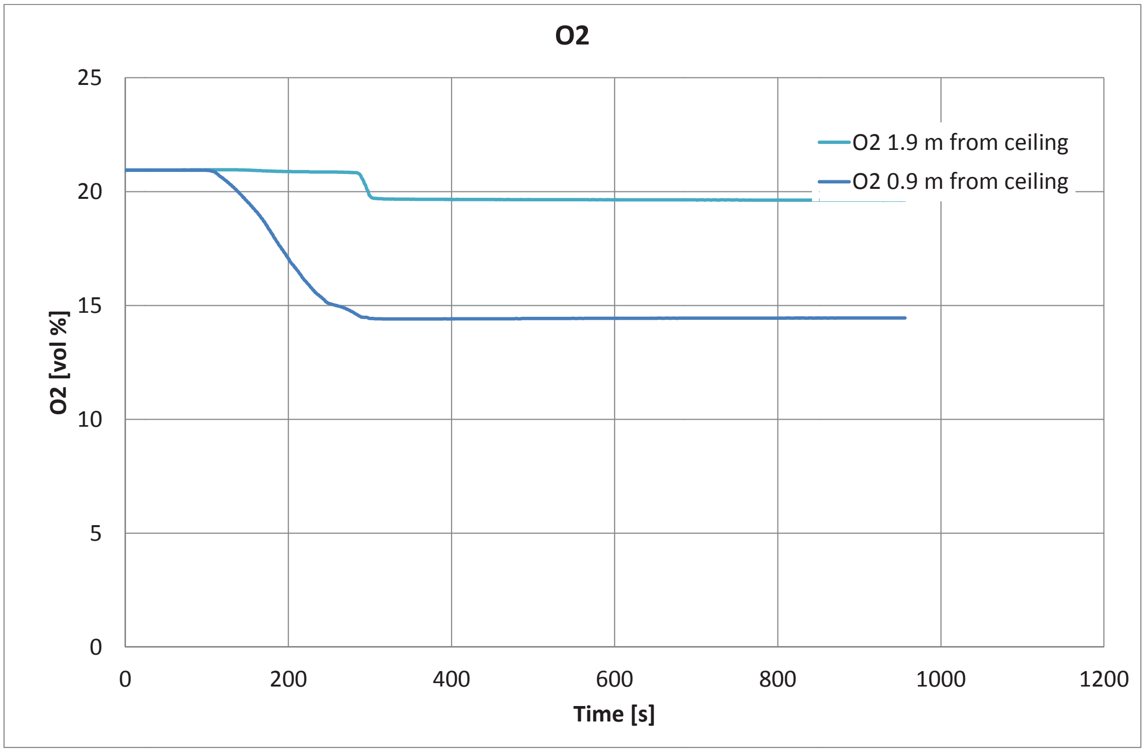

Figure 67. Test 14, O2 level. Not time-adjusted. Problem with the sensor.

Test protocol

Test: 15

Date: 2012-02-01

Test engineer: Michael Rahm, Johan Lindström

Type of test	Sand torpedo, water mist system
Pool fire size (Ø in mm)	1170
Position of pool fire	1
Obstruction (% of pool area)	Torpedo, placed 50mm above pool surface
Amount of diesel (L)	15
Height of freeboard (mm)	25
Water mist nozzle	BETE TF8-170
Bulkhead nozzle	
Drencher nozzle	
Distance from nozzle to pool area	
Pressure (bar)	10
Water flow (L/min)	171
Notes:	
Time (s)	
0	Start measuring program and video camera
60	Ignition
90	Activation of water mist system
94	Full flow of water in the system
100	Suppressed fire (approximately 1 m high flames around the torpedo)
180	70 cm high flames on one side of the torpedo
890	The temperature curve seems to go down
960	The fire was extinguished with foam
1005	The water mist system was activated to cool down the room
	Chanel 17 (P3 torpedo left side) measures 100 °C (water boiling temp. This element is exchanged to next test.

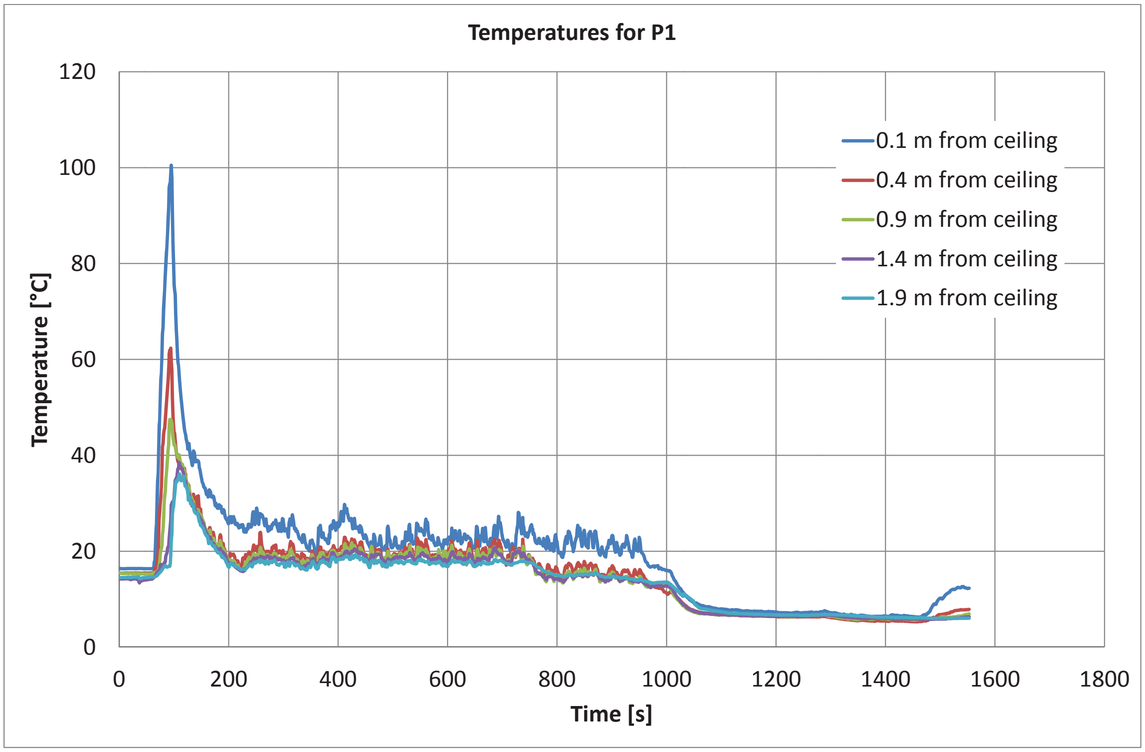

Figure 68. Test 15, Temperatures for P1

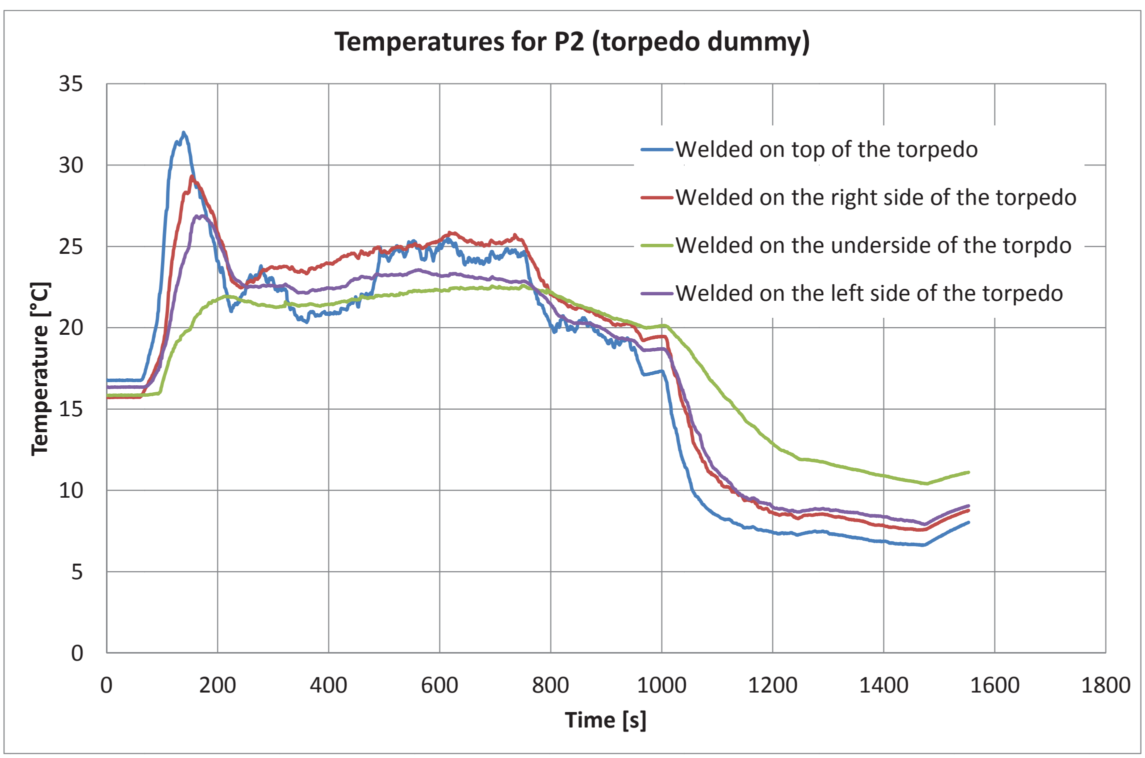

Figure 69. Test 15, Temperatures for P2 (dummy torpedo)

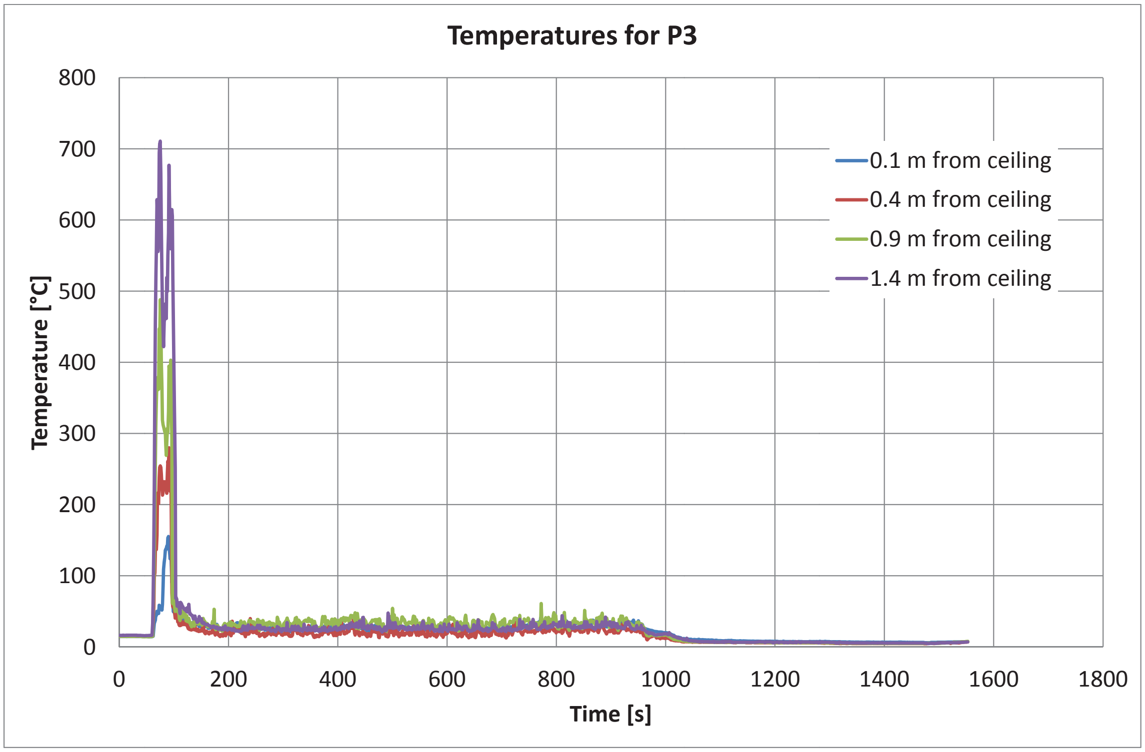

Figure 70. Test 15, Temperatures for P3

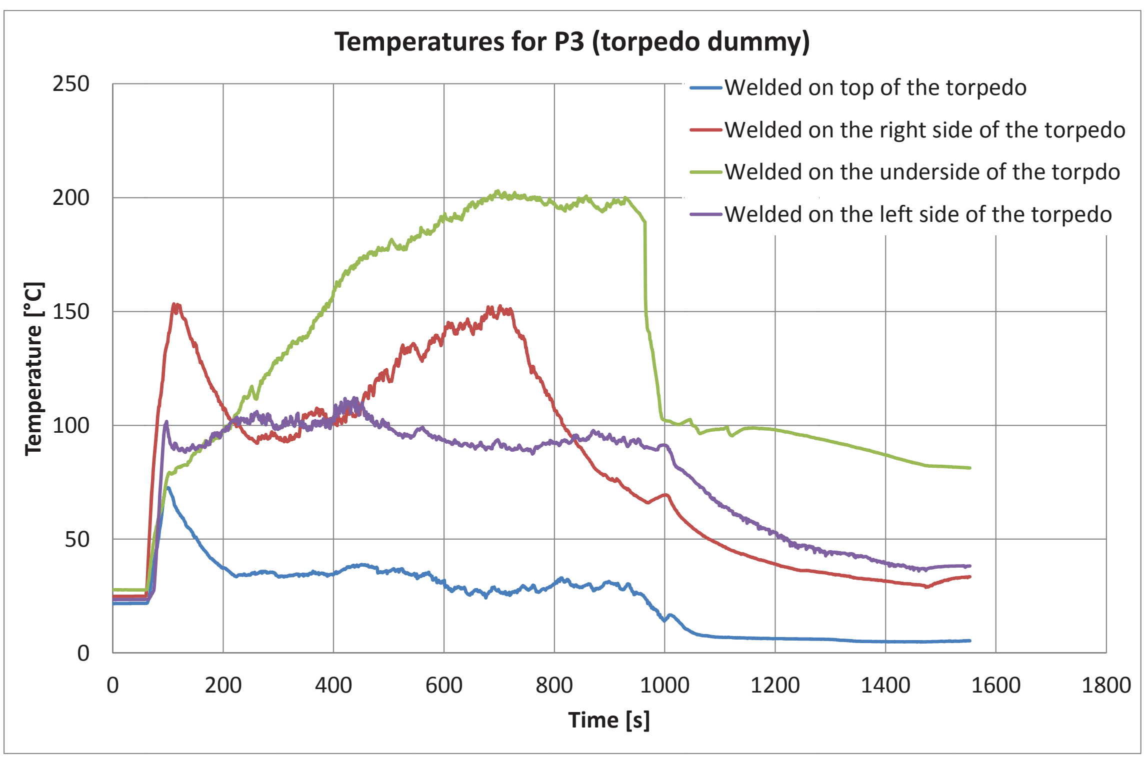

Figure 71. Test 15, Temperatures for P3 (dummy torpedo)

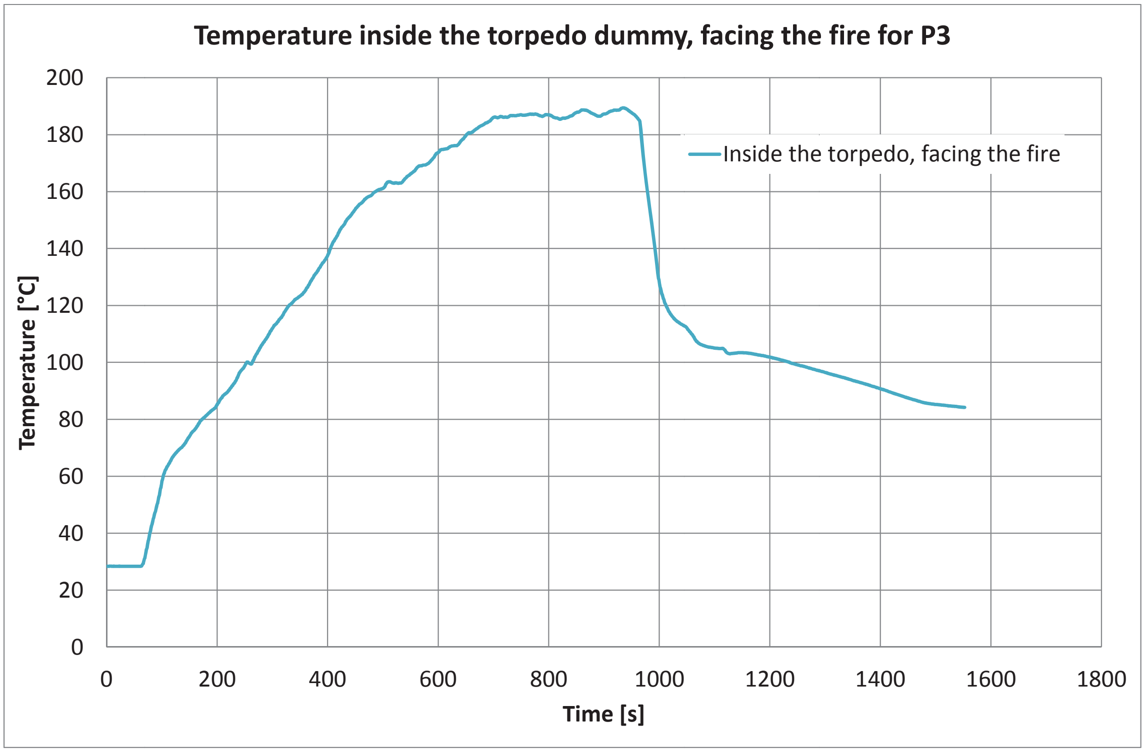

Figure 72. Test 15, Temperature inside the dummy torpedo, facing the fire for P3

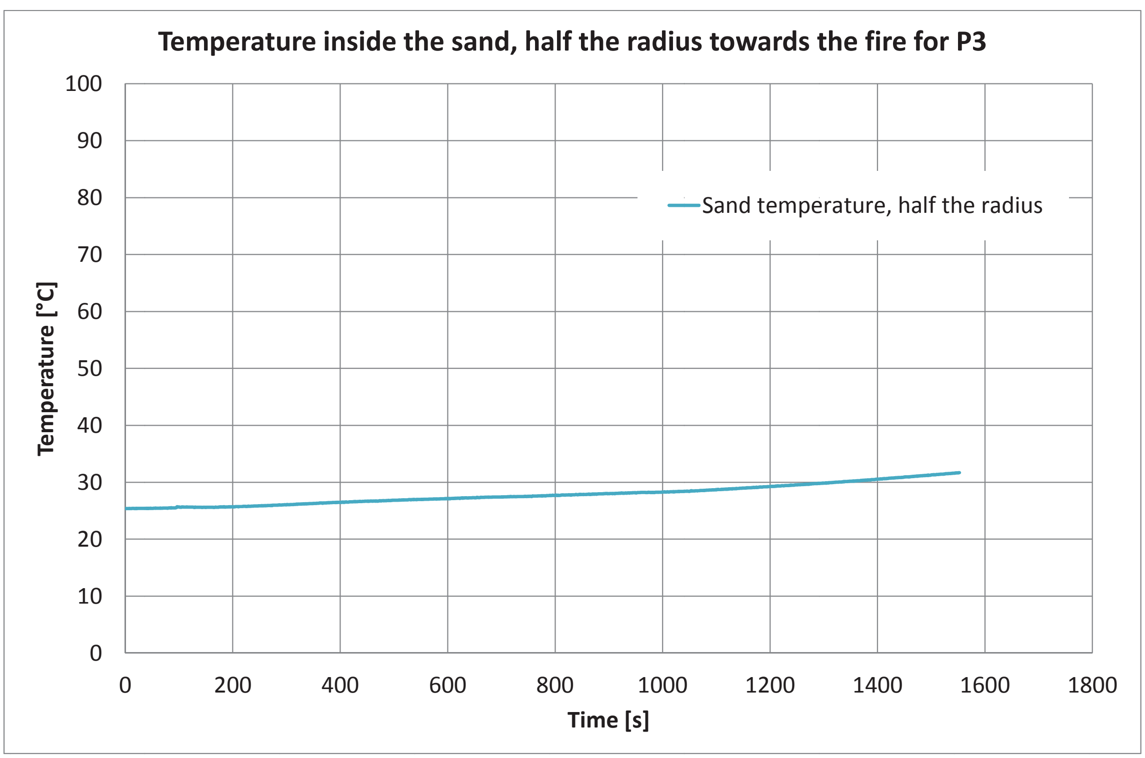

Figure 73. Test 15, Temperature inside the sand, half the radius towards the fire for P3

Appendix 1

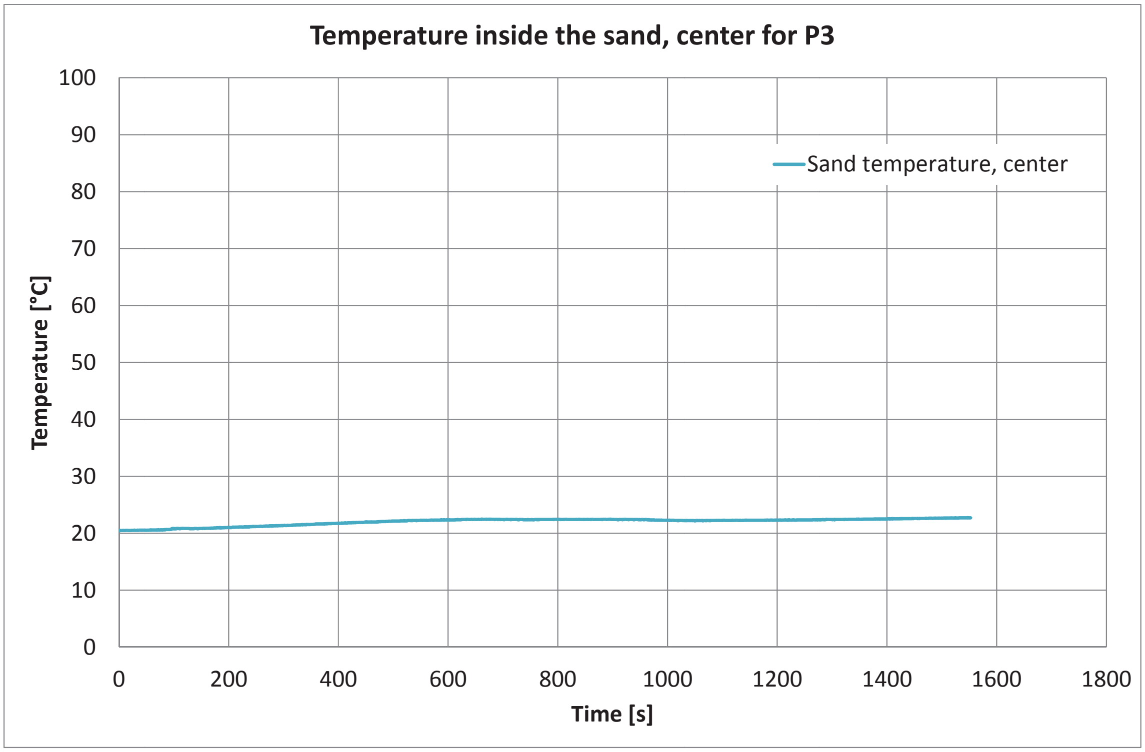

Figure 74. Test 15, Temperature inside the sand, center for P3

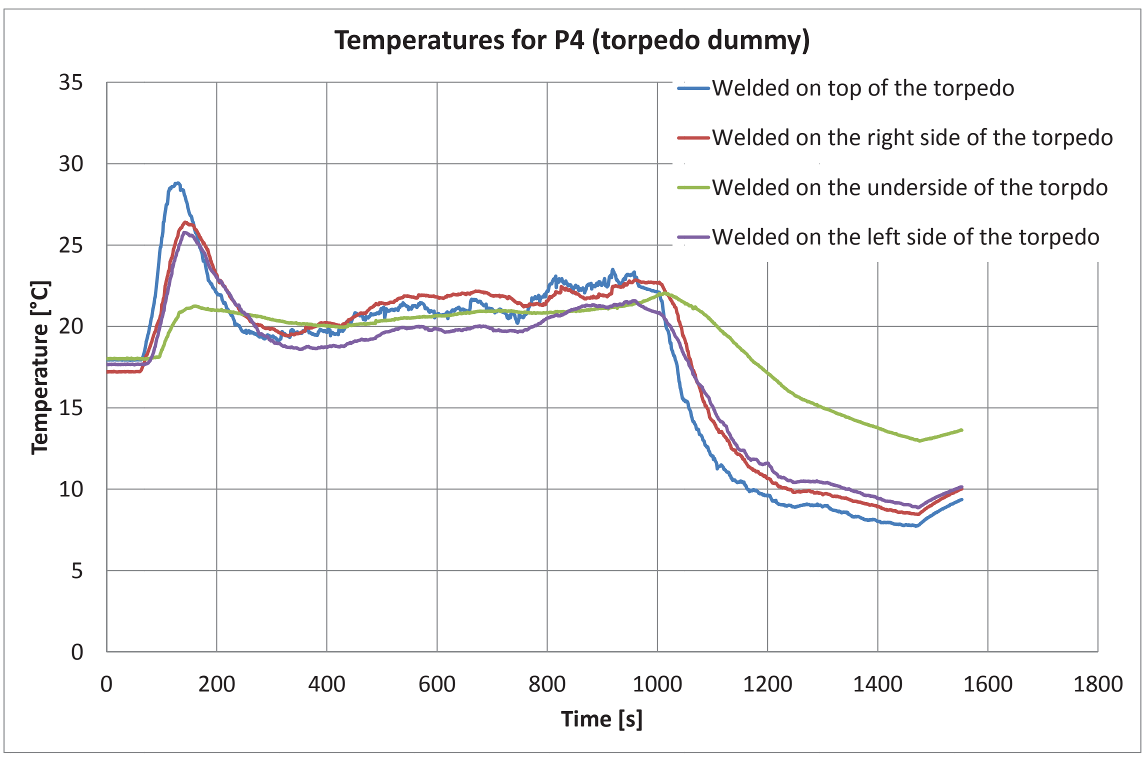

Figure 75. Test 15, Temperatures for P4 (dummy torpedo)

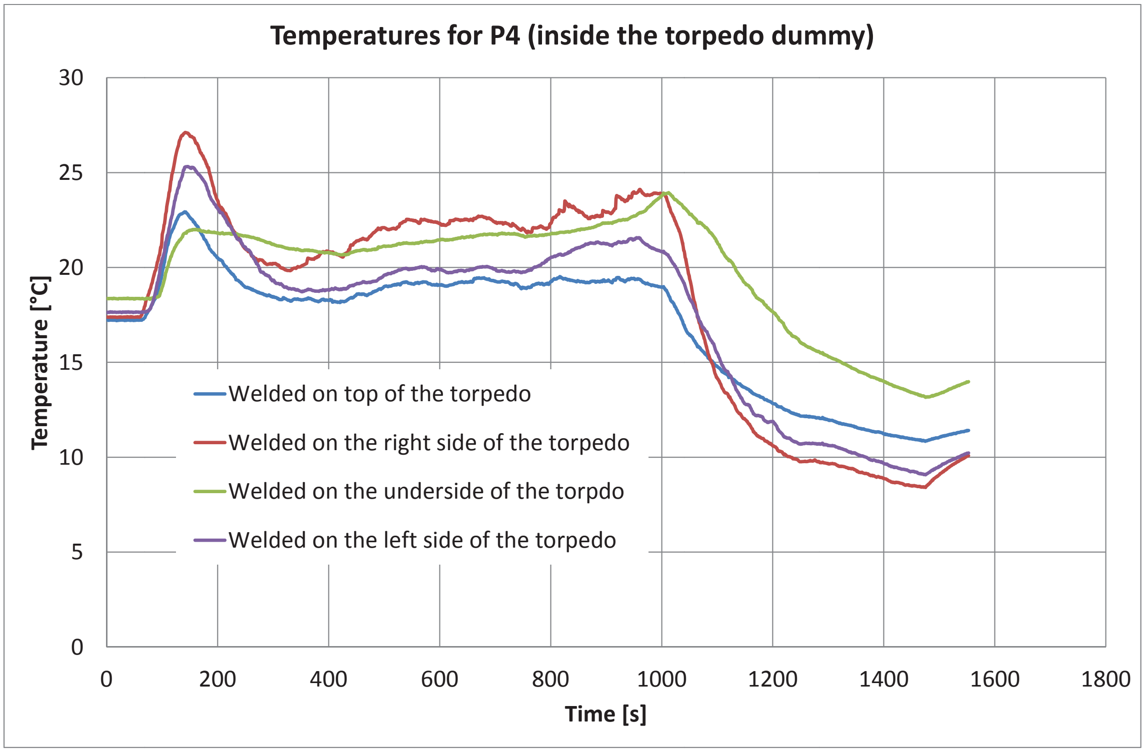

Figure 76. Test 15, Temperatures for P4 (inside the dummy torpedo)

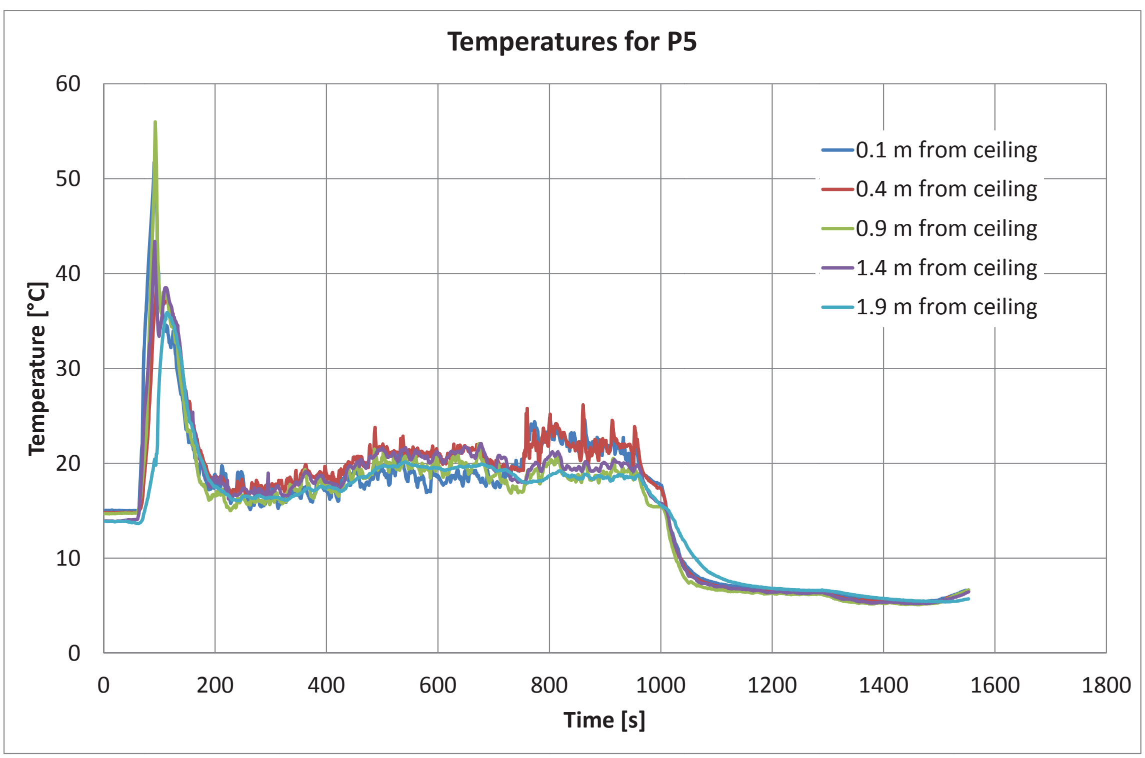

Figure 77. Test 15, Temperatures for P5

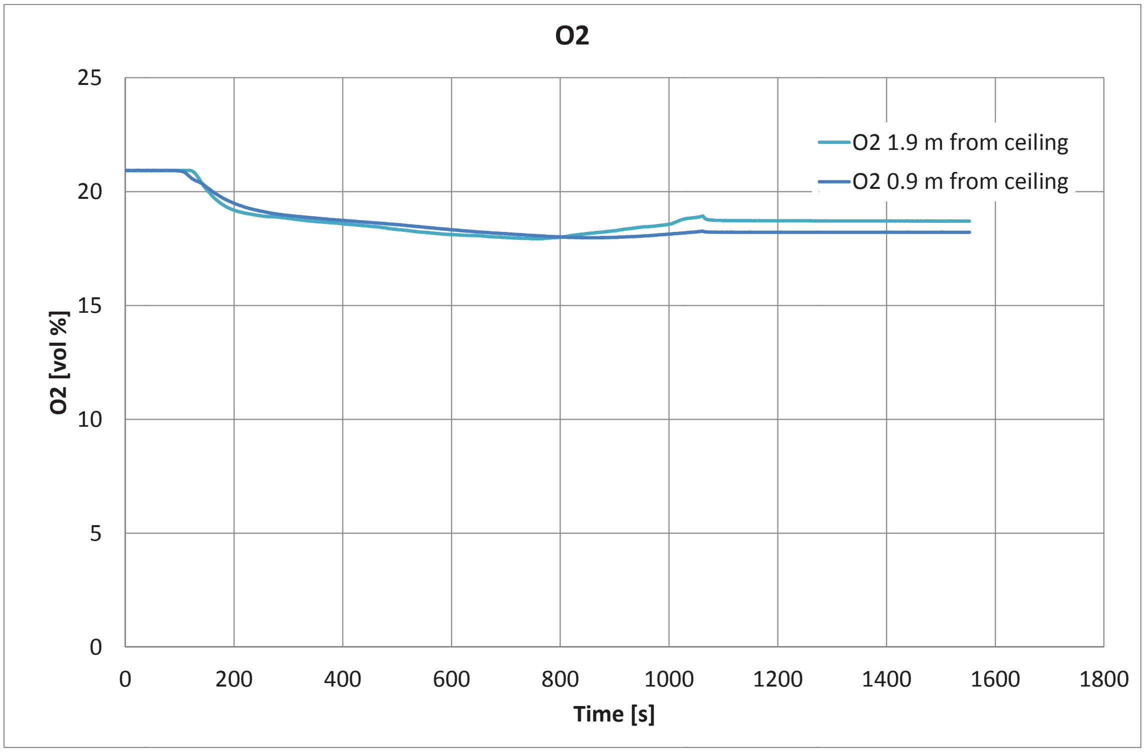

Figure 78. Test 15, O2 level. Not time-adjusted.

Appendix 1

Test protocol

Test: 16

Date: 2012-02-01

Test engineer: Michael Rahm, Johan Lindström

Type of test	Sand torpedo, drencher system 32 mm/min
Pool fire size (Ø in mm)	1170
Position of pool fire	1
Obstruction (% of pool area)	Torpedo, placed 50mm above pool surface
Amount of diesel (L)	10
Height of freeboard (mm)	25
Water mist nozzle	
Bulkhead nozzle	
Drencher nozzle	LECHLER 460.928
Distance from nozzle to pool area	
Pressure (bar)	10
Water flow (L/min)	157
Notes:	
Time (s)	
0	Start measuring program and video camera
60	Ignition
90	Activation of drencher system
114	The fire was extinguished
360	The water flow to the drencher nozzles was stopped
	Might be some problems with the O_2 measurement 900 mm from ceiling. Separate test to see the response time will be run.

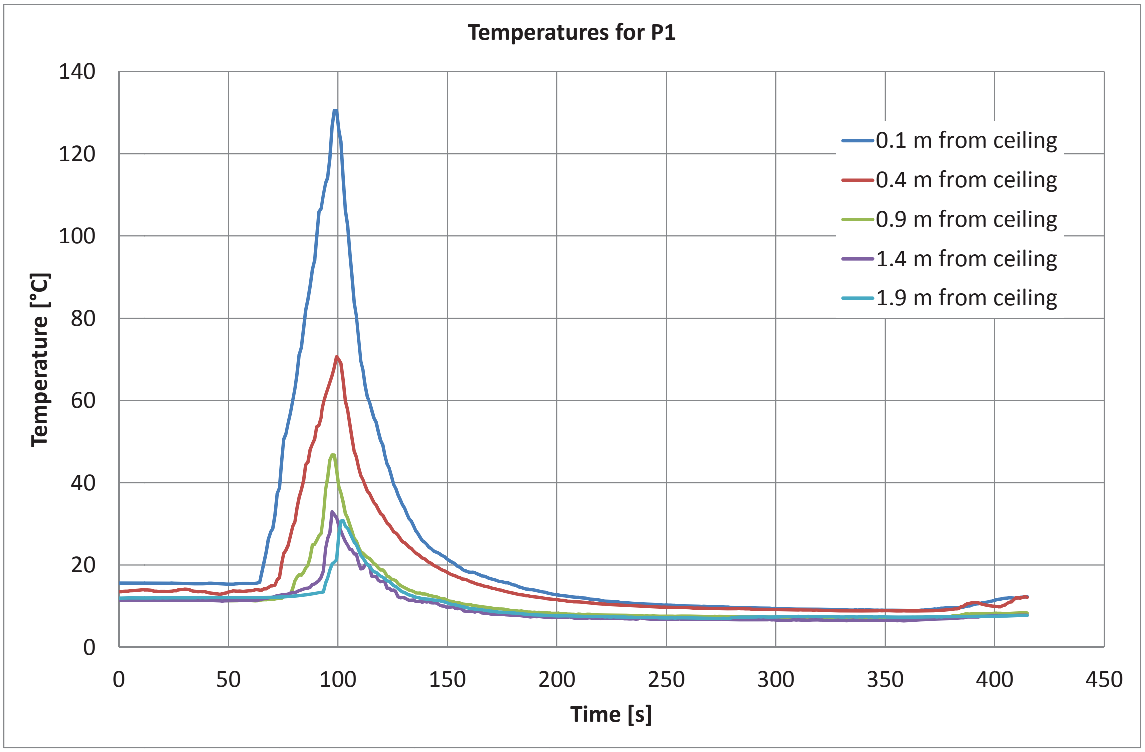

Figure 79. Test 16, Temperatures for P1

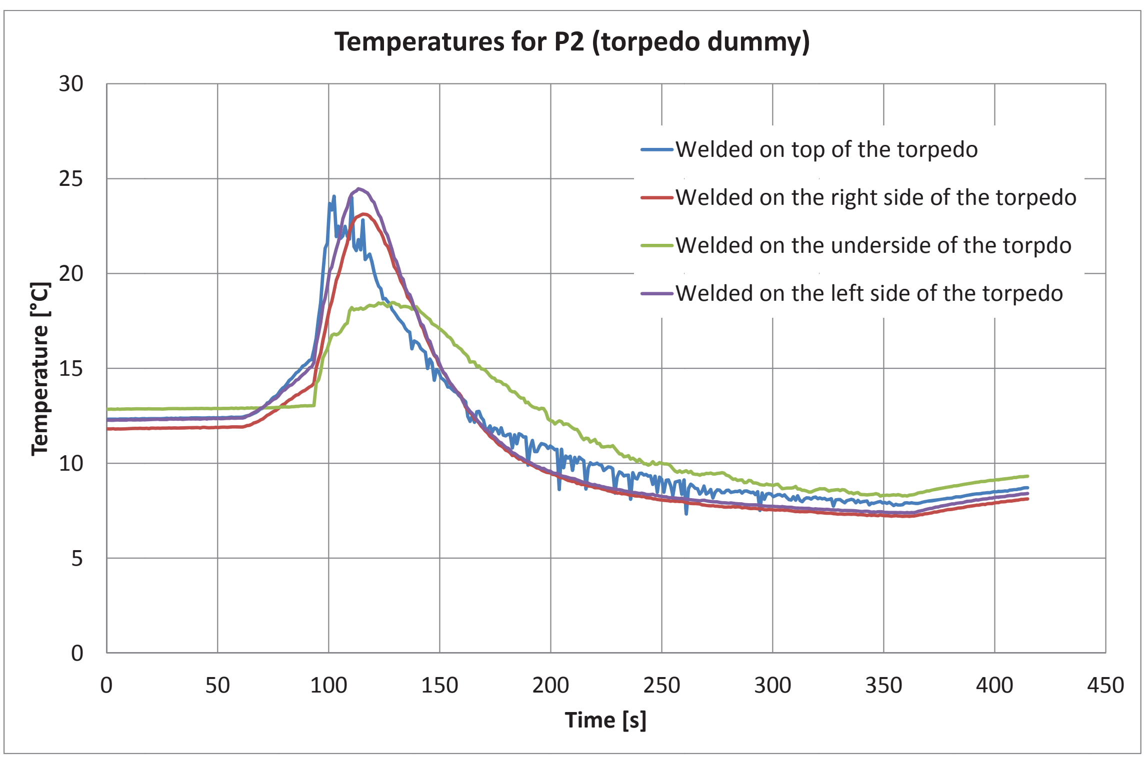

Figure 80. Test 16, Temperatures for P2 (dummy torpedo)

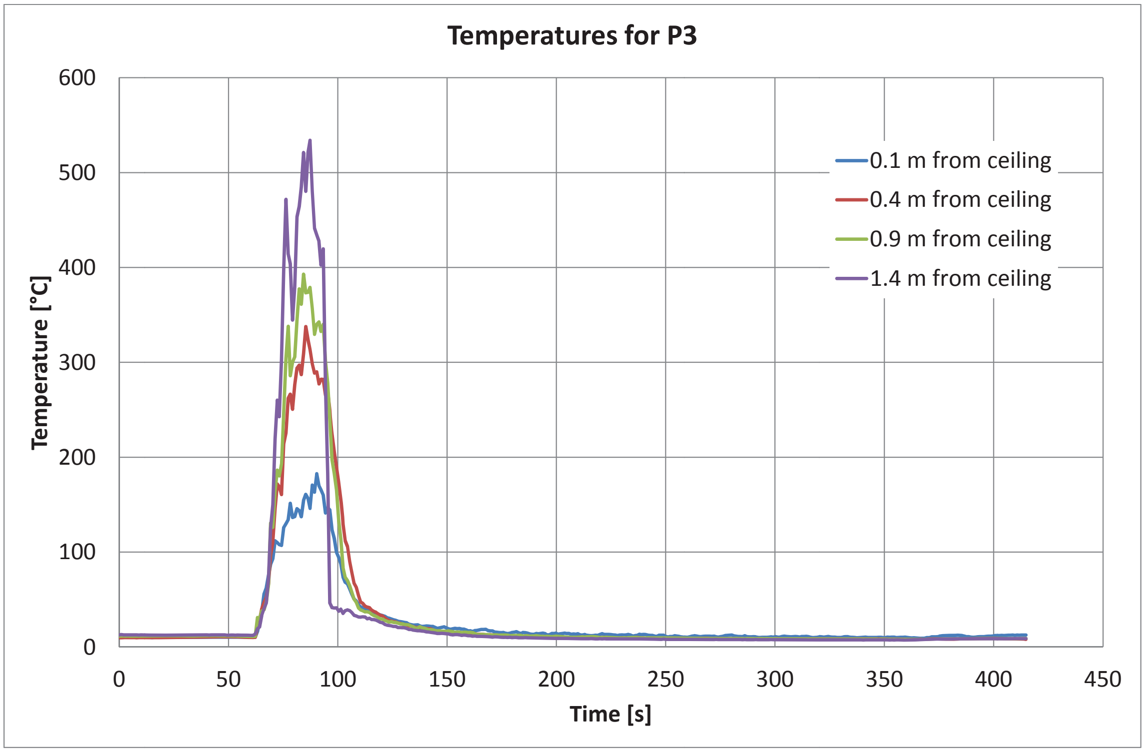

Figure 81. Test 16, Temperatures for P3

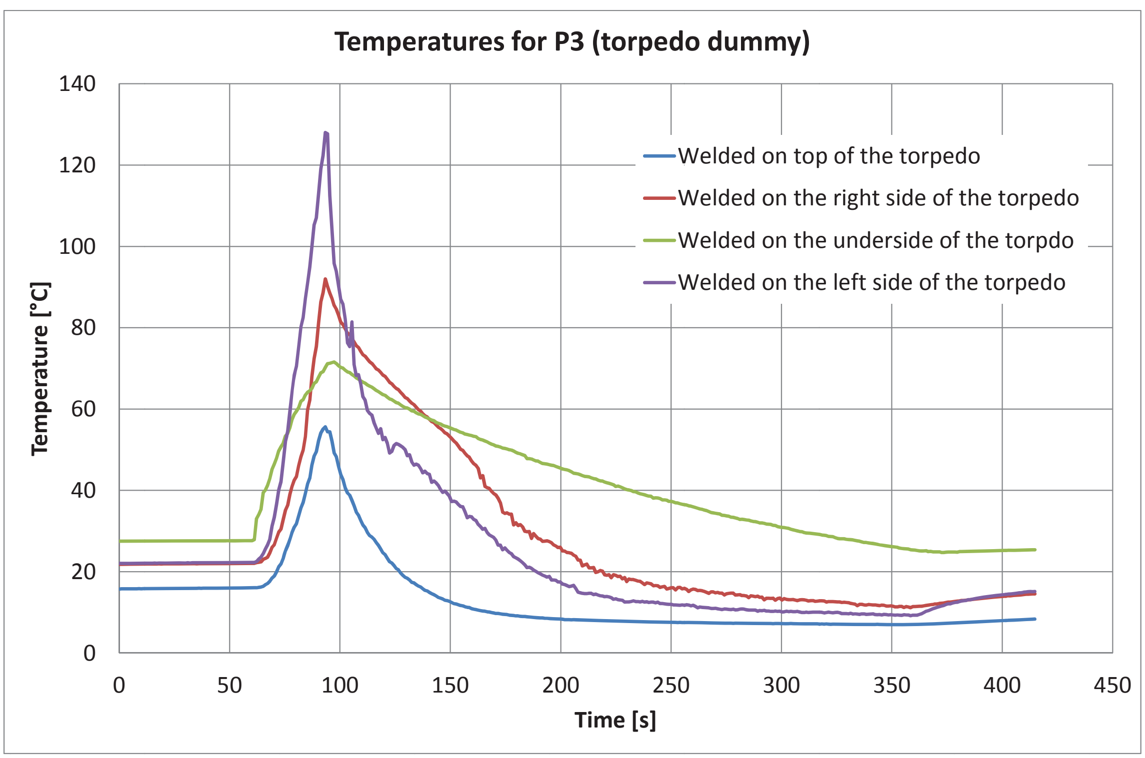

Figure 82. Test 16, Temperatures for P3 (dummy torpedo)

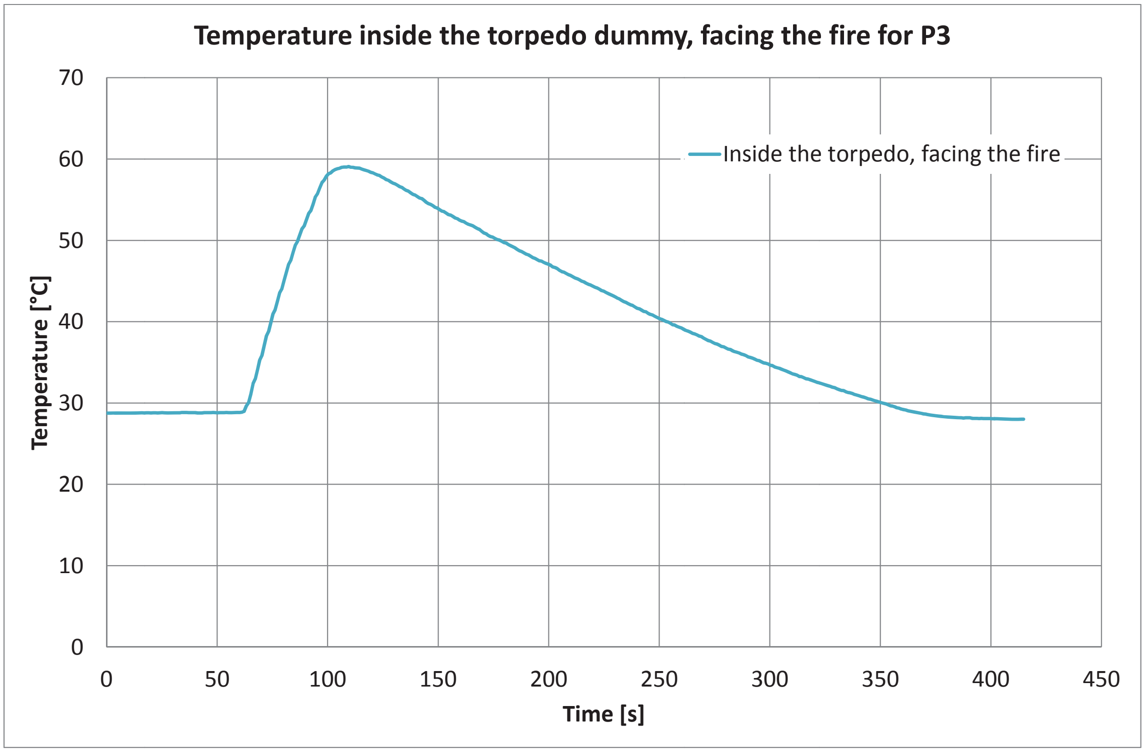

Figure 83. Test 16, Temperature inside the torpedo, facing the fire for P3

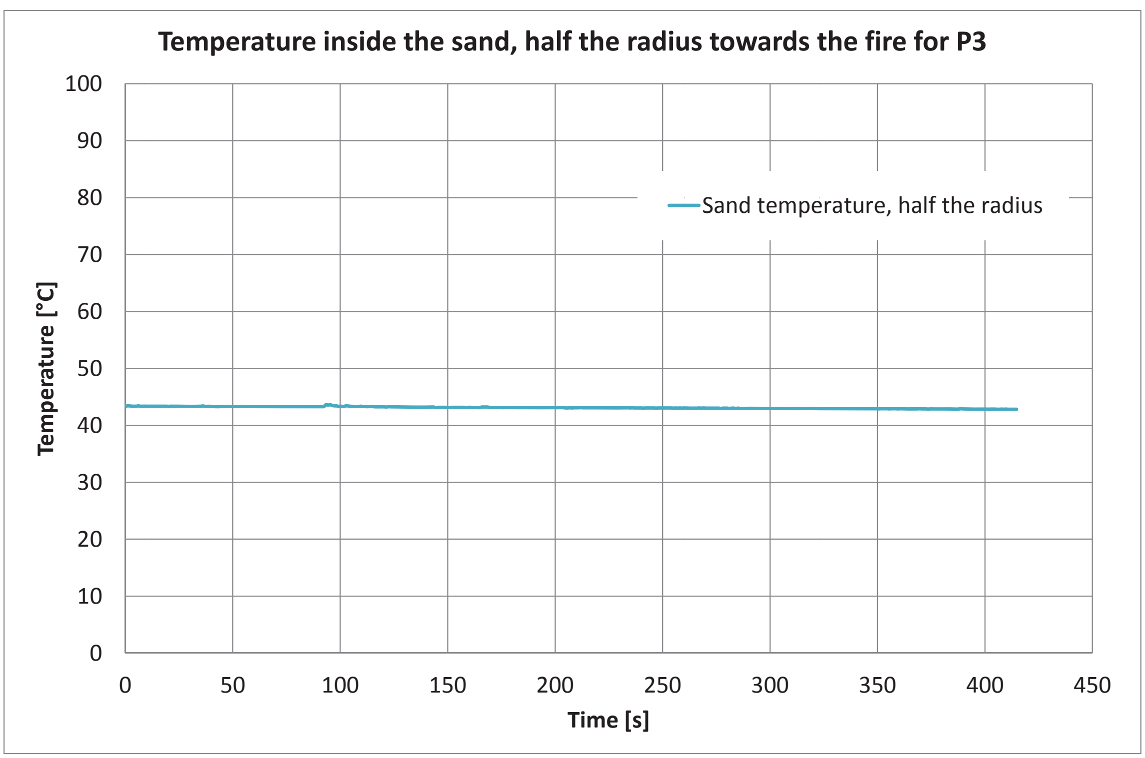

Figure 84. Test 16, Temperature inside the sand, half the radius towards the fire for P3

Appendix 1

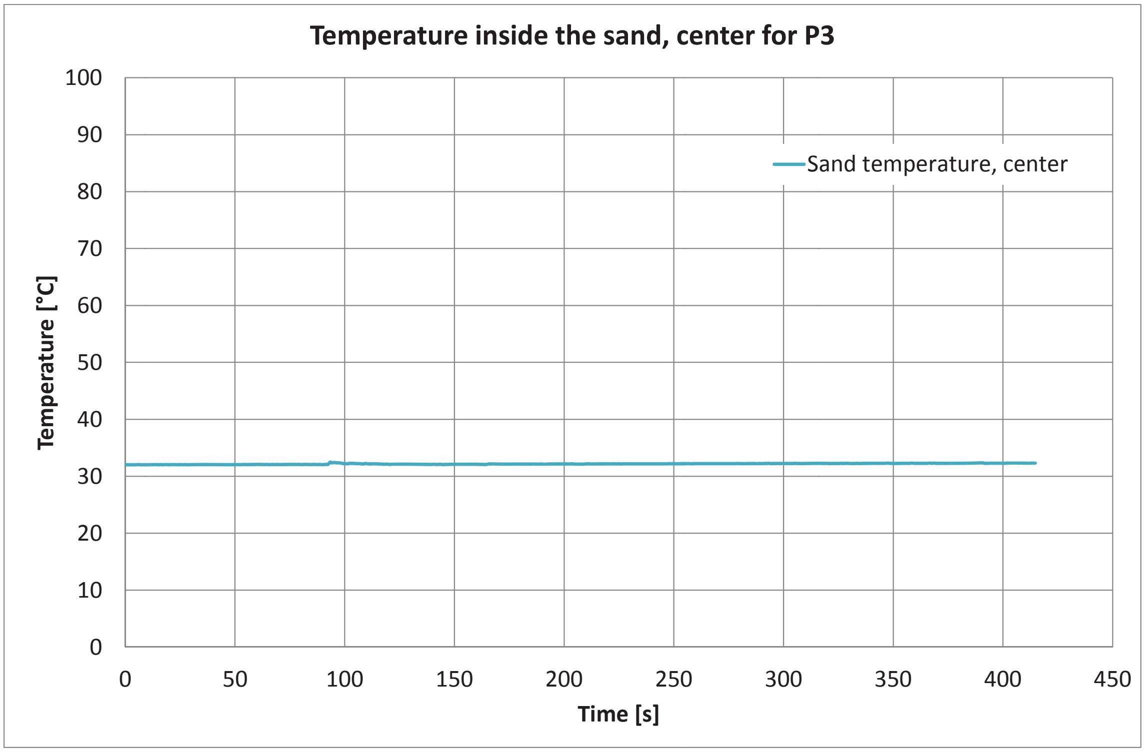

Figure 85. Test 16, Temperature inside the sand, center for P3

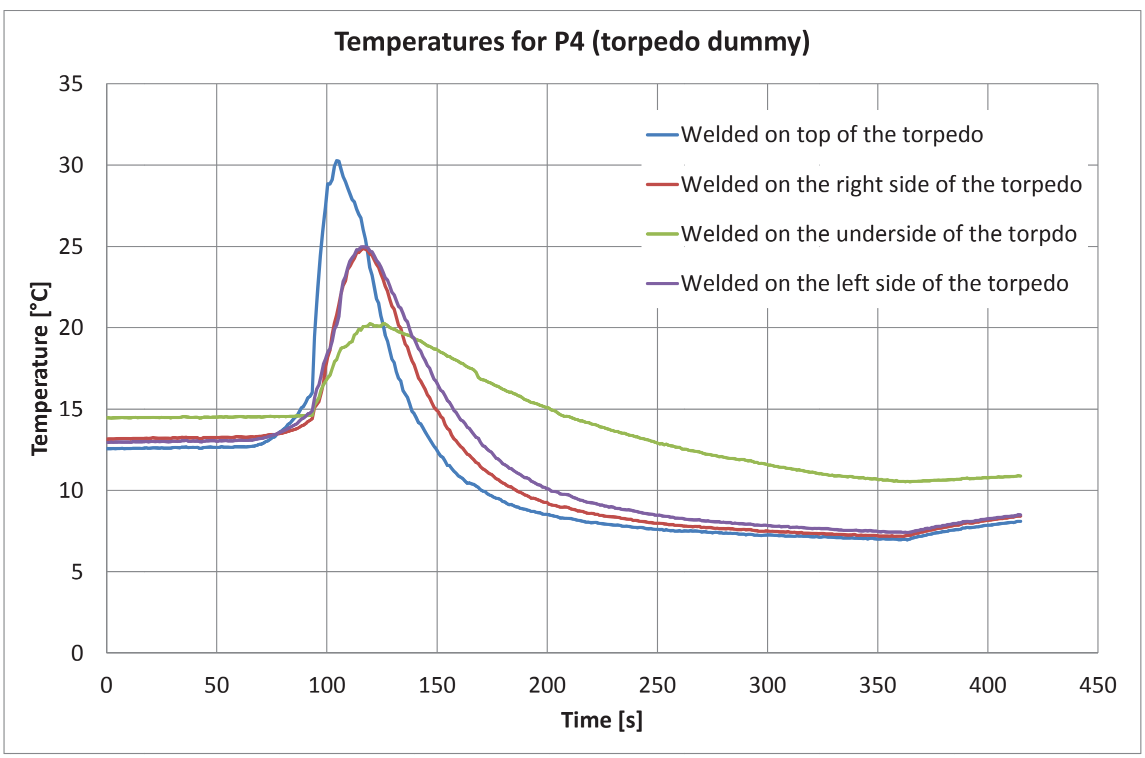

Figure 86. Test 16, Temperatures for P4 (dummy torpedo)

Appendix 1

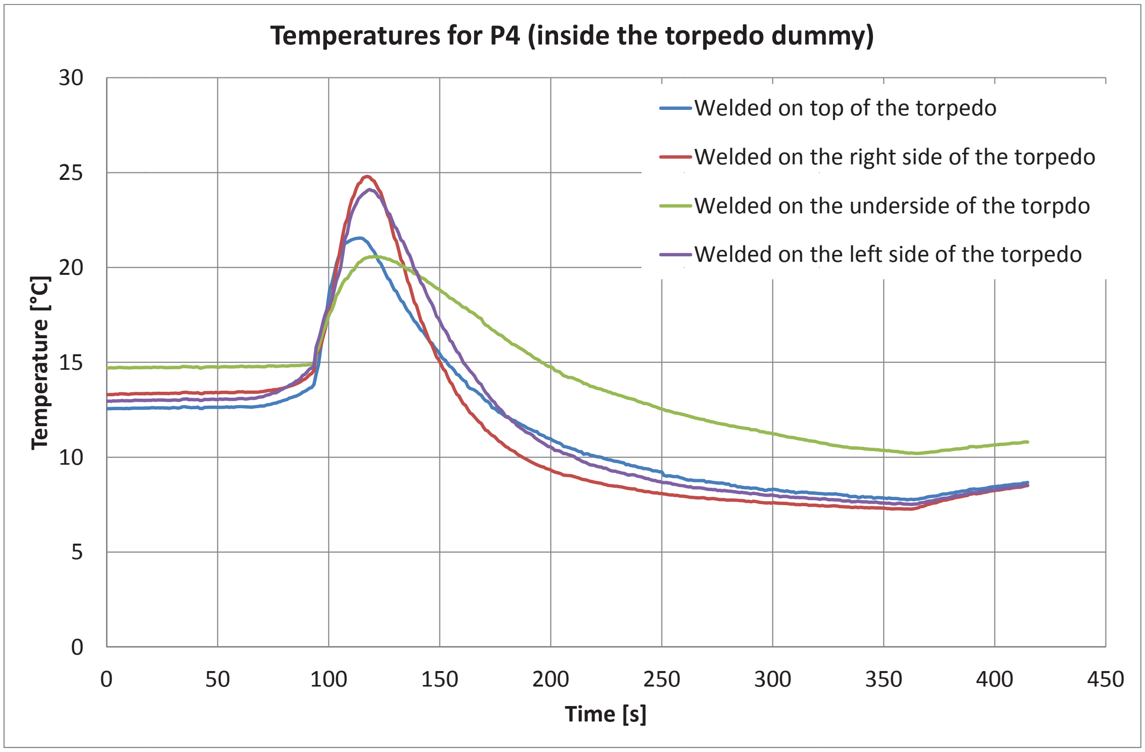

Figure 87. Test 16, Temperatures for P4 (inside the dummy torpedo)

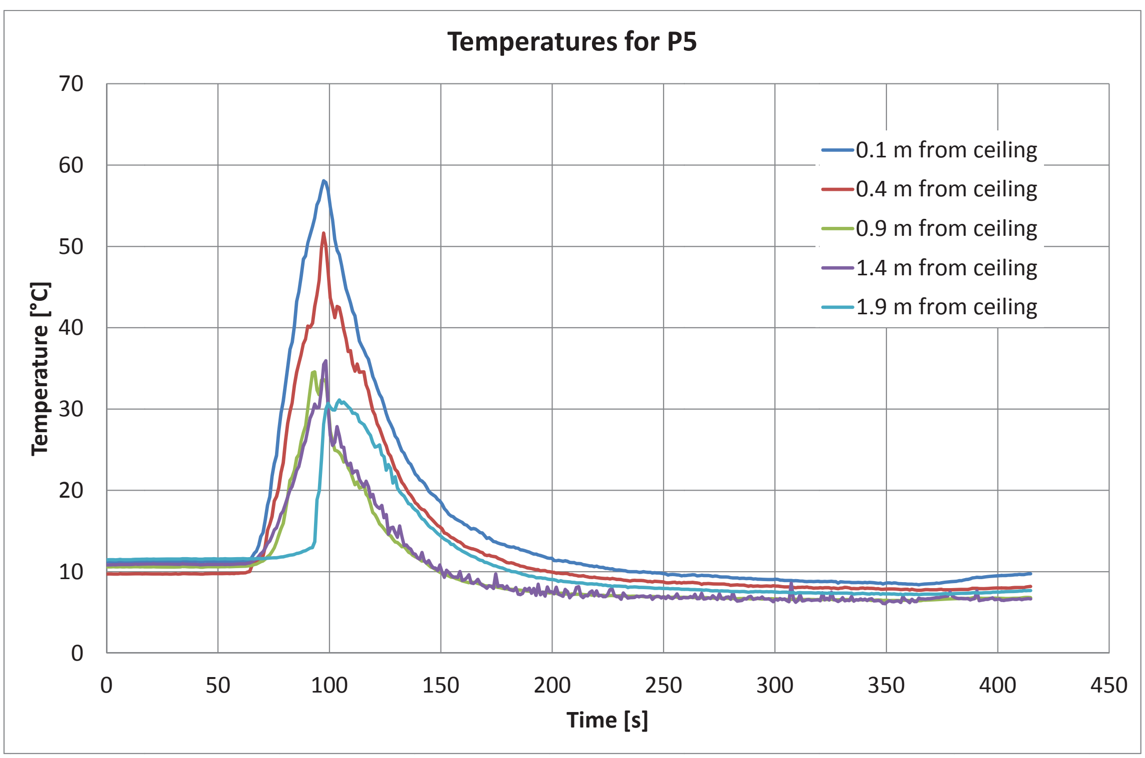

Figure 88. Test 16, Temperatures for P5

Appendix 1

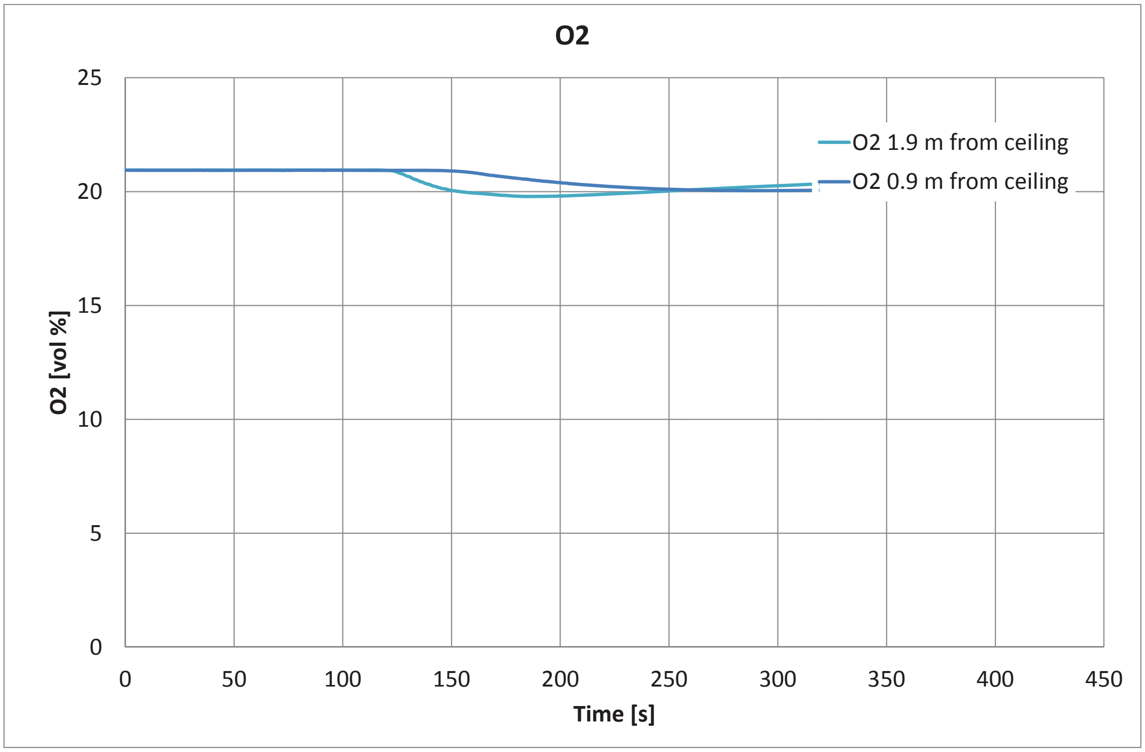

Figure 89. Test 16, O2 level. Not time-adjusted

Appendix 1

Test protocol

Test: 17

Date: 2012-02-02

Test engineer: Michael Rahm, Johan Lindström

Type of test	Sand torpedo, drencher system 10 mm/min
Pool fire size (Ø in mm)	1170
Position of pool fire	1
Obstruction (% of pool area)	Torpedo, placed 50mm above pool surface
Amount of diesel (L)	15
Height of freeboard (mm)	25
Water mist nozzle	
Bulkhead nozzle	
Drencher nozzle	LECHLER 460.728
Distance from nozzle to pool area	172 cm
Pressure (bar)	10
Water flow (L/min)	51
Notes:	
Time (s)	
0	Start measuring program and video camera
60	Ignition
90	Activation of drencher system
110	Small flames at the edge of the pool area
135	The fire was extinguished
360	The water flow to the drencher nozzles was stopped
	Might be some problems with the O_2 measurement 900 mm from ceiling. Separate test to see the response time will be run.

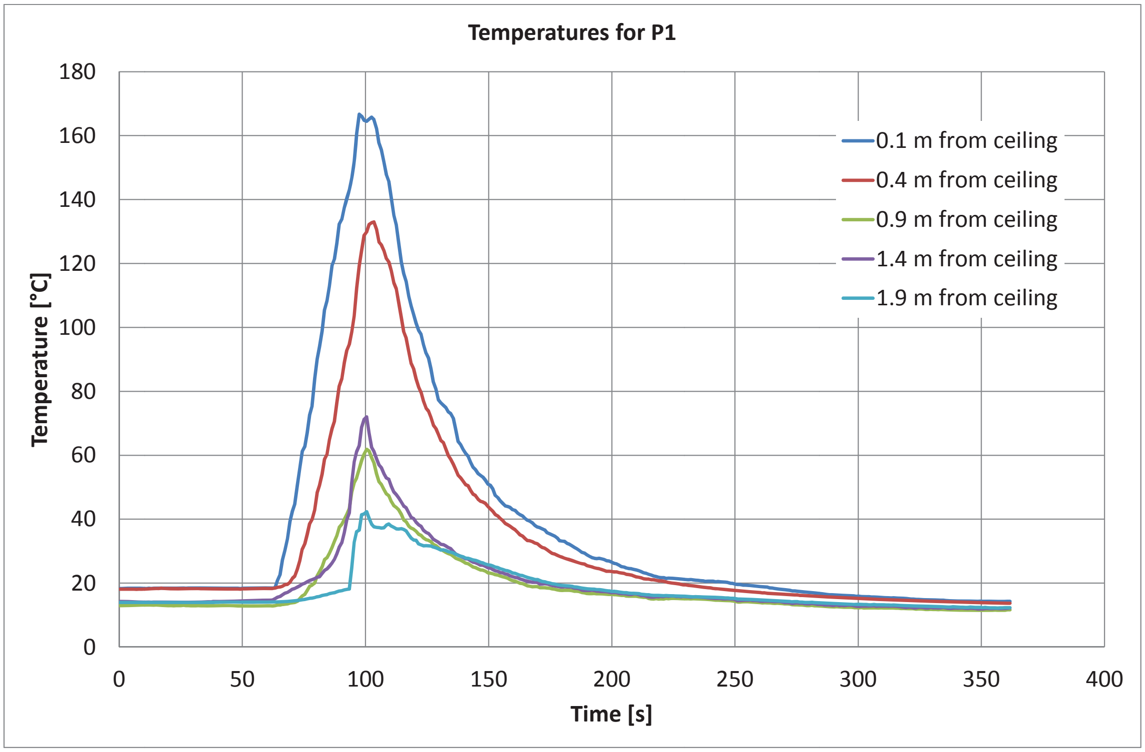

Figure 90. Test 17, Temperatures for P1

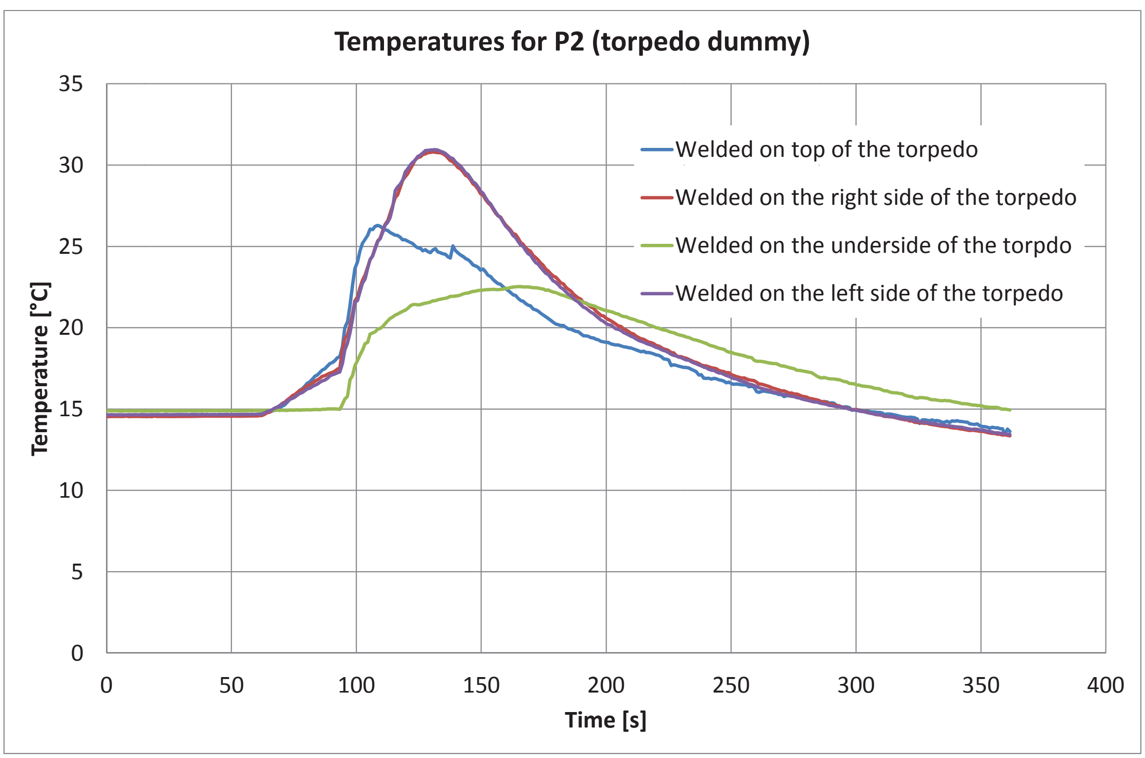

Figure 91. Test 17, Temperatures for P2 (dummy torpedo)

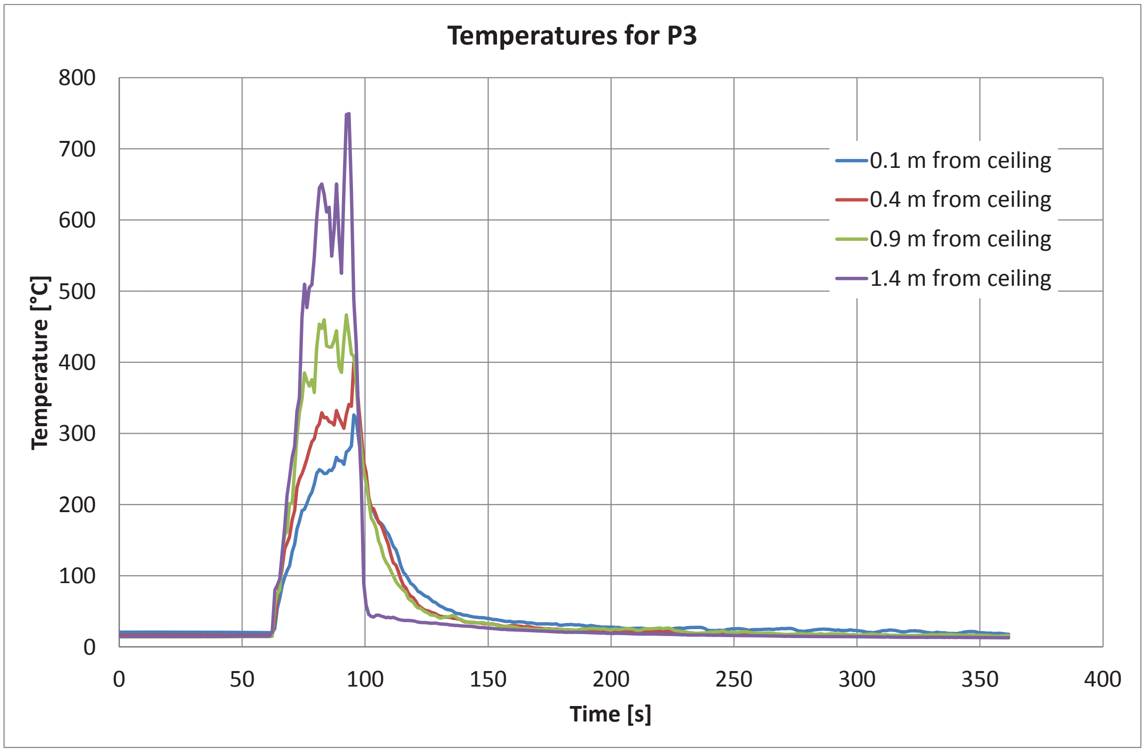

Figure 92. Test 17, Temperatures for P3

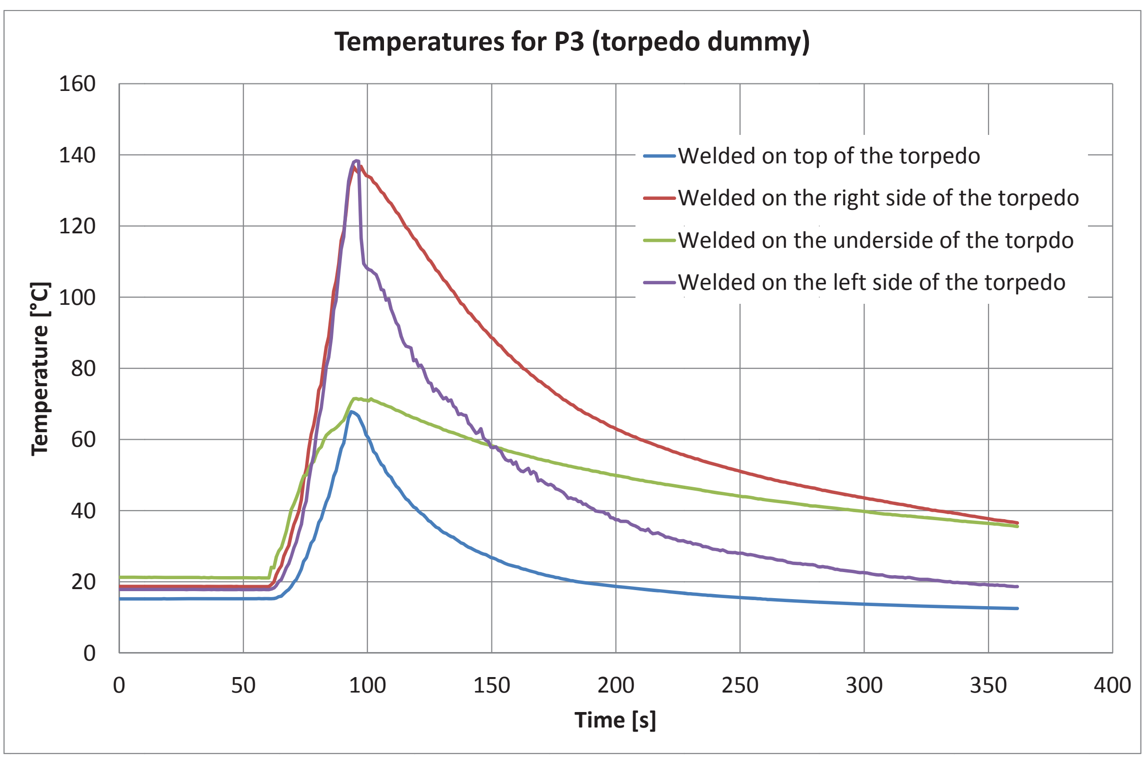

Figure 93. Test 17, Temperatures for P3 (dummy torpedo)

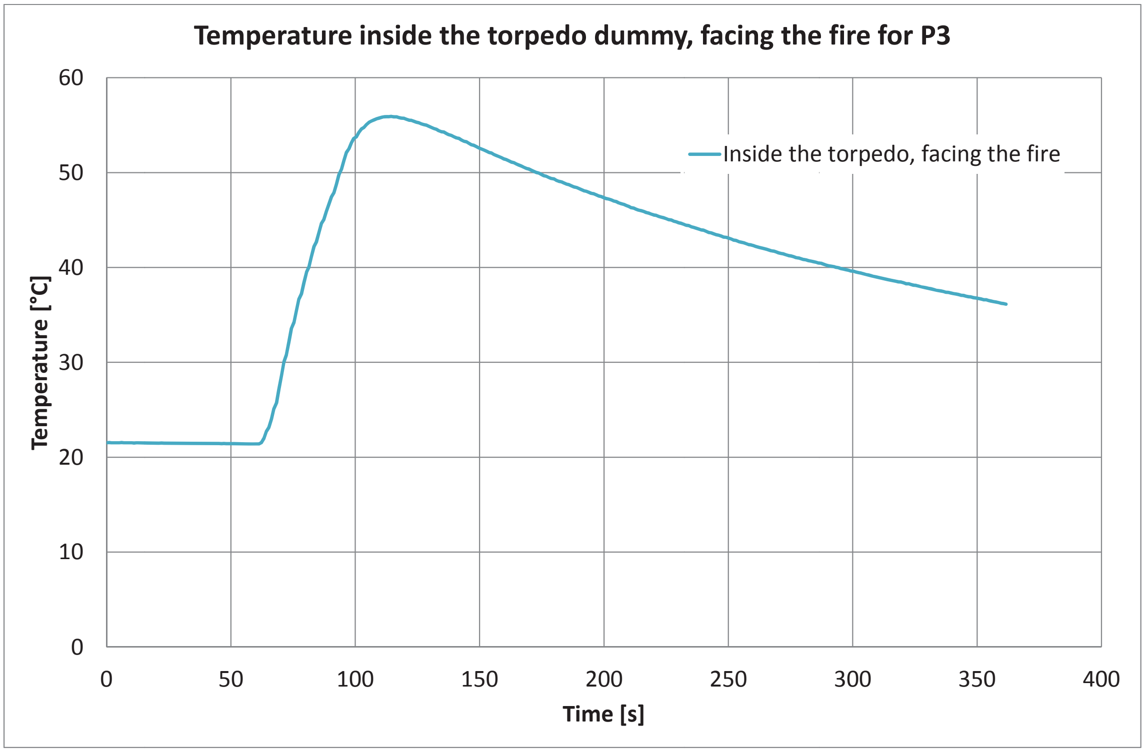

Figure 94. Test 17, Temperature inside the torpedo dummy, facing the fire for P3

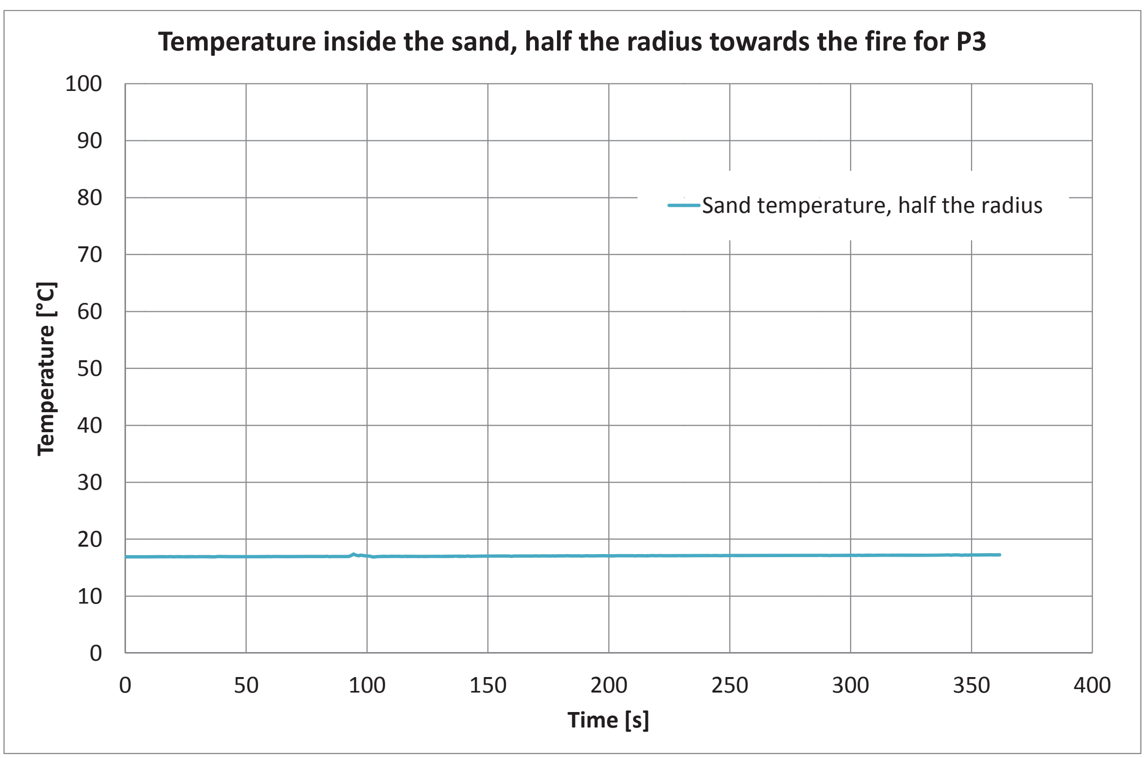

Figure 95. Test 17, Temperature inside the sand, half the radius towards the fire for P3

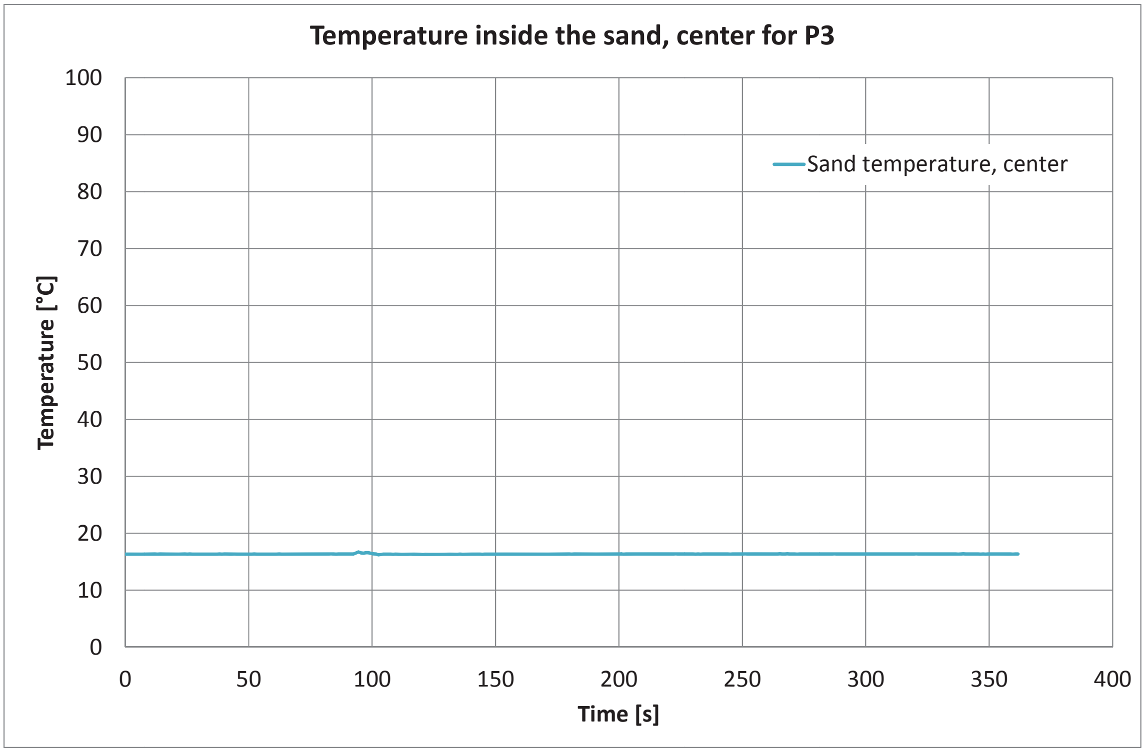

Figure 96. Test 17, Temperature inside the sand, center for P3

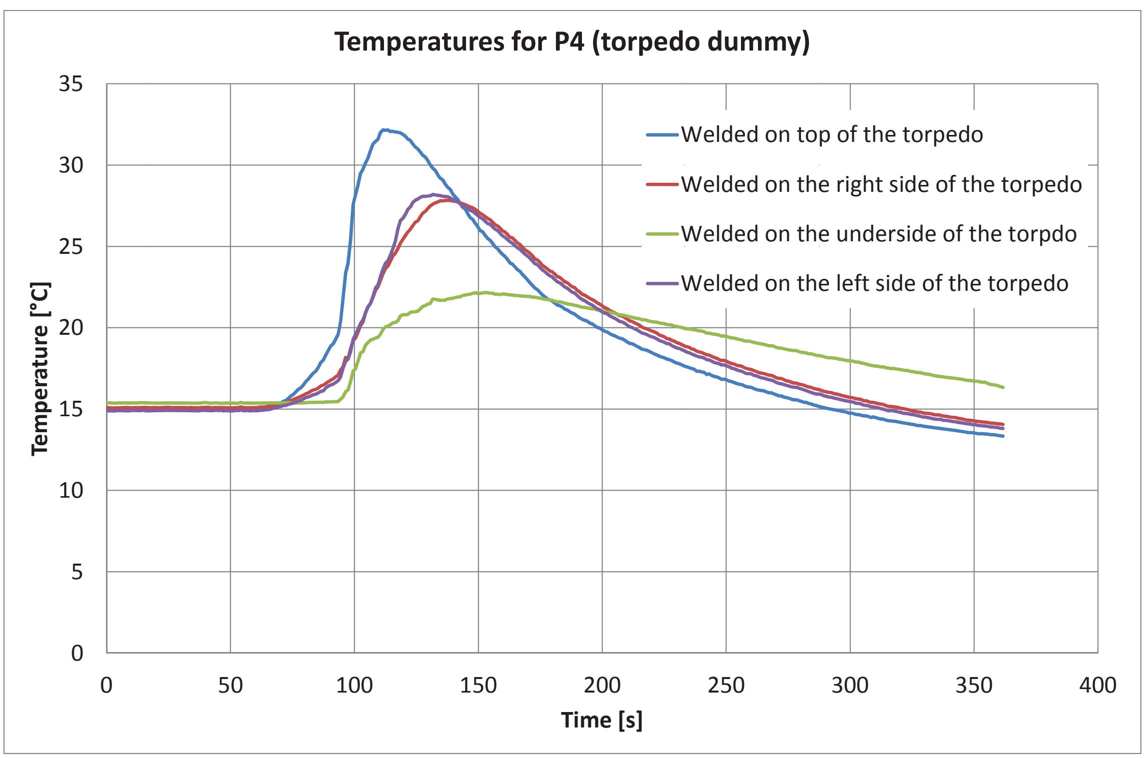

Figure 97. Test 17, Temperatures for P4 (dummy torpedo)

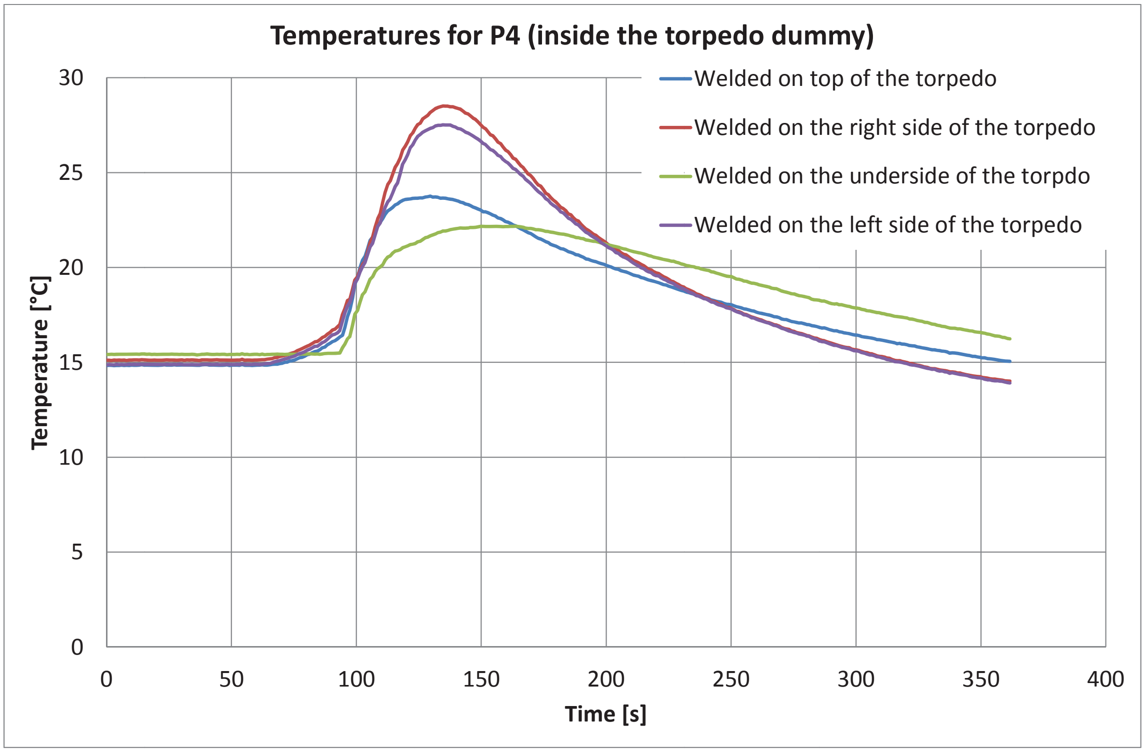

Figure 98. Temperatures for P4 (inside the dummy torpedo)

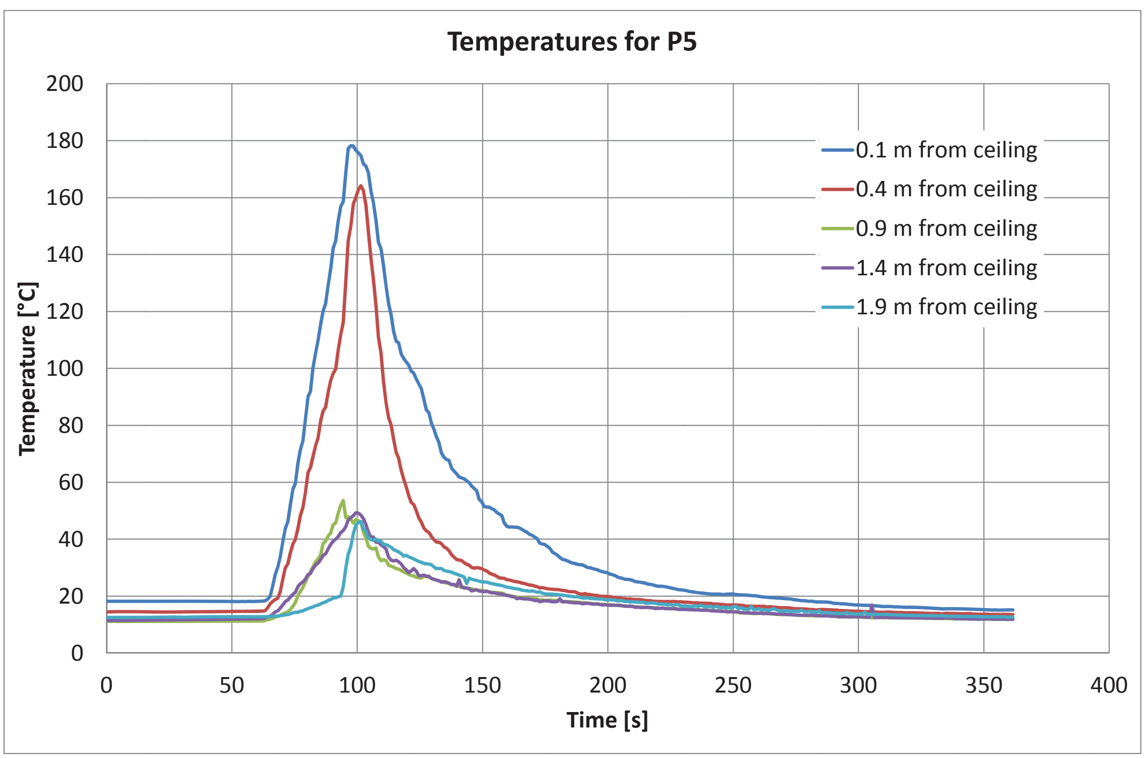

Figure 99. Test 17, Temperatures for P5

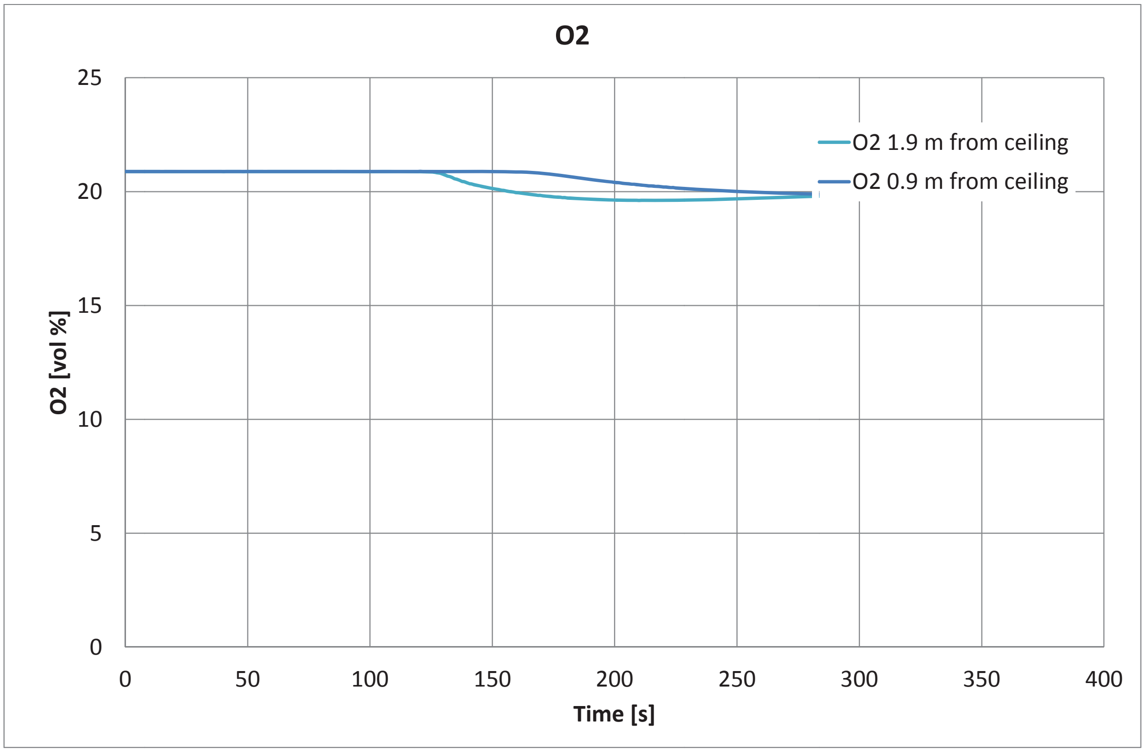

Figure 100. Test 17, O2 level. Not time-adjusted

Test protocol

Test: 18

Date: 2012-02-02

Test engineer: Michael Rahm, Johan Lindström

Type of test	Sand torpedo, drencher system 5 mm/min + water mist
Pool fire size (Ø in mm)	1170
Position of pool fire	1
Obstruction (% of pool area)	Torpedo, placed 50mm above pool surface
Amount of diesel (L)	15
Height of freeboard (mm)	25
Water mist nozzle	BETE TF 8-170
Bulkhead nozzle	
Drencher nozzle	LECHLER 460.608
Distance from nozzle to pool area	172 cm (drencher)
Pressure (bar)	10 in both systems
Water flow (L/min)	25 (in the drencher system)
Notes:	
Time (s)	
0	Start measuring program and video camera
60	Ignition
90	Activation of drencher and water mist system
100	Suppressed fire (approximately 1.5 m high flames)
120	Small flames under the torpedo
143	The fire was extinguished
370	Stops the water flow to the drencher and water mist nozzles
	Might be some problems with the O_2 measurement 900 mm from ceiling. Separate test to see the response time will be run.

Appendix 1

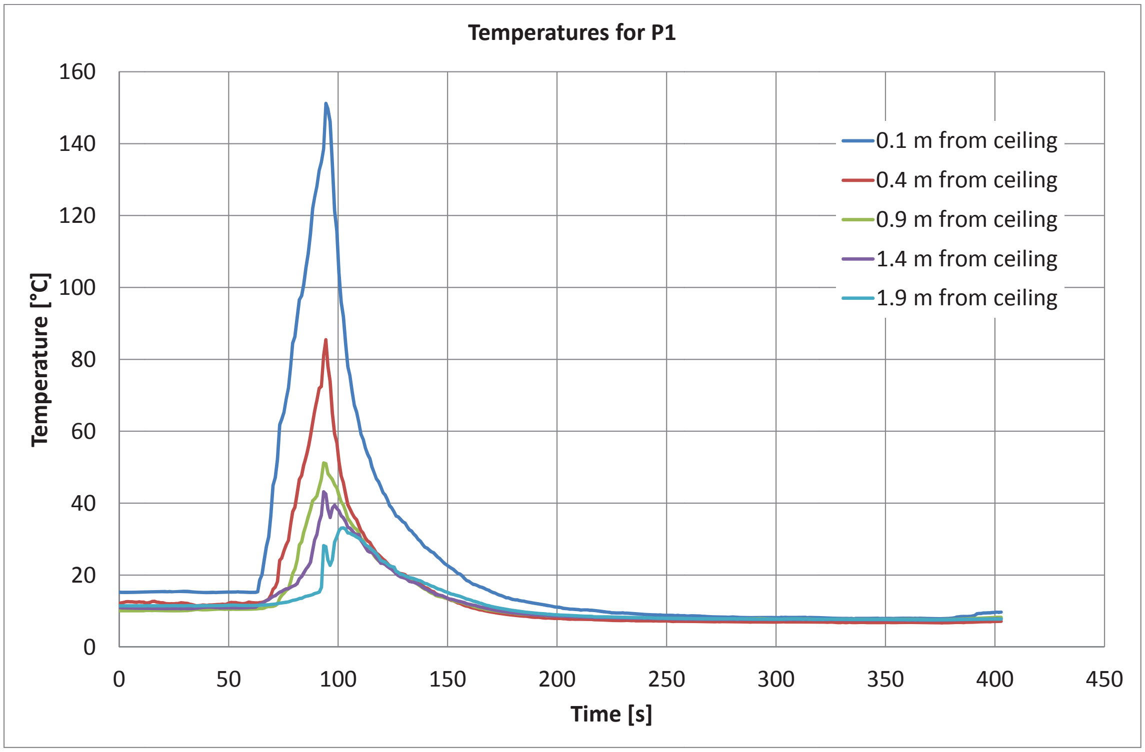

Figure 101. Test 18, Temperatures for P1

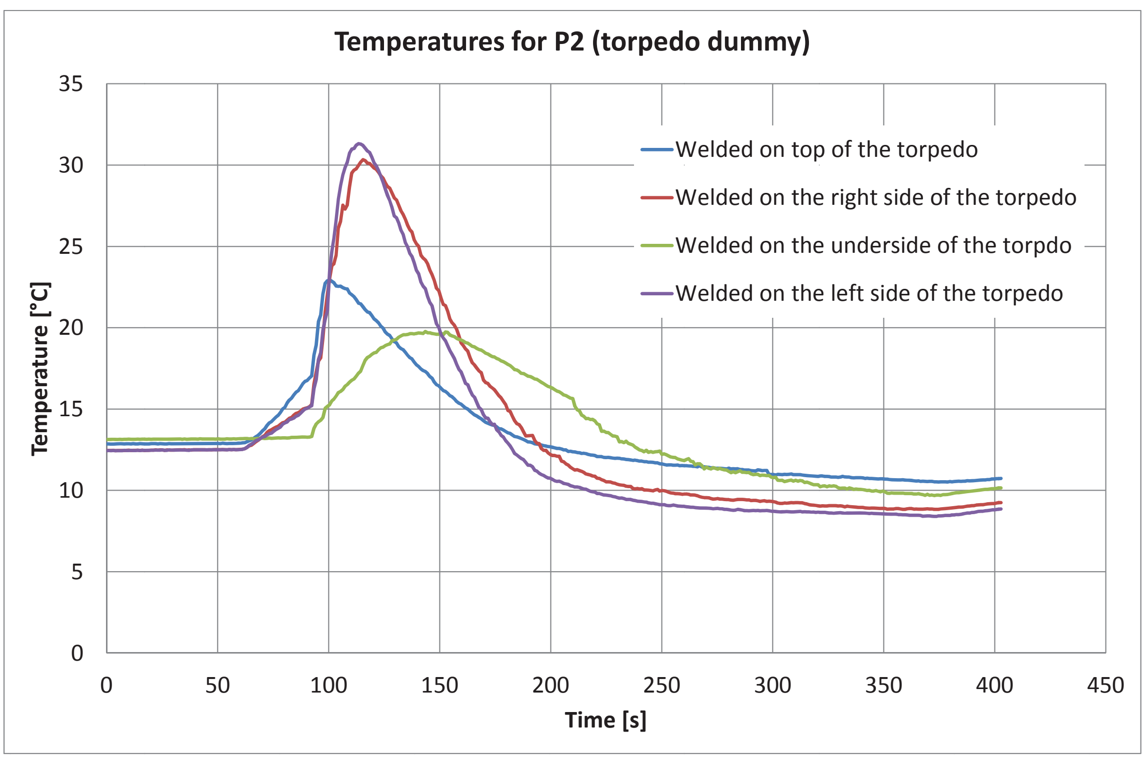

Figure 102. Test 18, Temperatures for P2 (dummy torpedo)

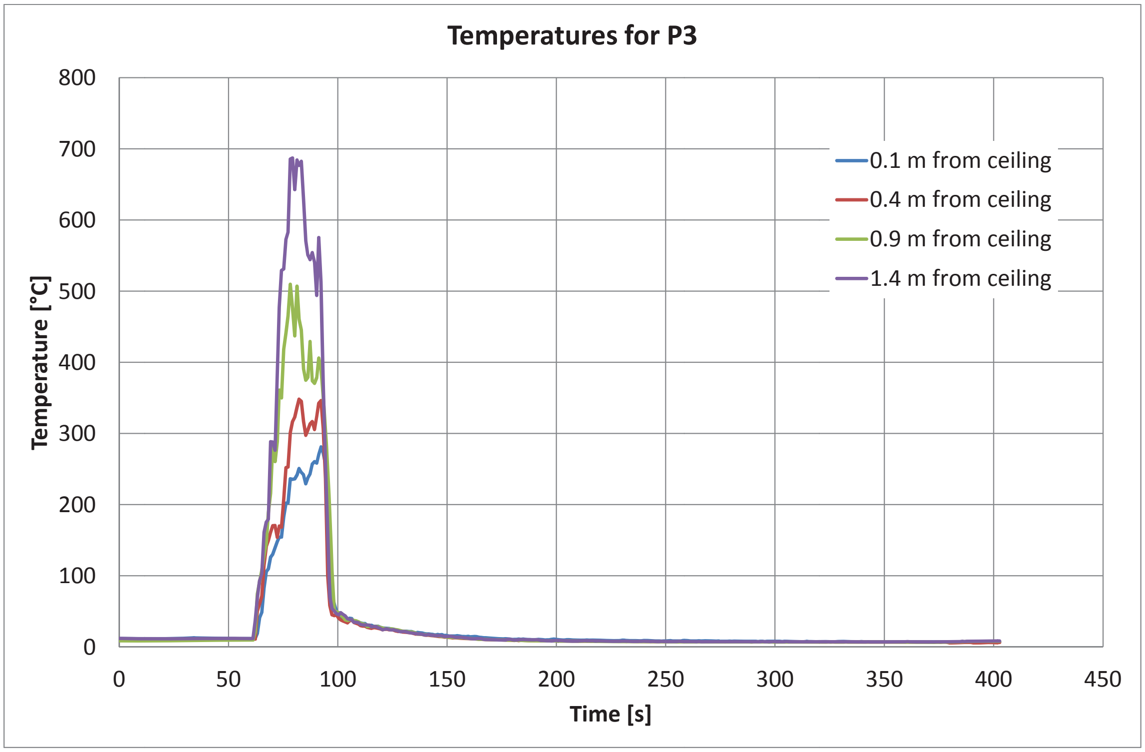

Figure 103. Test 18, Temperatures for P3

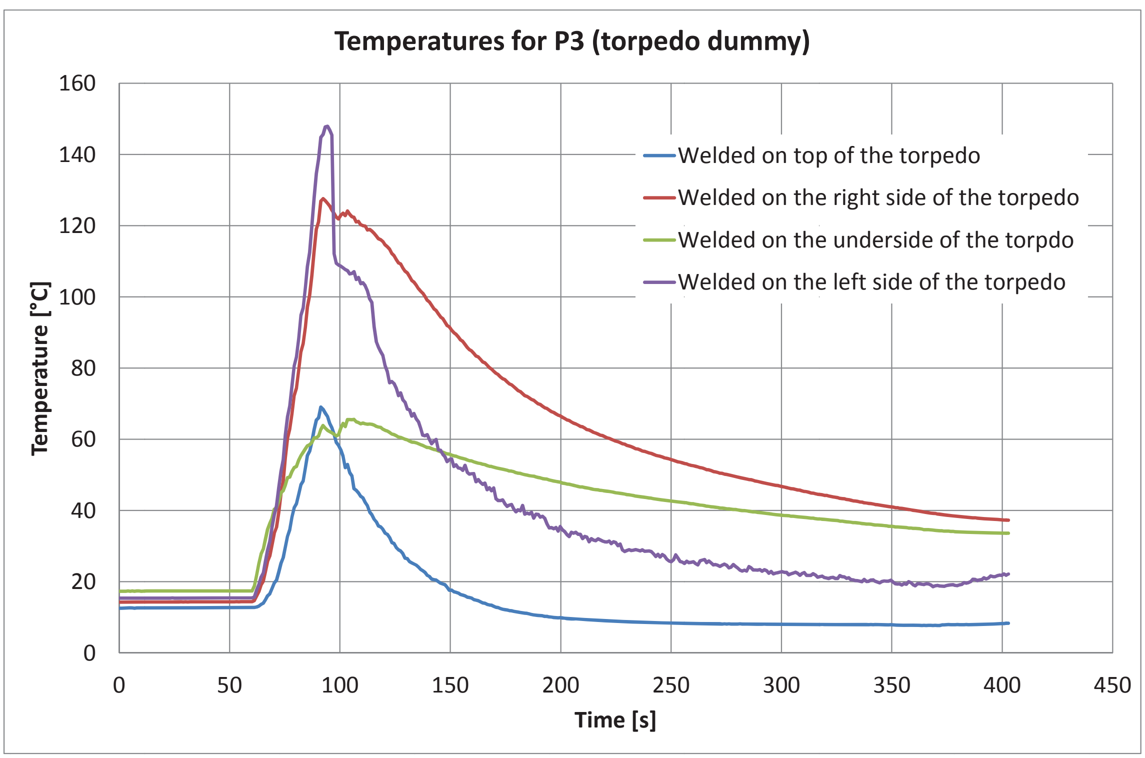

Figure 104. Test 18, Temperatures for P3 (dummy torpedo)

Appendix 1

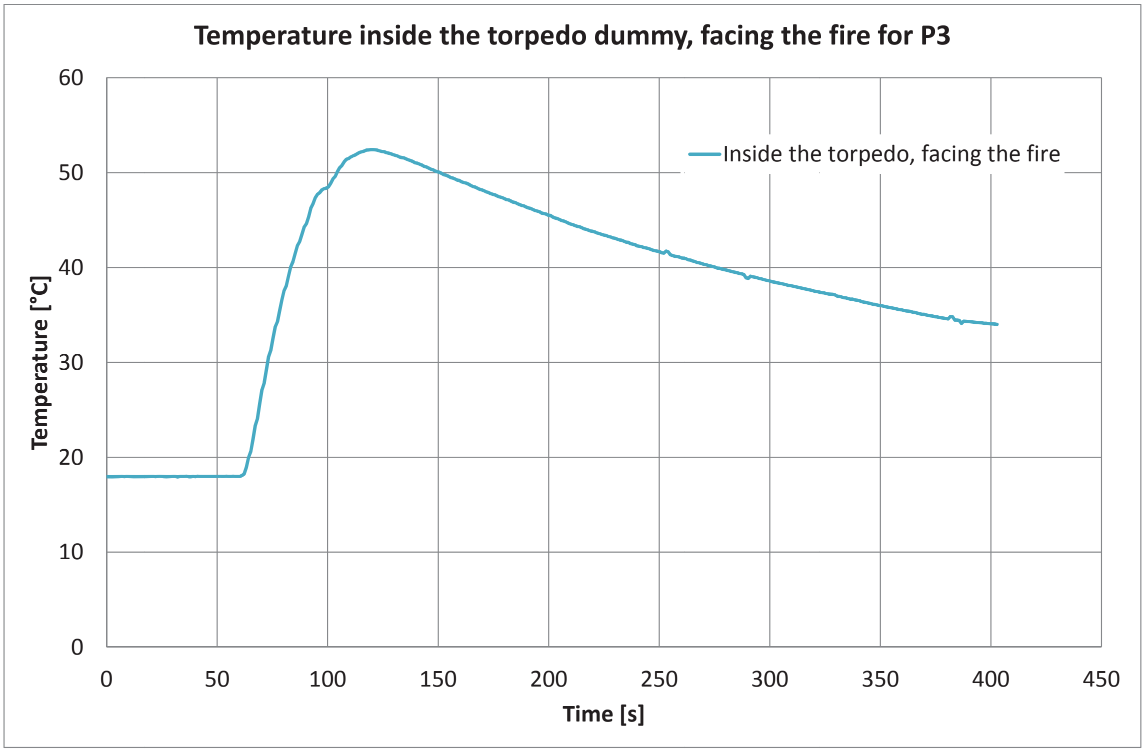

Figure 105. Test 18, Temperature inside the dummy torpedo, facing the fire for P3

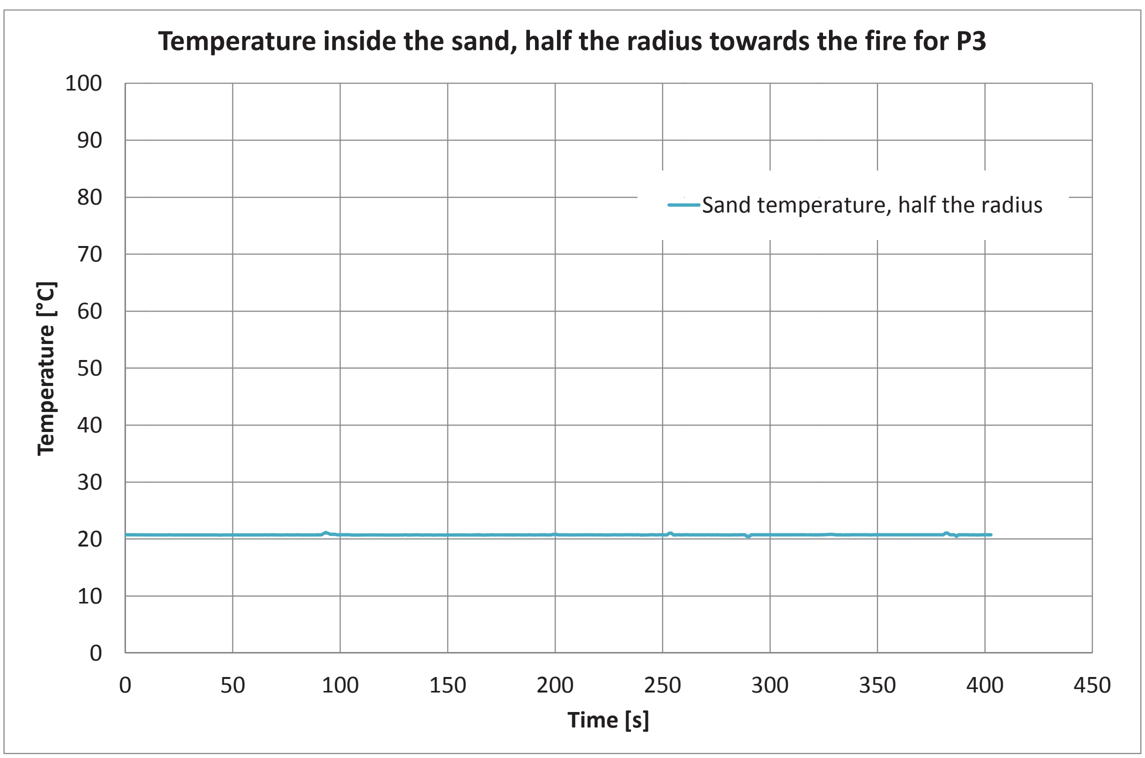

Figure 106. Test 18, Temperature inside the sand, half the radius towards the fire for P3

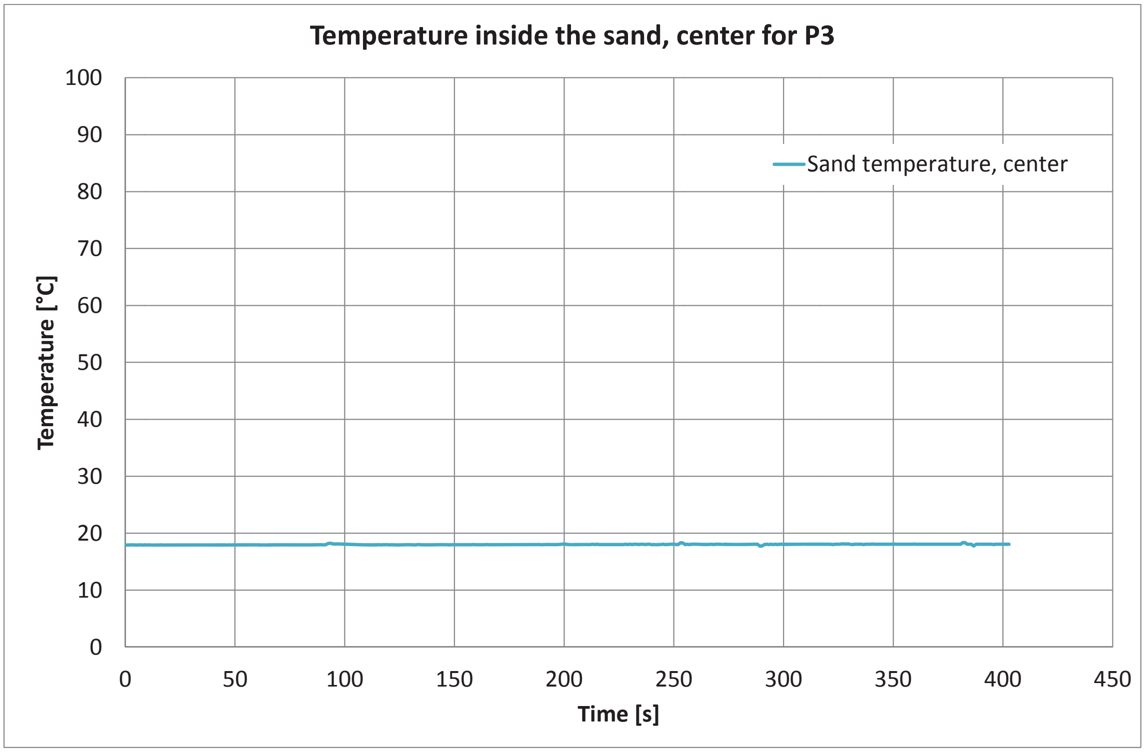

Figure 107. test 18, Temperature inside the sand, center for P3

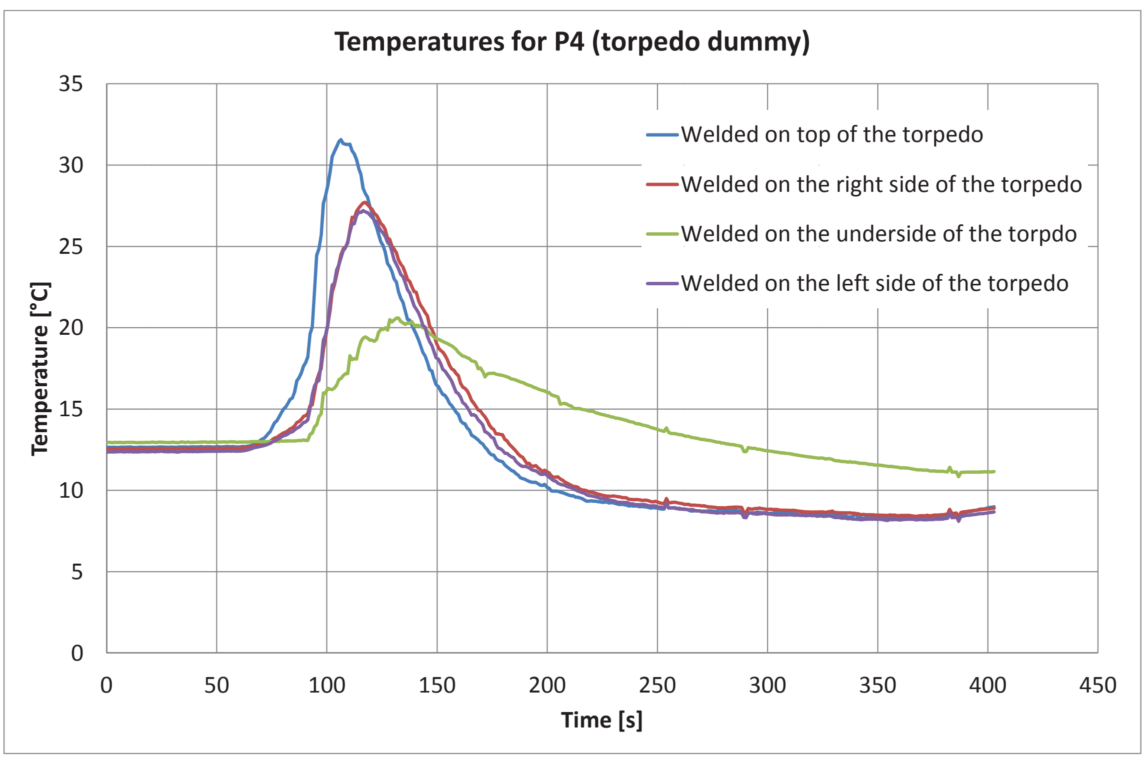

Figure 108. Test 18, Temperatures for P4 (dummy torpedo)

Appendix 1

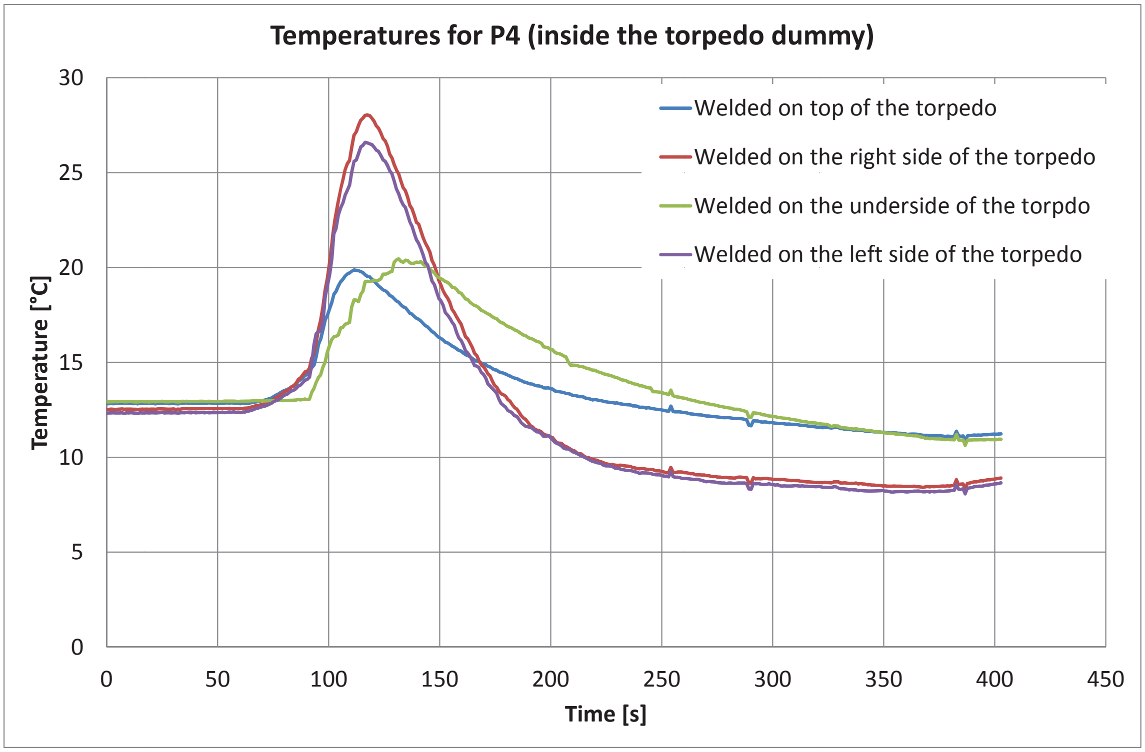

Figure 109. Test 18, Temperatures for P4 (inside the dummy torpedo)

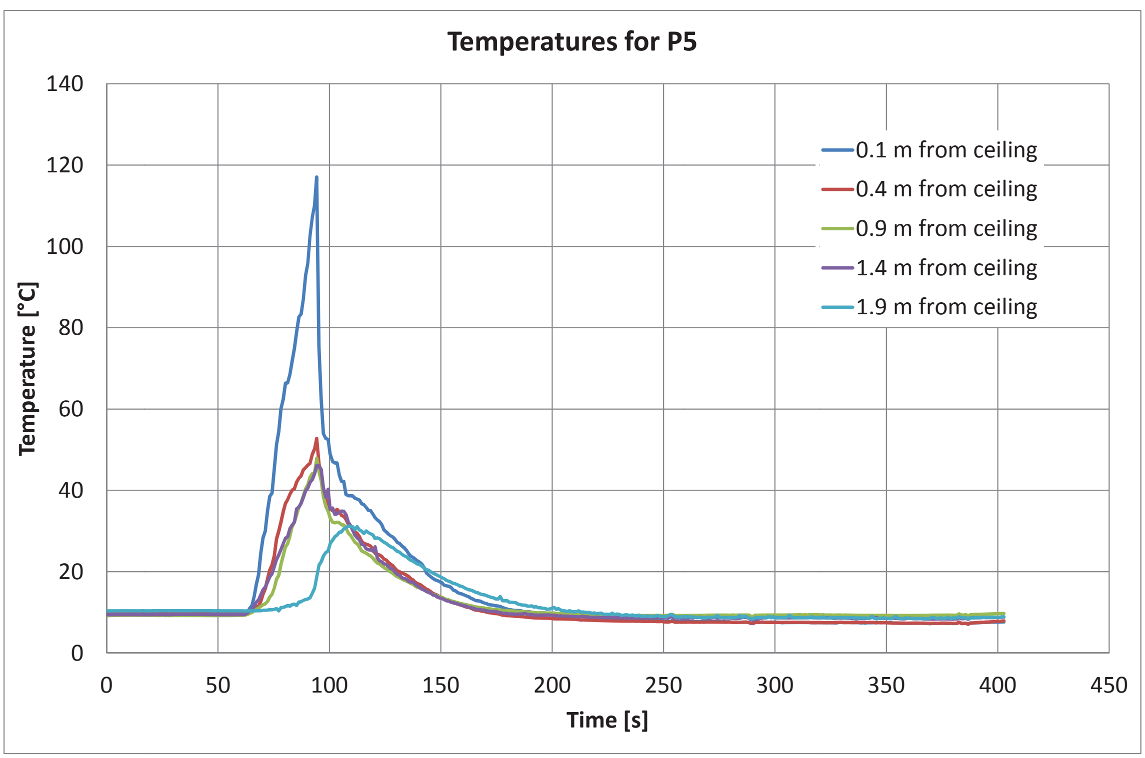

Figure 110. Test 18, Temperatures for P5

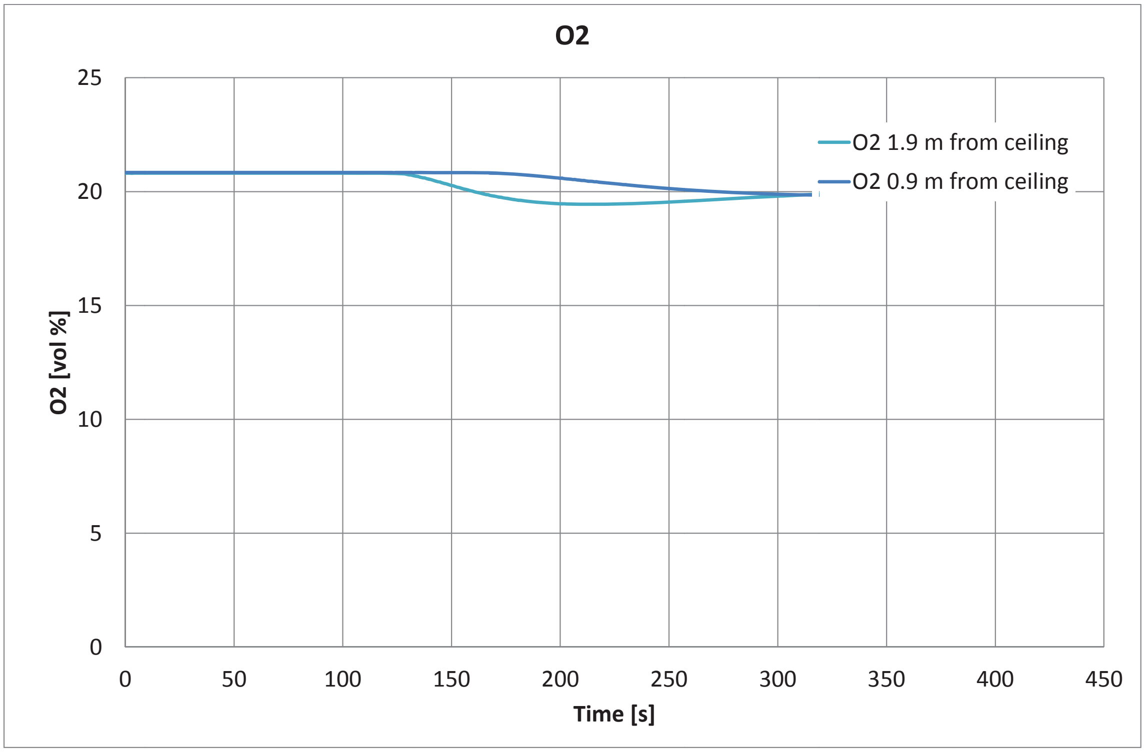

Figure 111. O2 level. Not time-adjusted

Appendix 1

Test protocol

Test: 19

Date: 2012-02-02

Test engineer: Michael Rahm, Johan Lindström

Type of test	Sand torpedo, drencher system 5 mm/min + water mist, pos 2 obstructed
Pool fire size (Ø in mm)	1170
Position of pool fire	2
Obstruction (% of pool area)	100 (Promatect sheet covering the entire pool area. Placed edge to edge with the torpedo and 425 mm above the pool surface)
Amount of diesel (L)	15
Height of freeboard (mm)	25
Water mist nozzle	BETE TF 8-170
Bulkhead nozzle	
Drencher nozzle	LECHLER 460.608
Distance from nozzle to pool area	172 cm (drencher)
Pressure (bar)	10 in both systems
Water flow (L/min)	25 (in the drencher system)
Notes:	
Time (s)	
0	Start measuring program and video camera
60	Ignition
90	Activation of drencher and water mist system
100	Suppressed fire (the flames stays mostly under the Promatect sheet)
480	The fire was extinguished with foam
	Might be some problems with the O_2 measurement 900 mm from ceiling. Separate test to see the response time will be run.

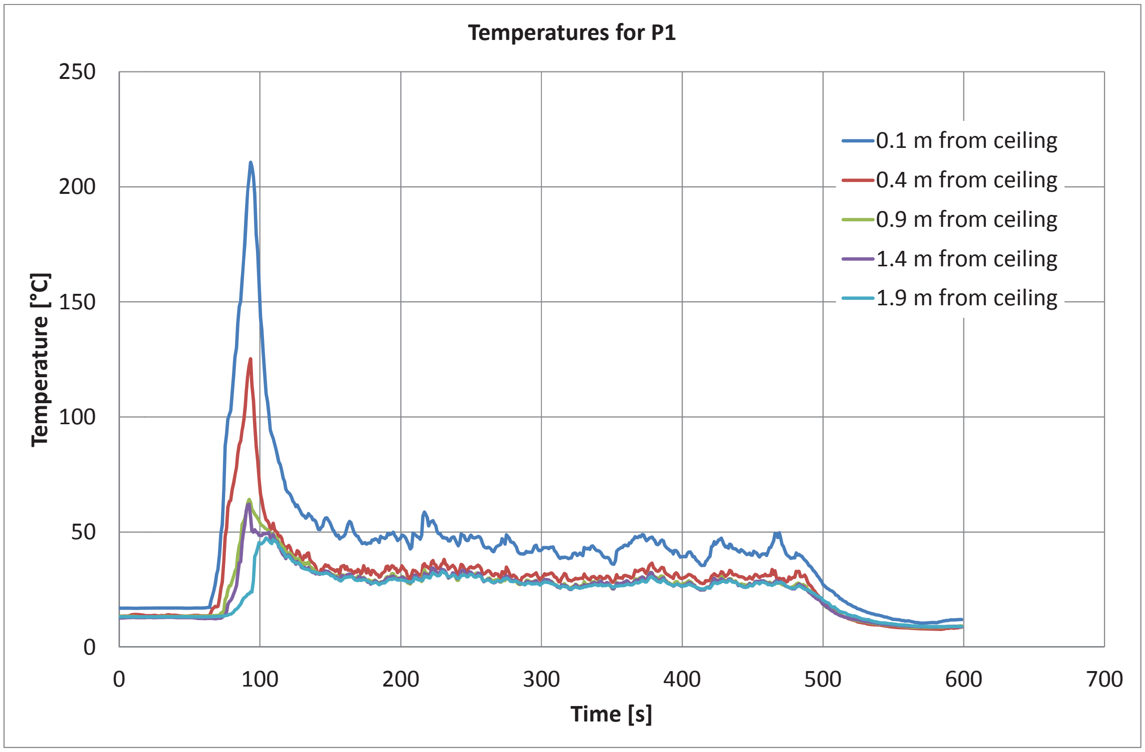

Figure 112. Test 19, Temperatures for P1

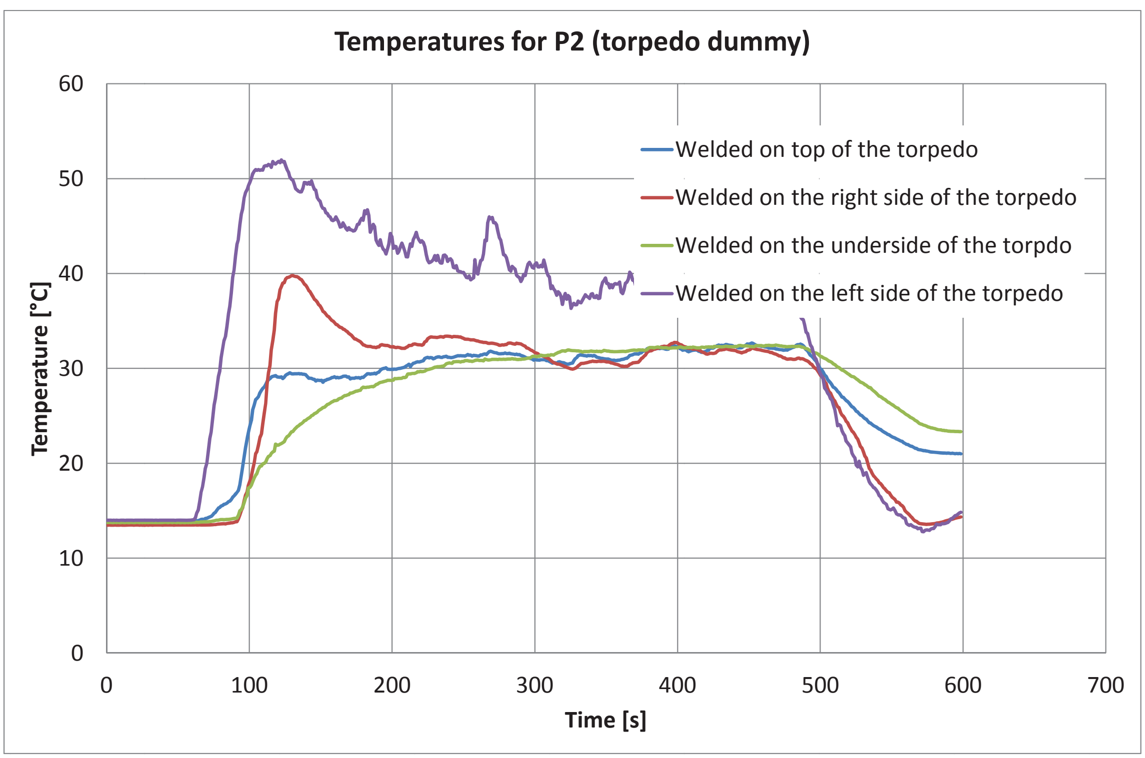

Figure 113. Test 19, Temperatures for P2 (dummy torpedo)

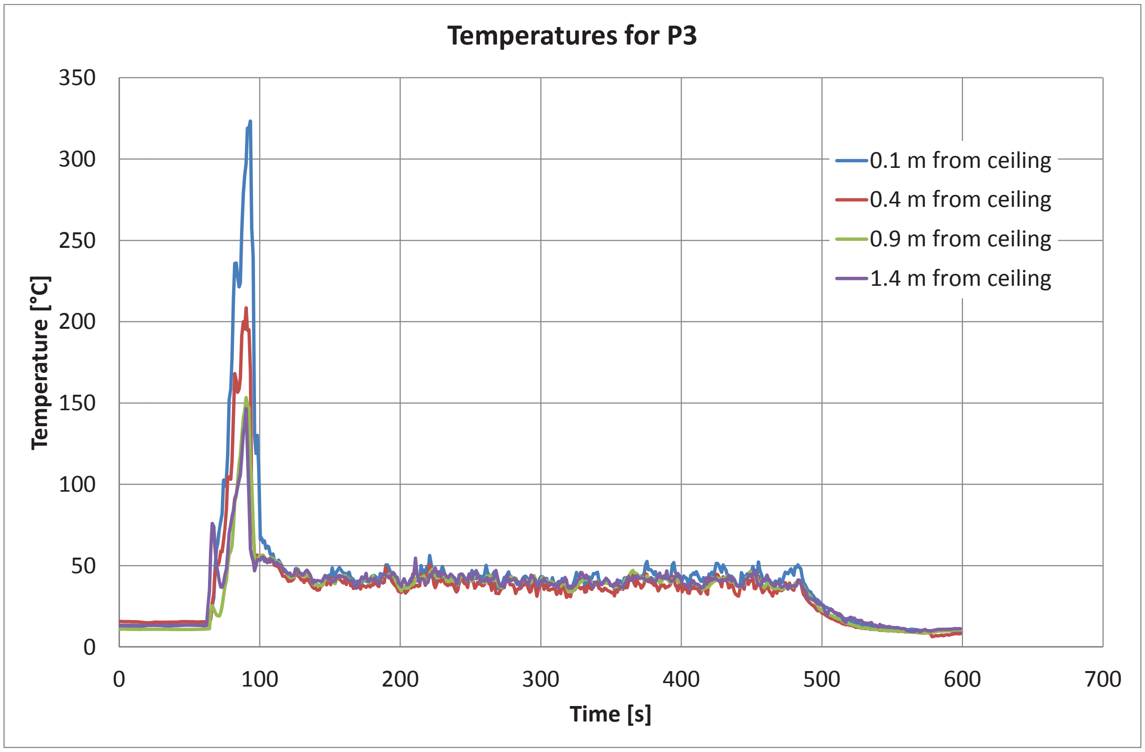

Figure 114. Test 19, Temperatures for P3

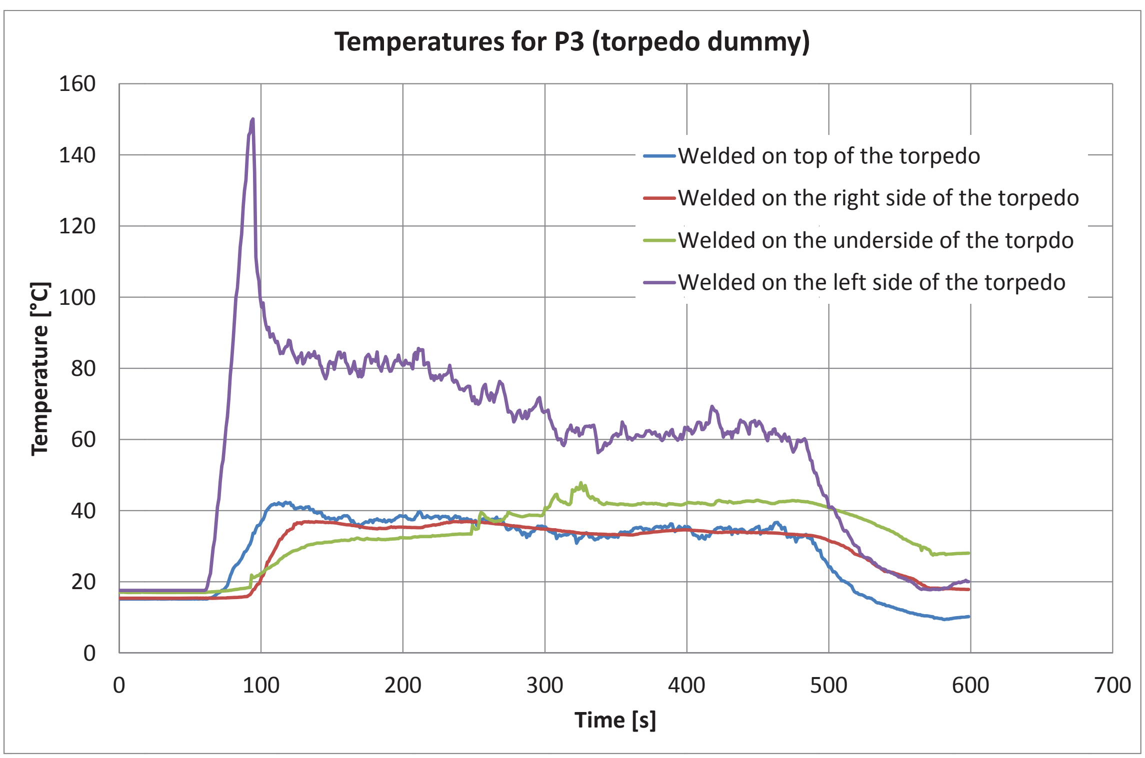

Figure 115. Test 19, Temperatures for P3 (dummy torpedo)

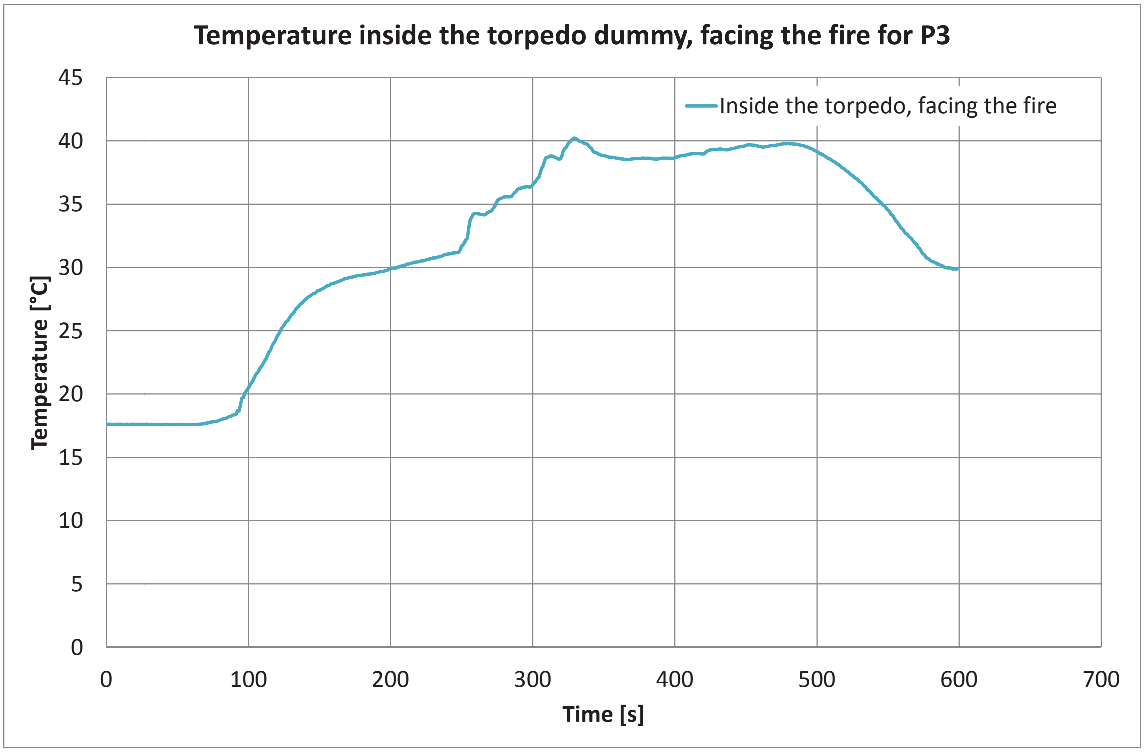

Figure 116. Test 19, Temperature inside the dummy torpedo, facing the fire for P3

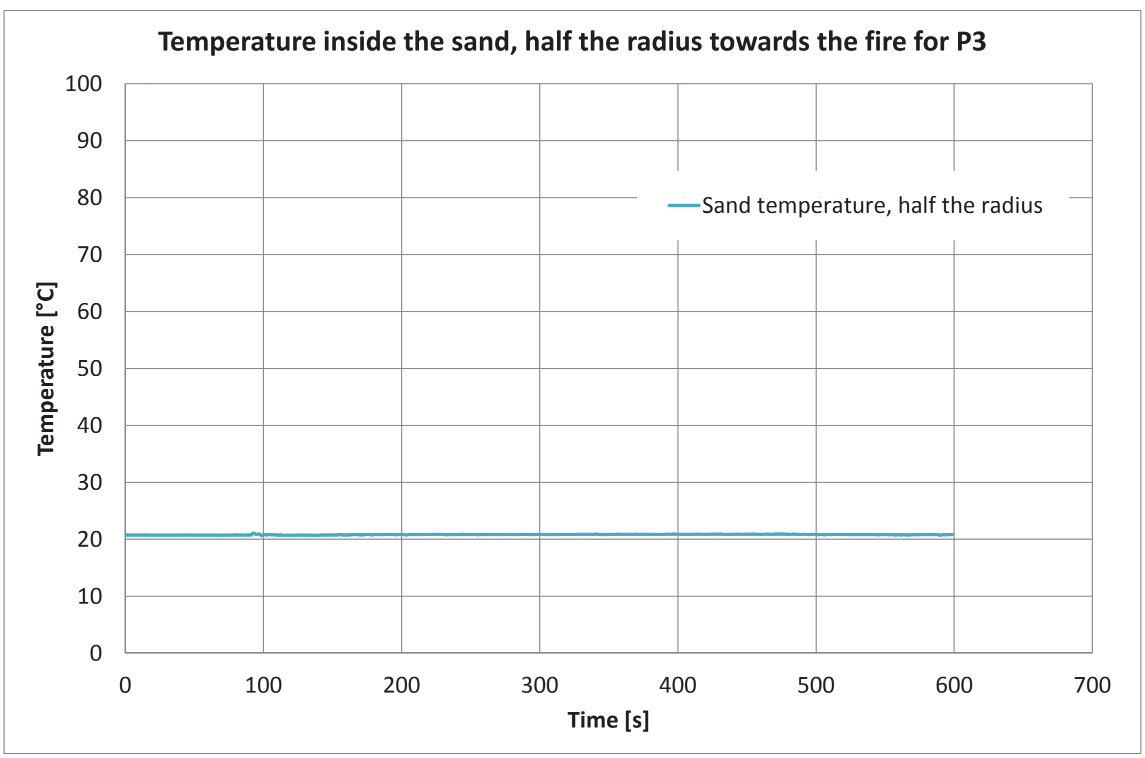

Figure 117. Test 19, Temperature inside the sand, half the radius towards the fire for P3

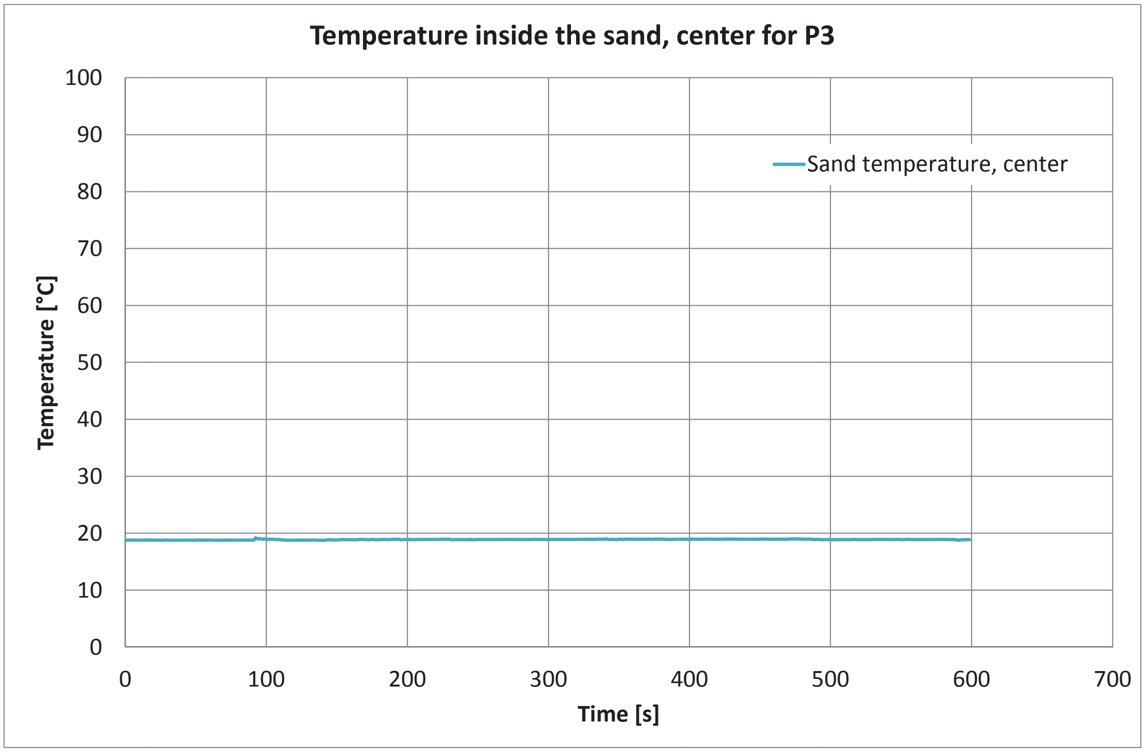

Figure 118. Test 19, Temperature inside the sand, center for P3

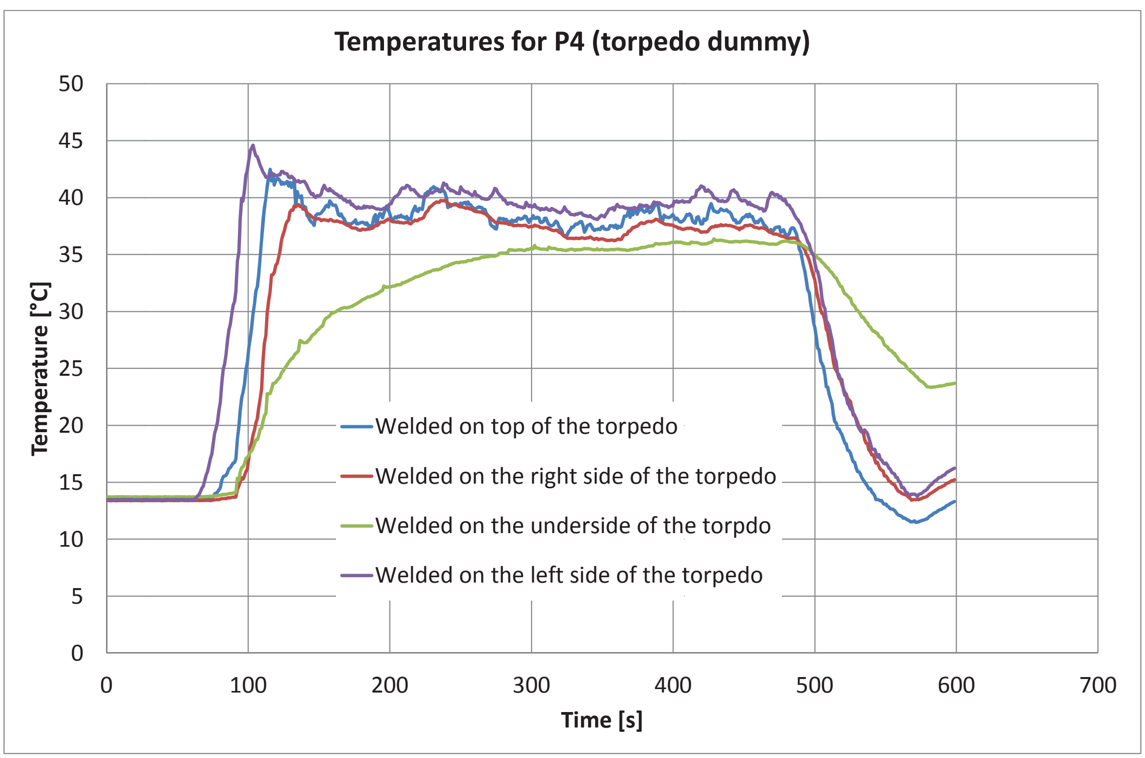

Figure 119. Test 19, Temperatures for P4 (dummy torpedo)

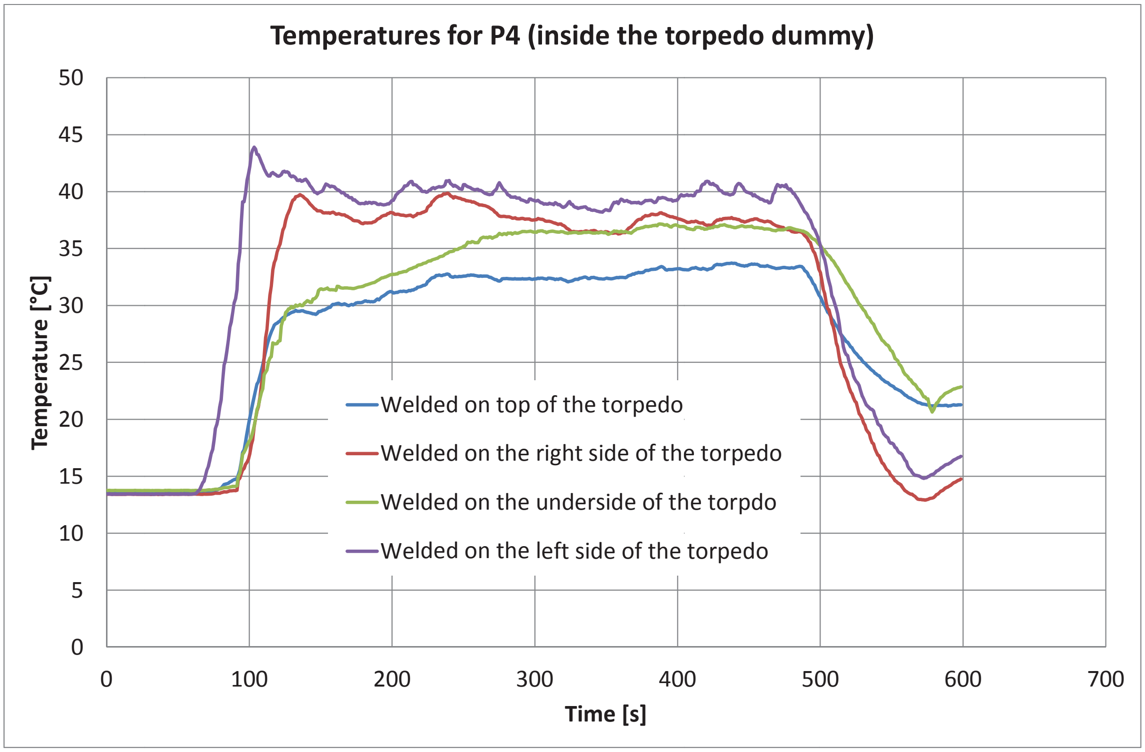

Figure 120. Test 19, Temperatures for P4 (inside the dummy torpedo)

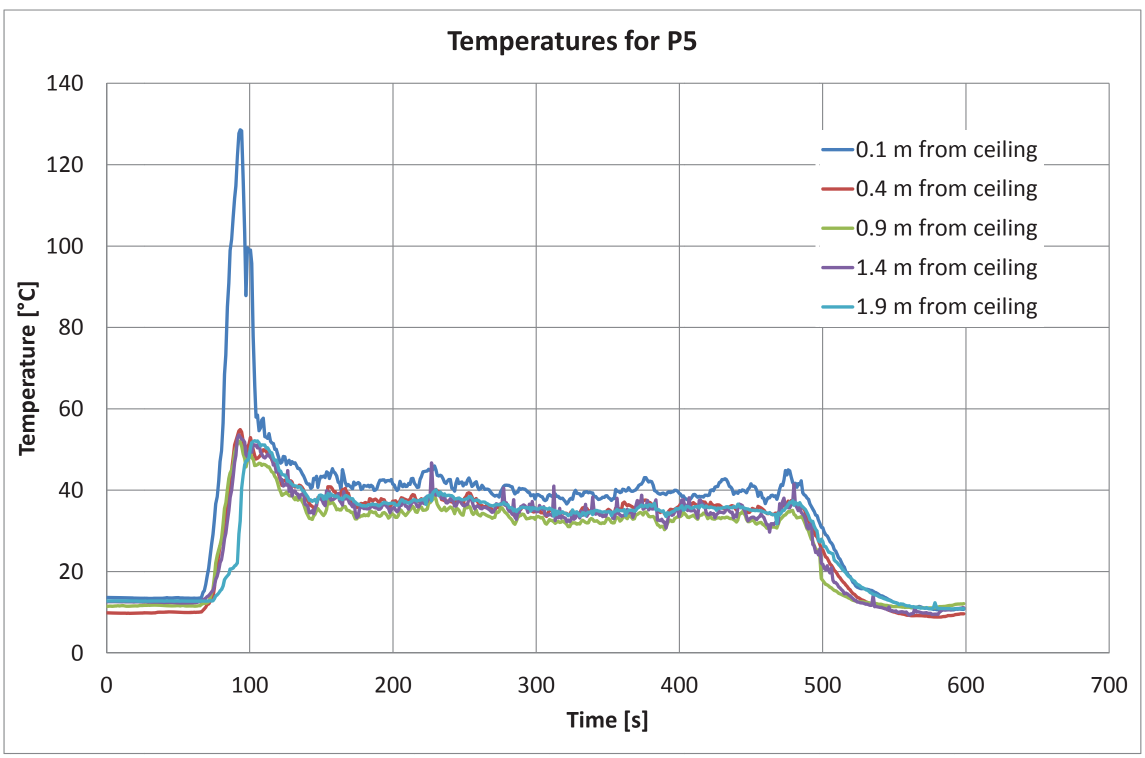

Figure 121. Test 19, Temperatures for P5

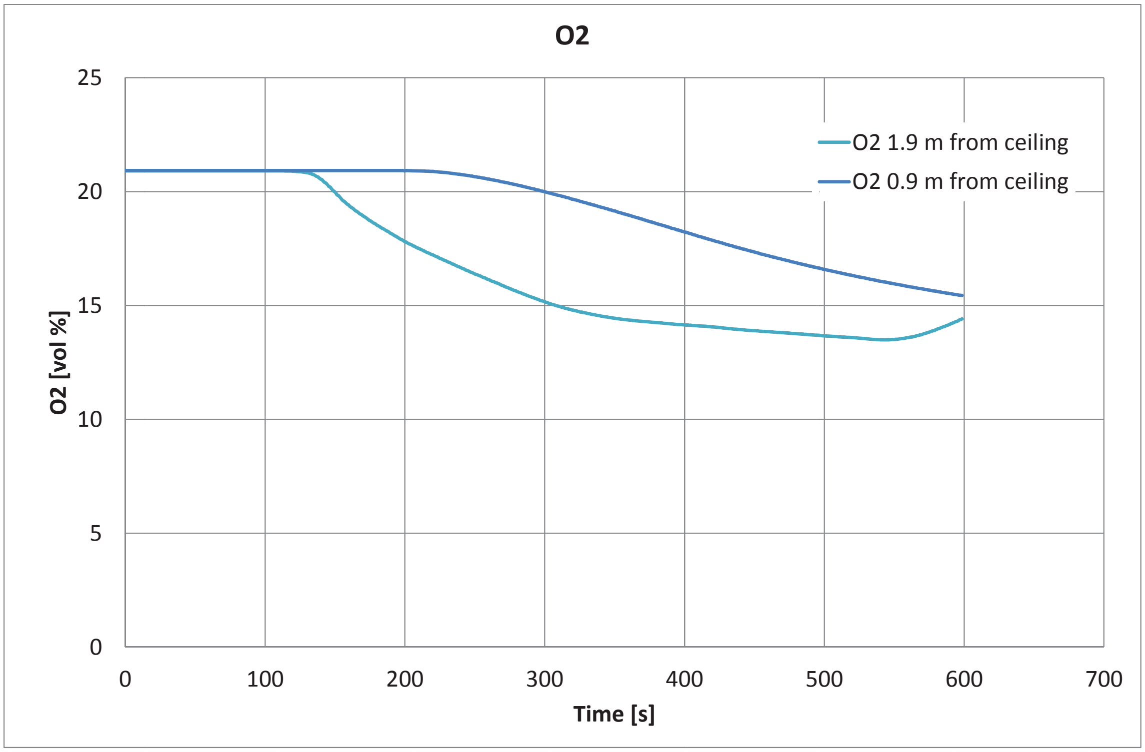

Figure 122. O2 level. Not time-adjusted

Test protocol

Test: 20

Date: 2012-02-03

Test engineer: Michael Rahm, Johan Lindström

Type of test	Sand torpedo, drencher system 32 mm/min, obstructed
Pool fire size (Ø in mm)	1170
Position of pool fire	2
Obstruction (% of pool area)	100 (Promatect sheet covering the entire pool area. Placed edge to edge with the torpedo and 425 mm above the pool surface)
Amount of diesel (L)	15
Height of freeboard (mm)	25
Water mist nozzle	
Bulkhead nozzle	
Drencher nozzle	LECHLER 460.928
Distance from nozzle to pool area	172 cm
Pressure (bar)	10
Water flow (L/min)	157
Notes:	
Time (s)	
0	Start measuring program and video camera
60	Ignition
90	Activation of drencher system
100	Suppressed fire (the flames stays mostly under the Promatect sheet)
117	The fire was extinguished
	Fast extinction. Probably due to water that travels from the torpedo and down on the pool surface. In coming tests the pool area will be moved longer from the torpedo.

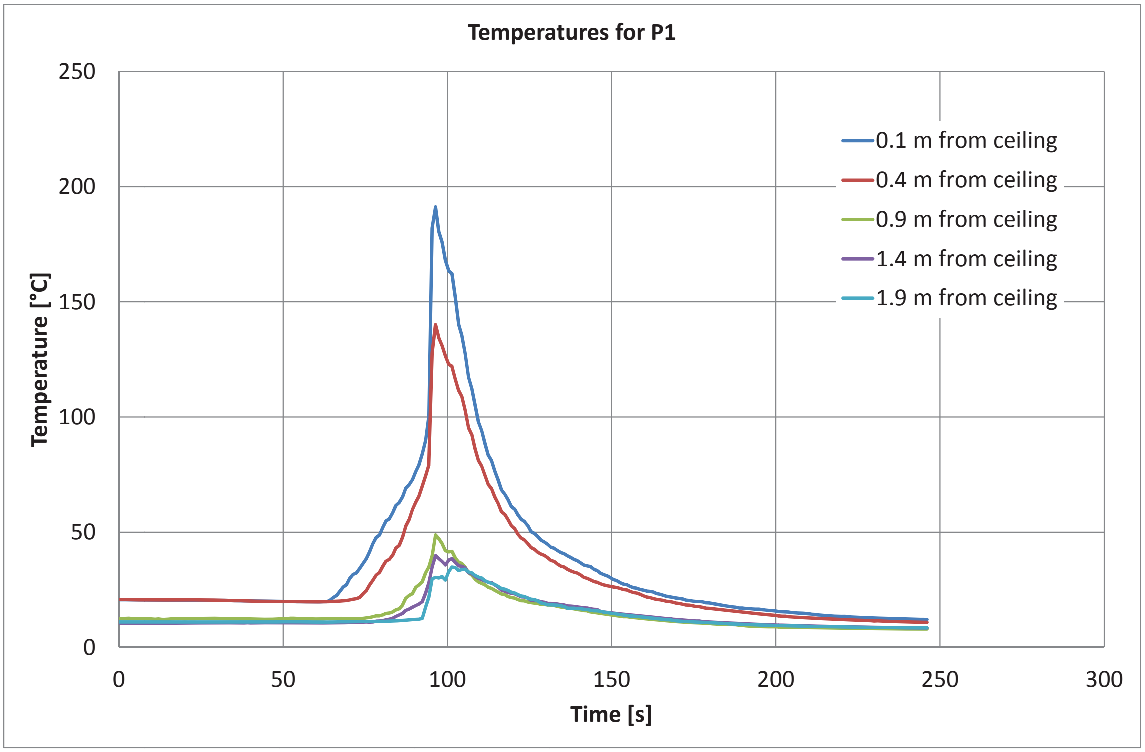

Figure 123. Test 20, Temperatures for P1

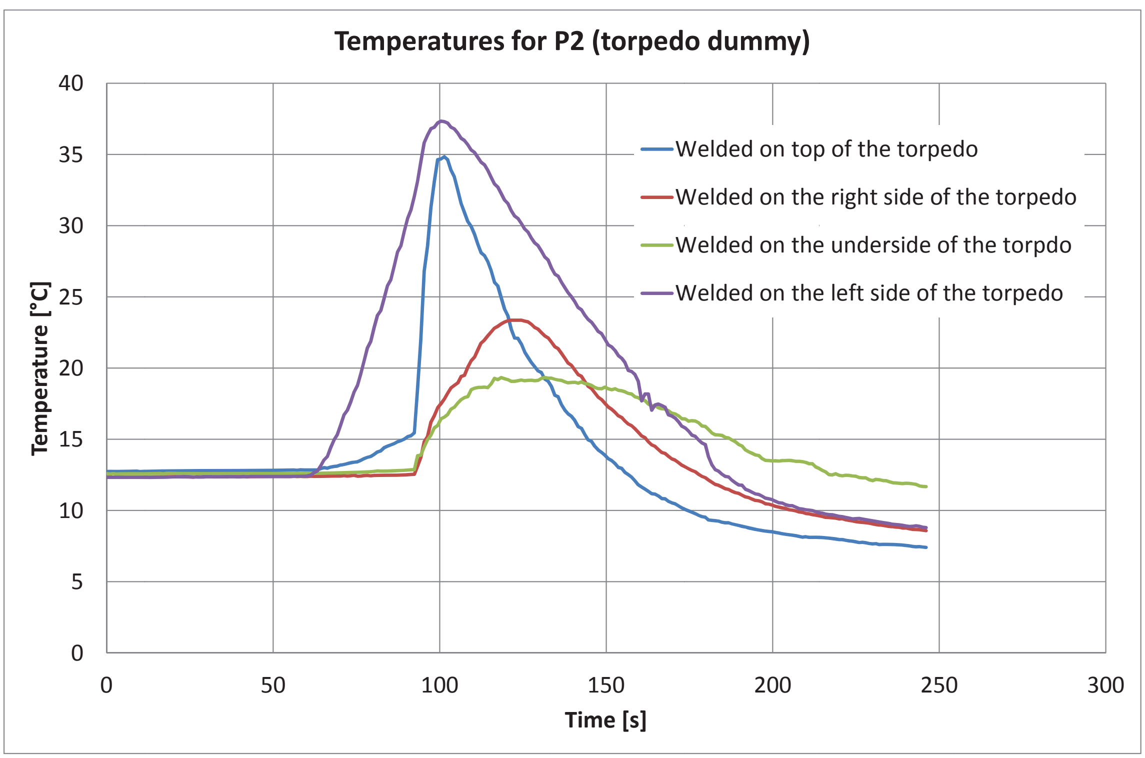

Figure 124. Test 20, Temperatures for P2 (dummy torpedo)

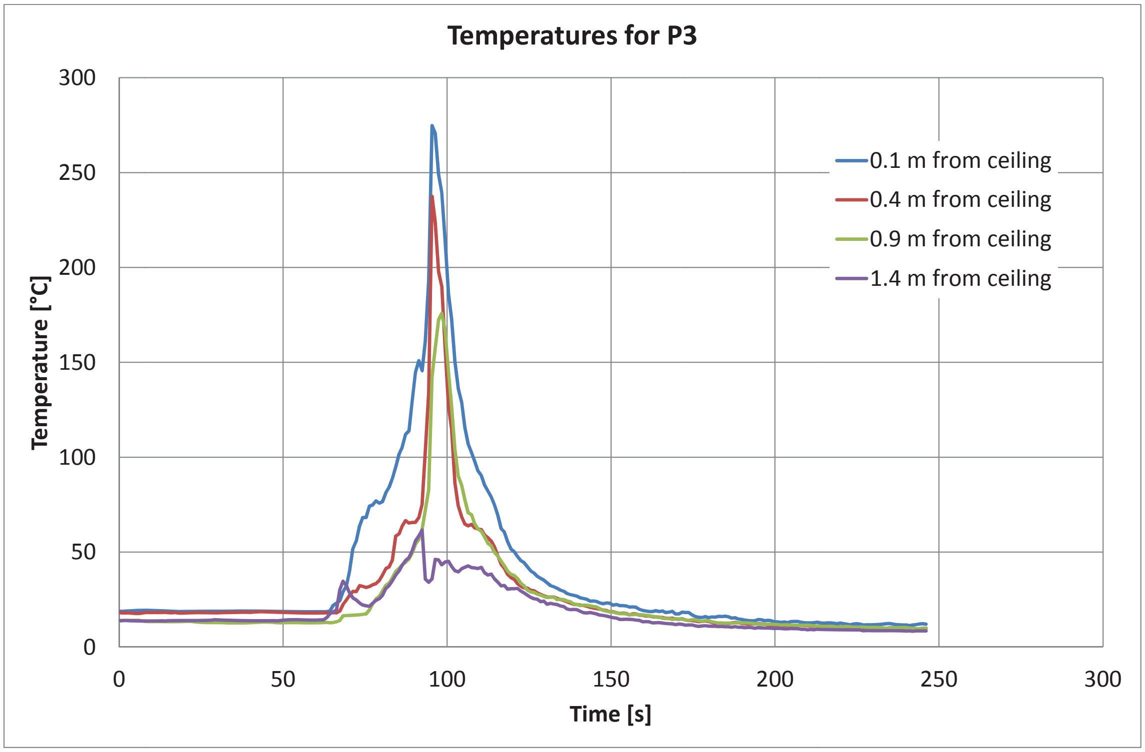

Figure 125. Test 20, Temperatures for P3

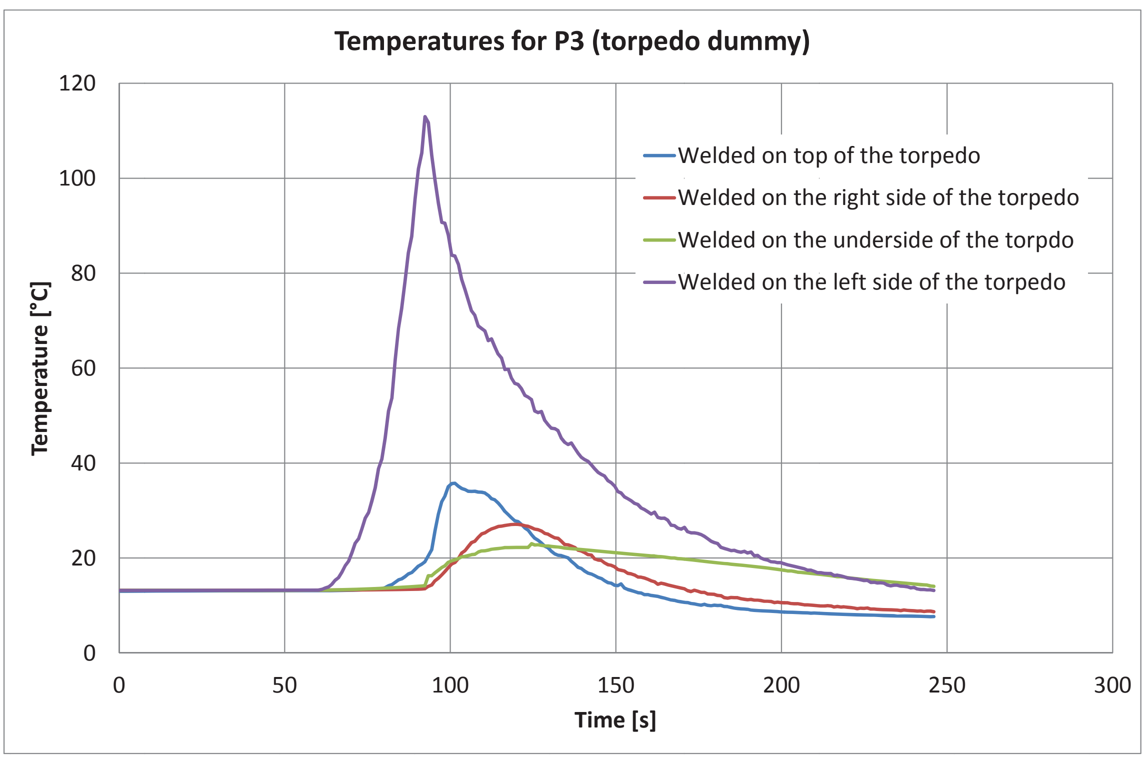

Figure 126. Test 20, Temperatures for P3 (dummy torpedo)

Appendix 1

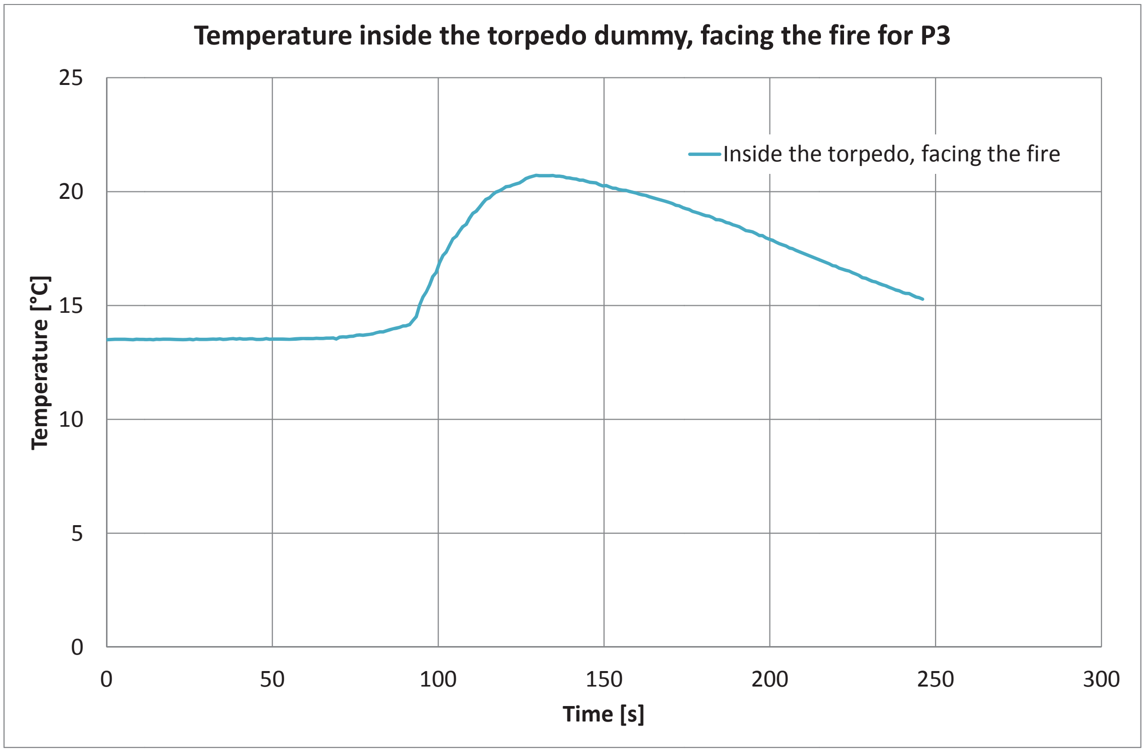

Figure 127. Test 20, Temperature inside the dummy torpedo, facing the fire for P3

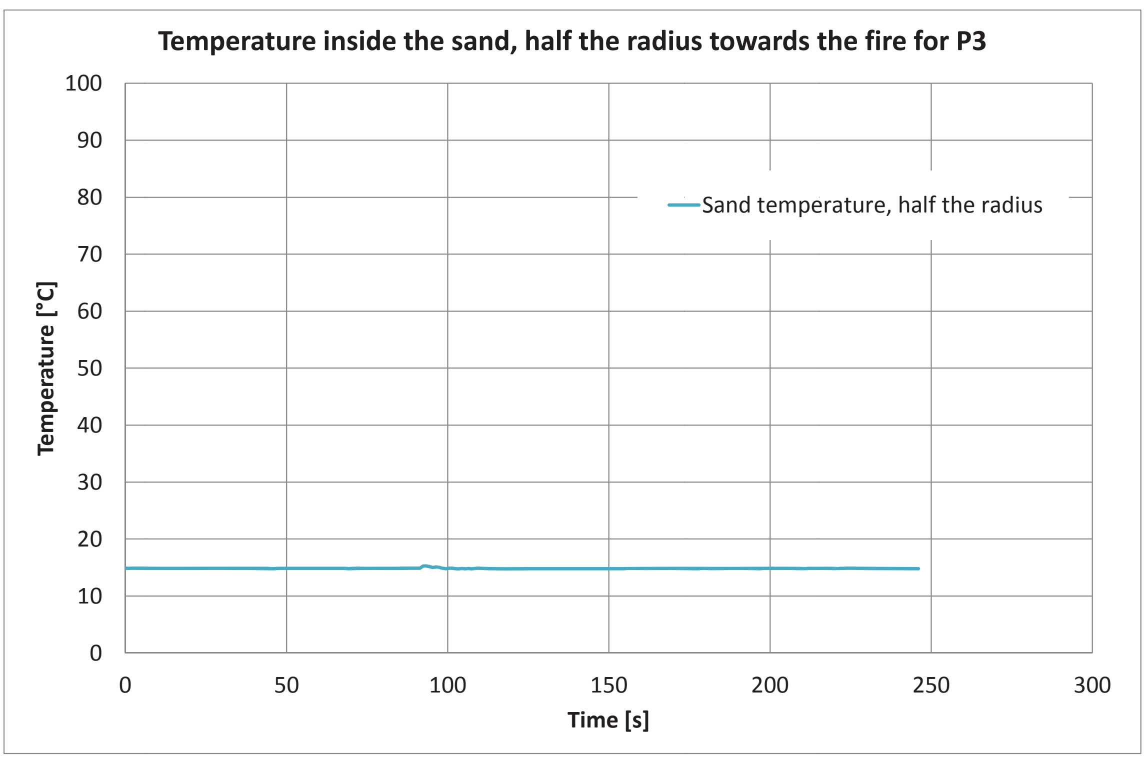

Figure 128. Test 20, Temperature inside the sand, half the radius towards the fire for P3

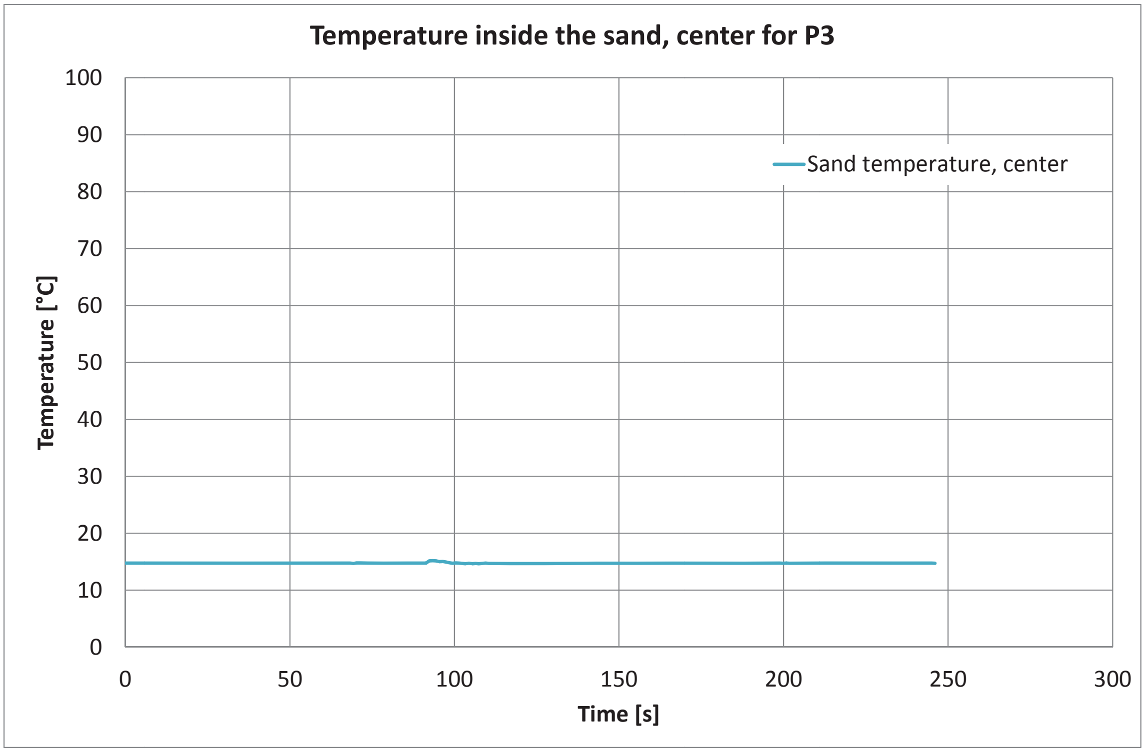

Figure 129. Test 20, Temperature inside the sand, center for P3

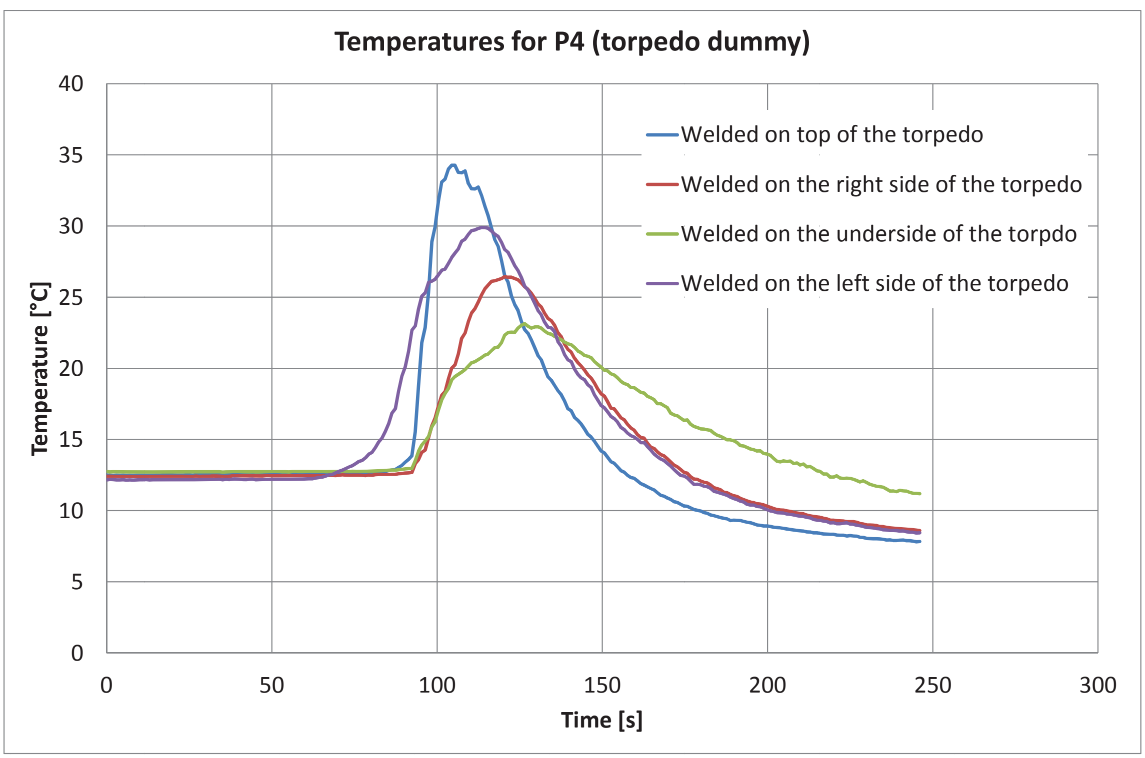

Figure 130. Test 20, Temperatures for P4 (dummy torpedo)

Appendix 1

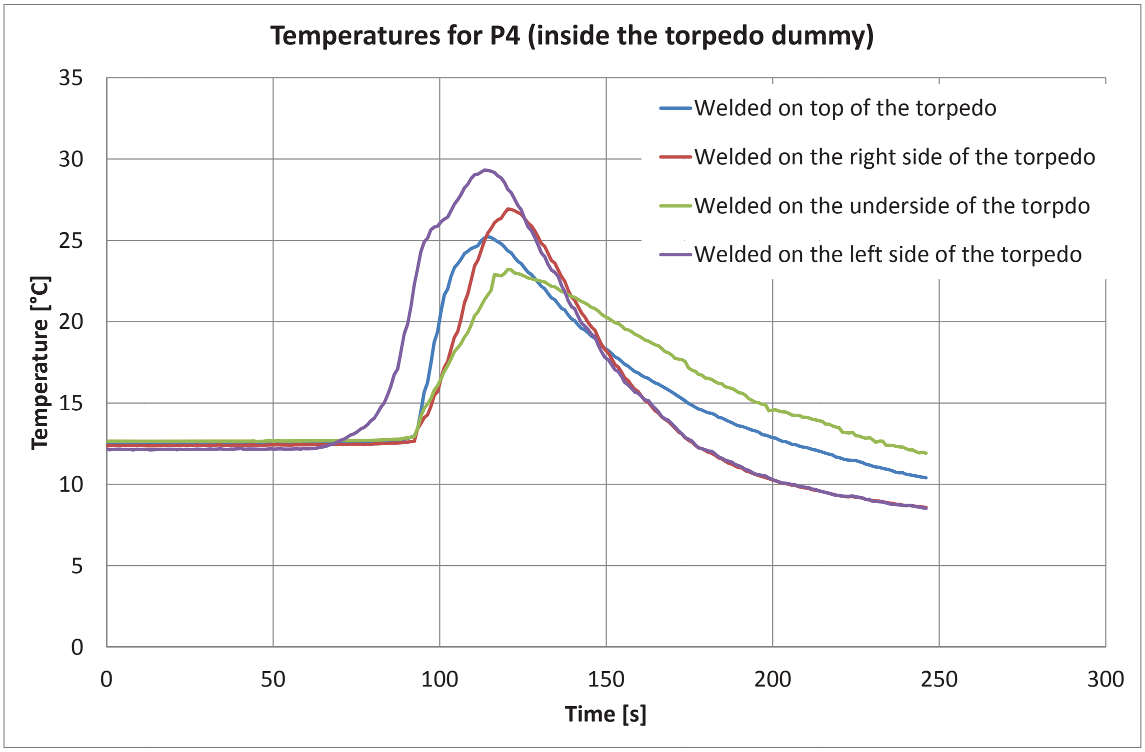

Figure 131. Test 20, Temperatures for P4 (inside the dummy torpedo)

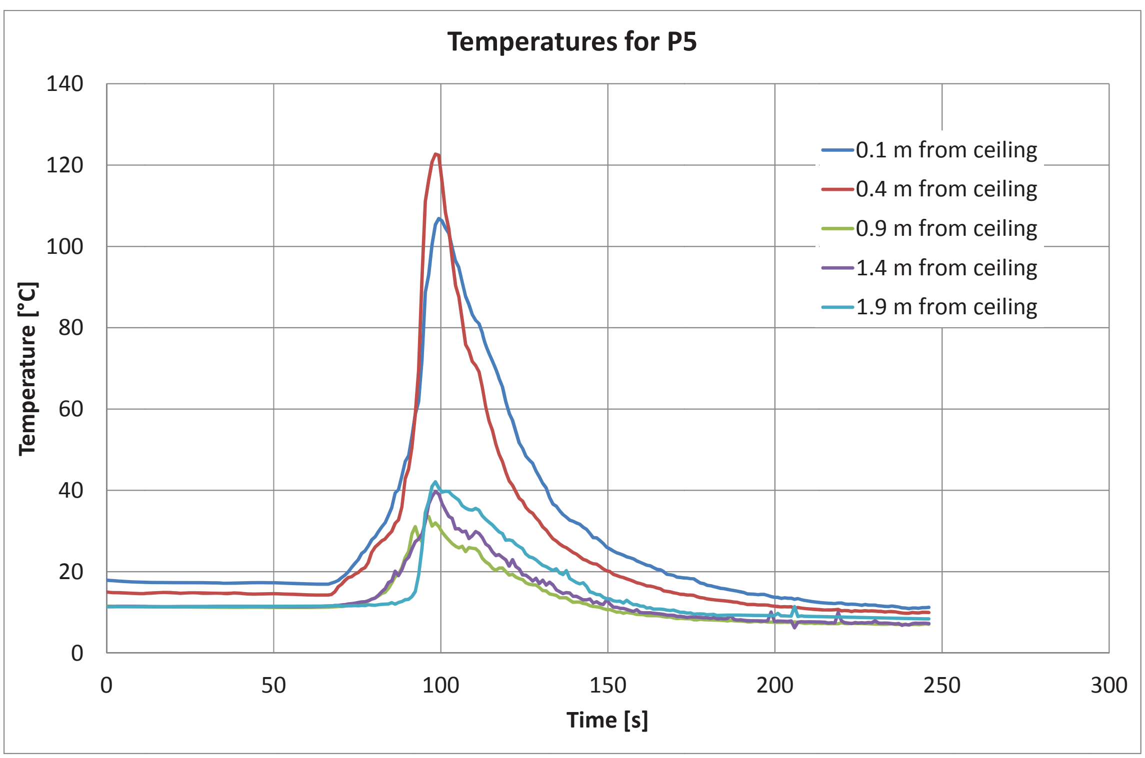

Figure 132. Test 20, Temperatures for P5

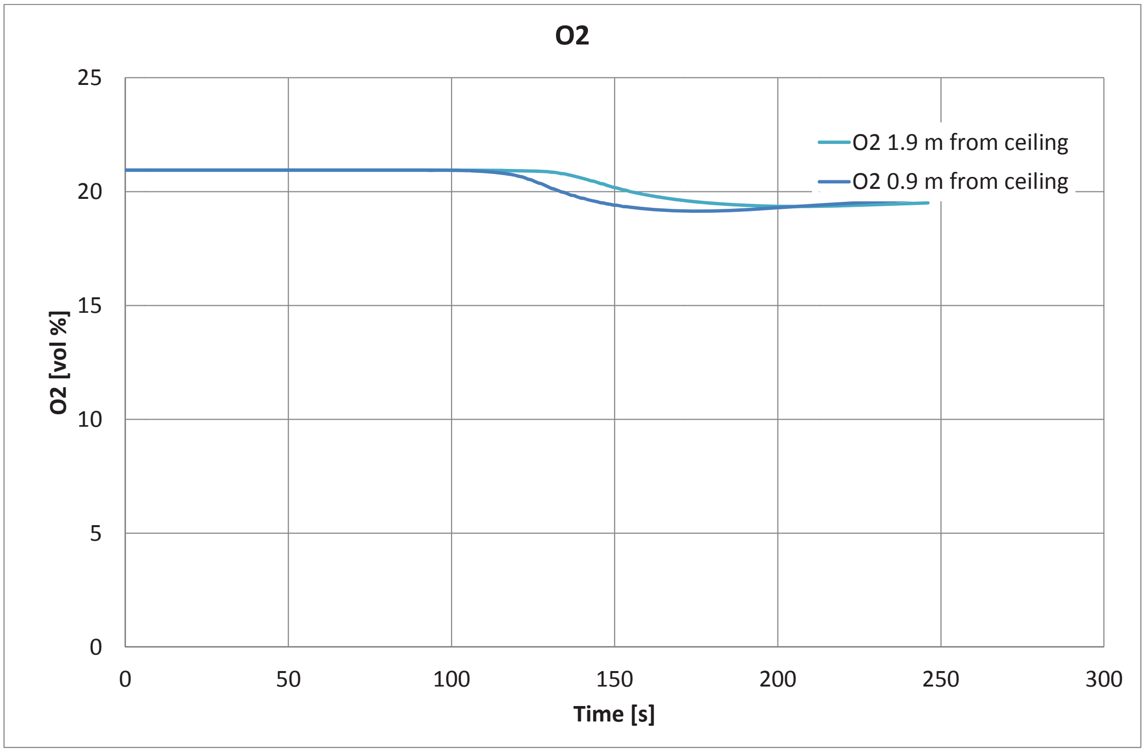

Figure 133. Test 20, O2 level. Not time-adjusted

Test protocol

Test: 21

Date: 2012-02-03

Test engineer: Michael Rahm, Johan Lindström

Type of test	Sand torpedo, drencher system 32 mm/min
Pool fire size (Ø in mm)	1170
Position of pool fire	2 (250 mm from the edge of the torpedo)
Obstruction (% of pool area)	100 (Promatect sheet covering the entire pool area. Placed 250 mm from the torpedo and 425 mm above the pool surface)
Amount of diesel (L)	15
Height of freeboard (mm)	25
Water mist nozzle	
Bulkhead nozzle	
Drencher nozzle	LECHLER 460.928
Distance from nozzle to pool area	172 cm
Pressure (bar)	10
Water flow (L/min)	157
Notes:	
Time (s)	
0	Start measuring program and video camera
60	Ignition
90	Activation of drencher system
97	The fire was extinguished
150	The water flow to the drencher nozzles was stopped

Appendix 1

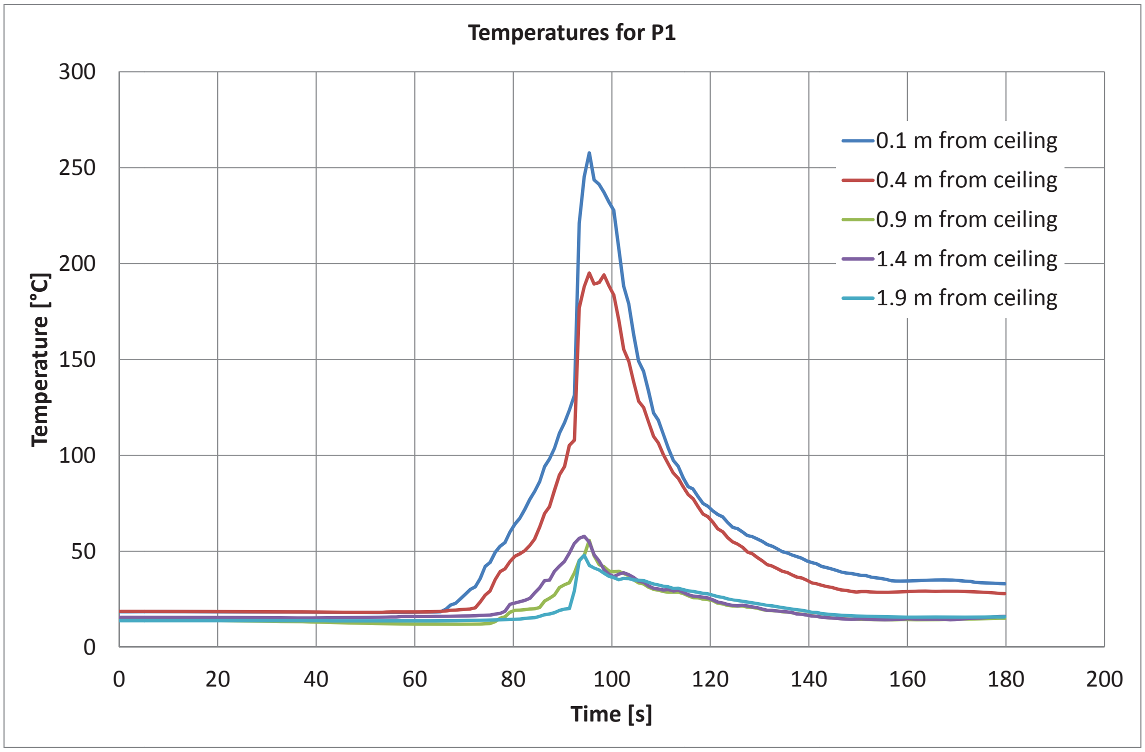

Figure 134. Test 21, Temperatures for P1

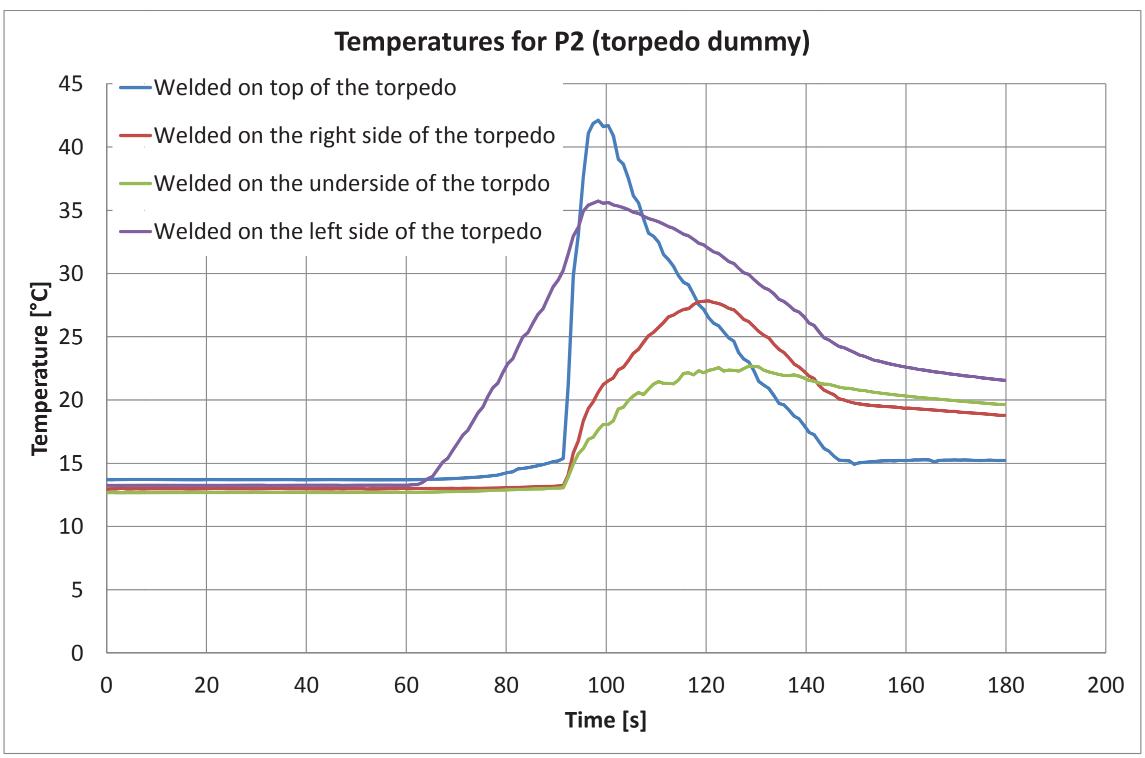

Figure 135. Test 21, Temperatures for P2 (dummy torpedo)

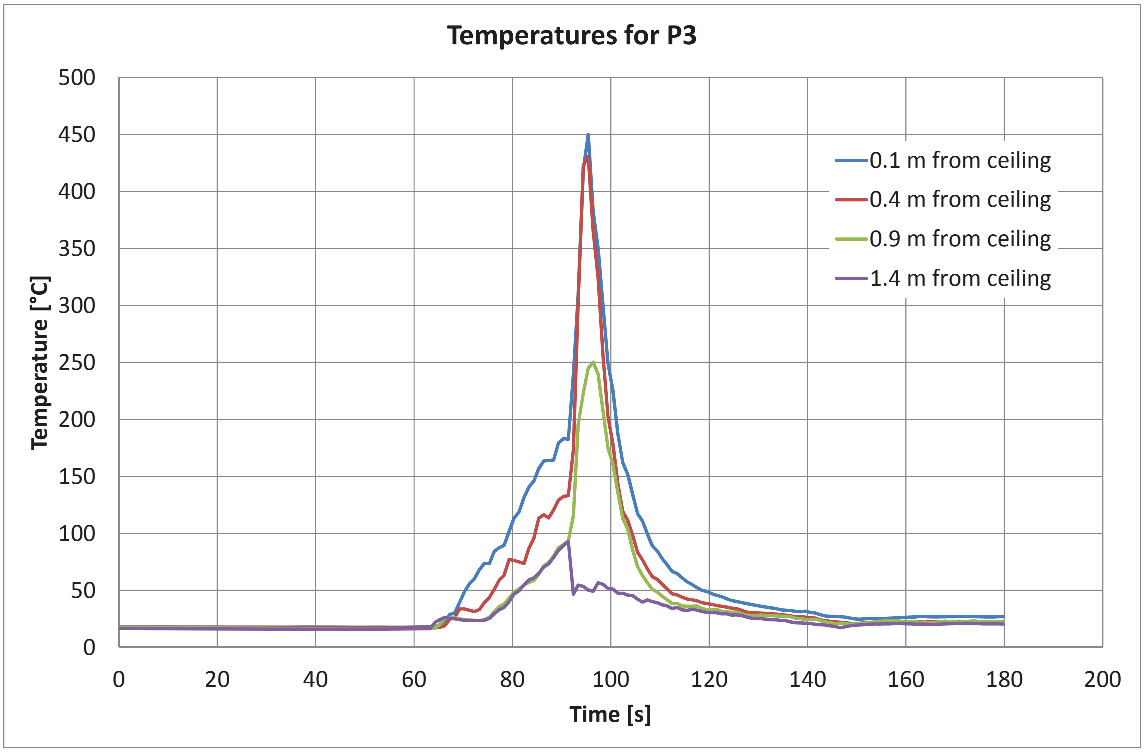

Figure 136. Test 21, Temperatures for P3

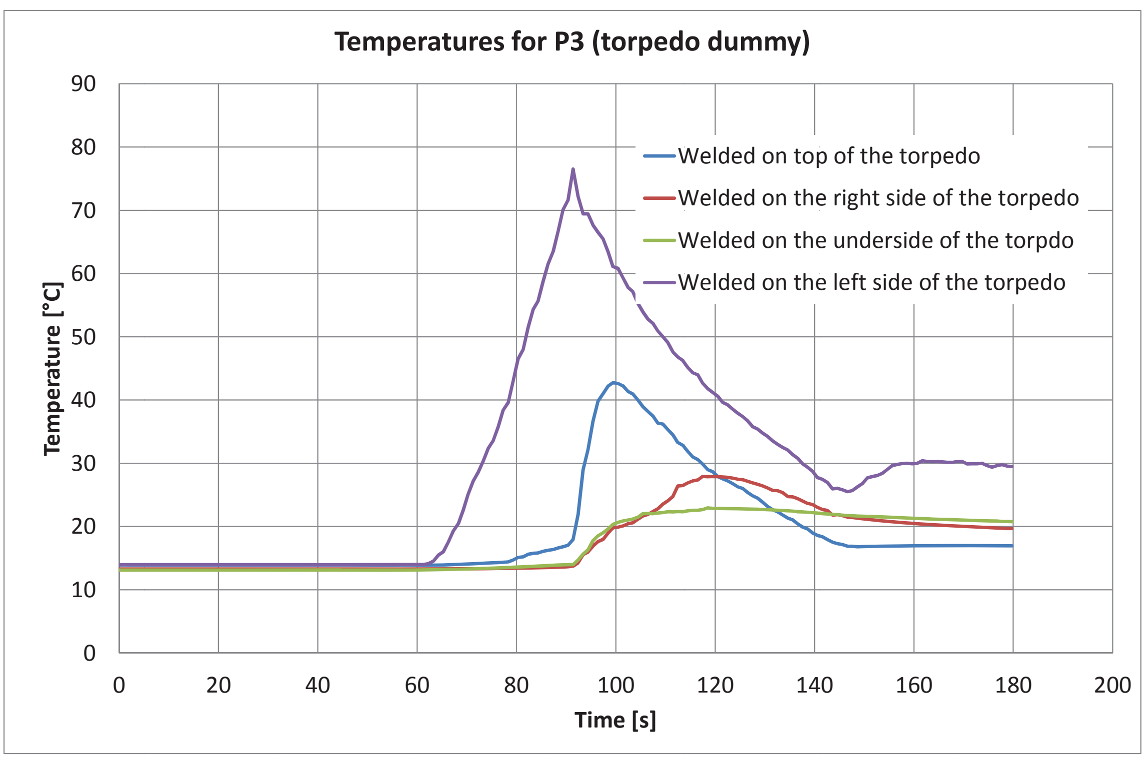

Figure 137. Test 21, Temperatures for P3 (dummy torpedo)

Appendix 1

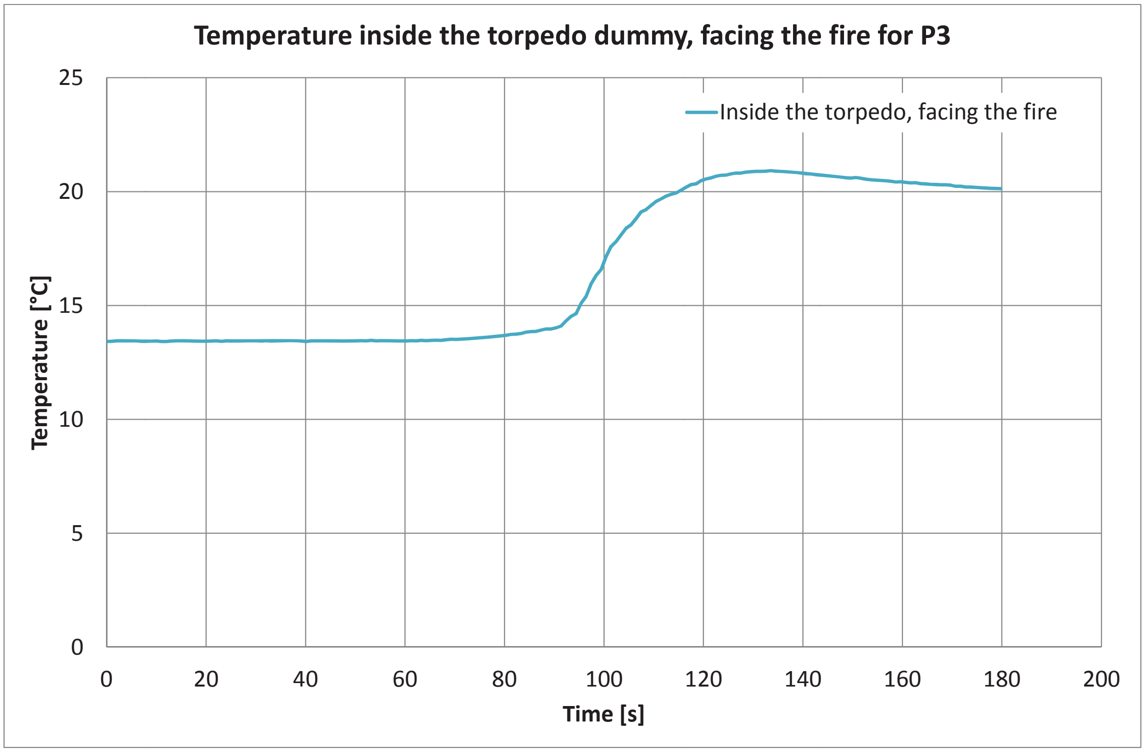

Figure 138. Test 21, Temperature inside the dummy torpedo, facing the fire for P3

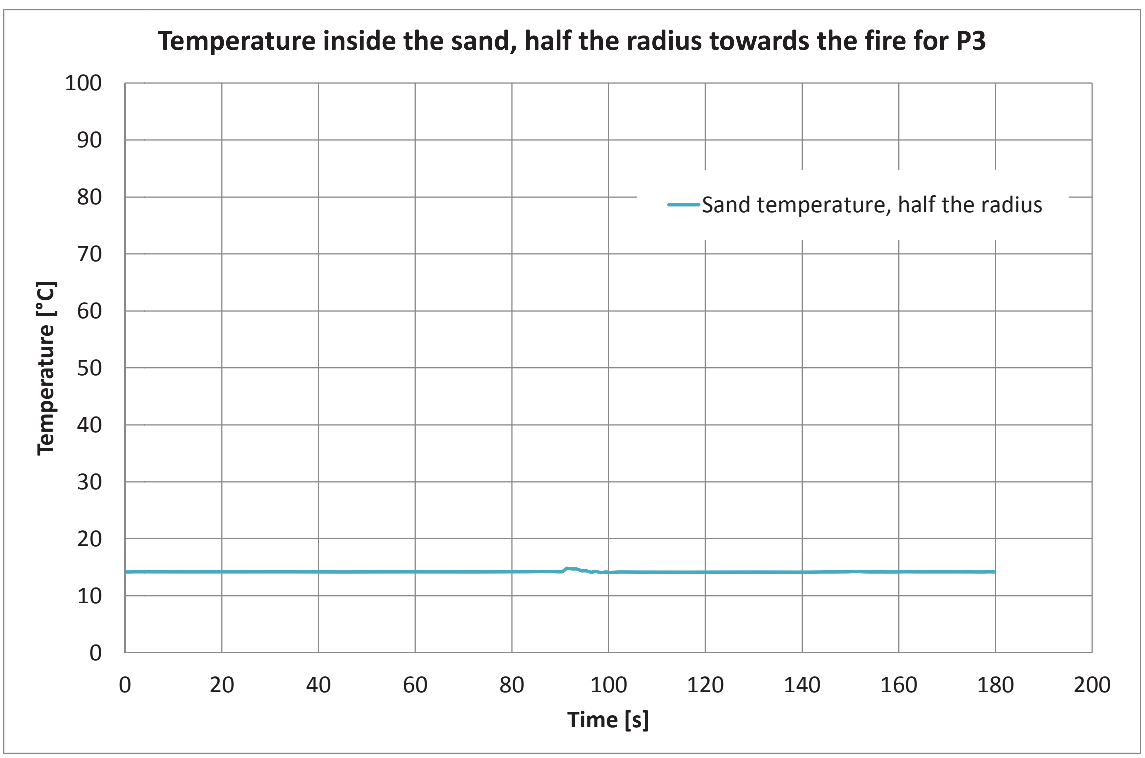

Figure 139. Test 21, Temperature inside the sand, half the radius towards the fire for P3

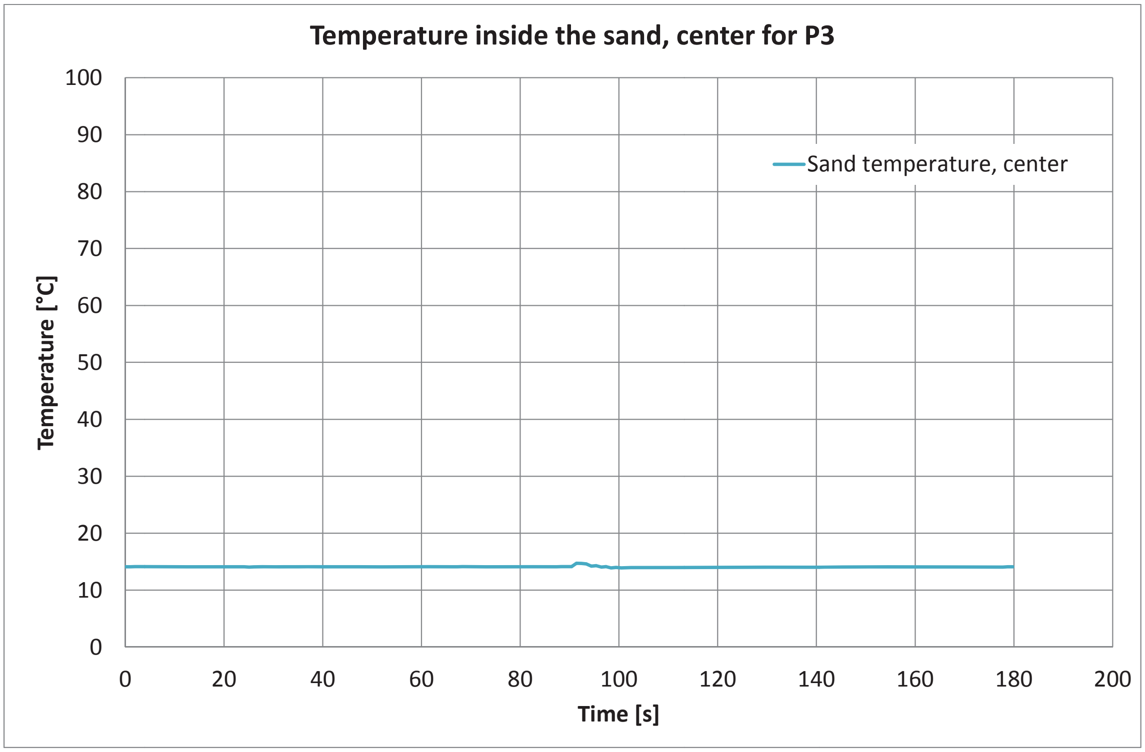

Figure 140. Test 21, Temperature inside the sand, center for P3

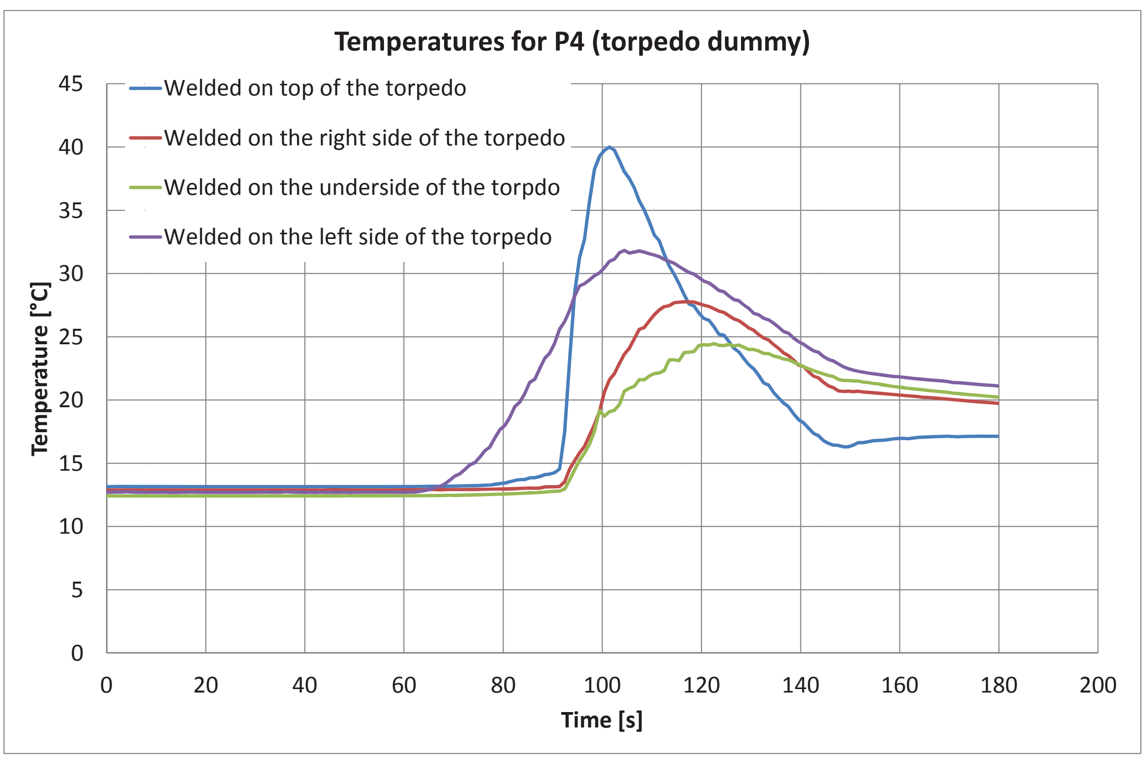

Figure 141. Test 21, Temperatures for P4 (dummy torpedo)

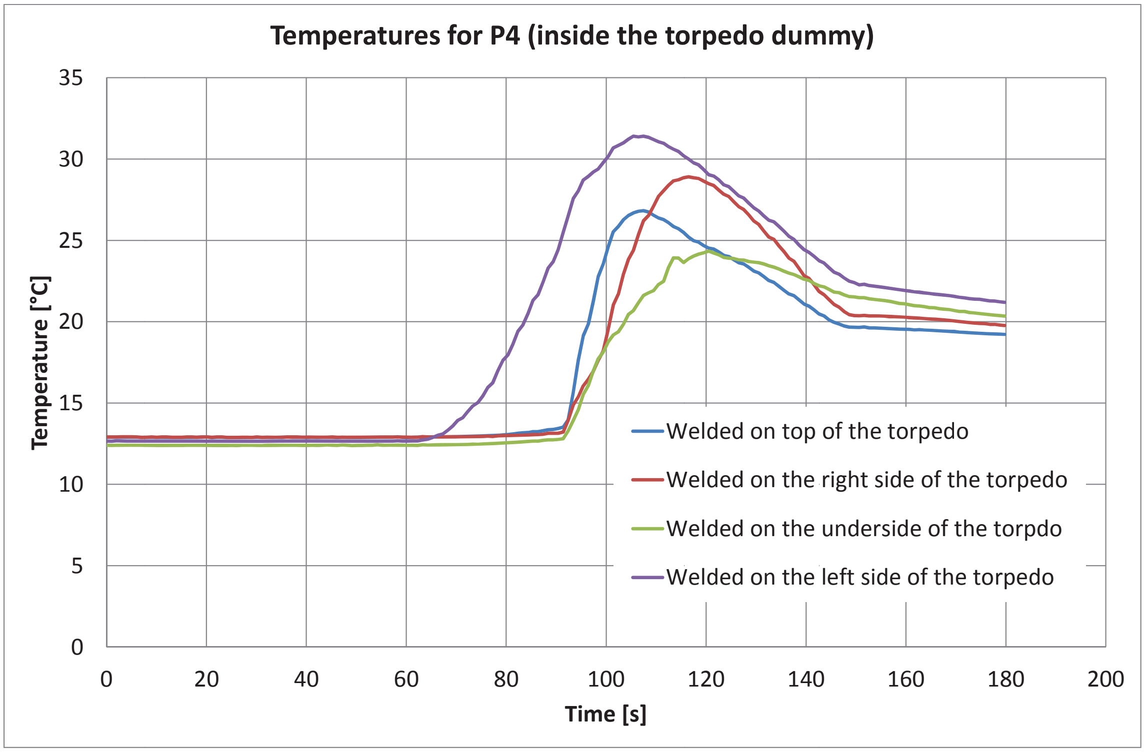

Figure 142. Test 21, Temperatures for P4 (inside the dummy torpedo)

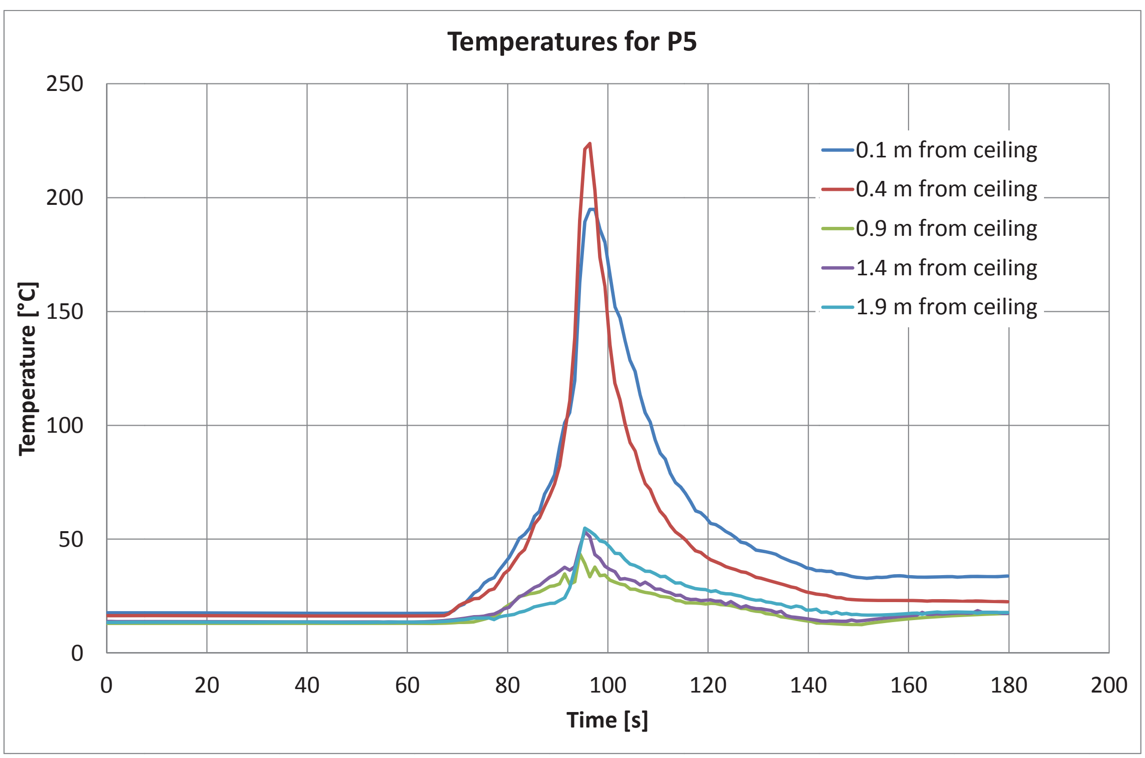

Figure 143. Test 21, Temperatures for P5

Appendix 1

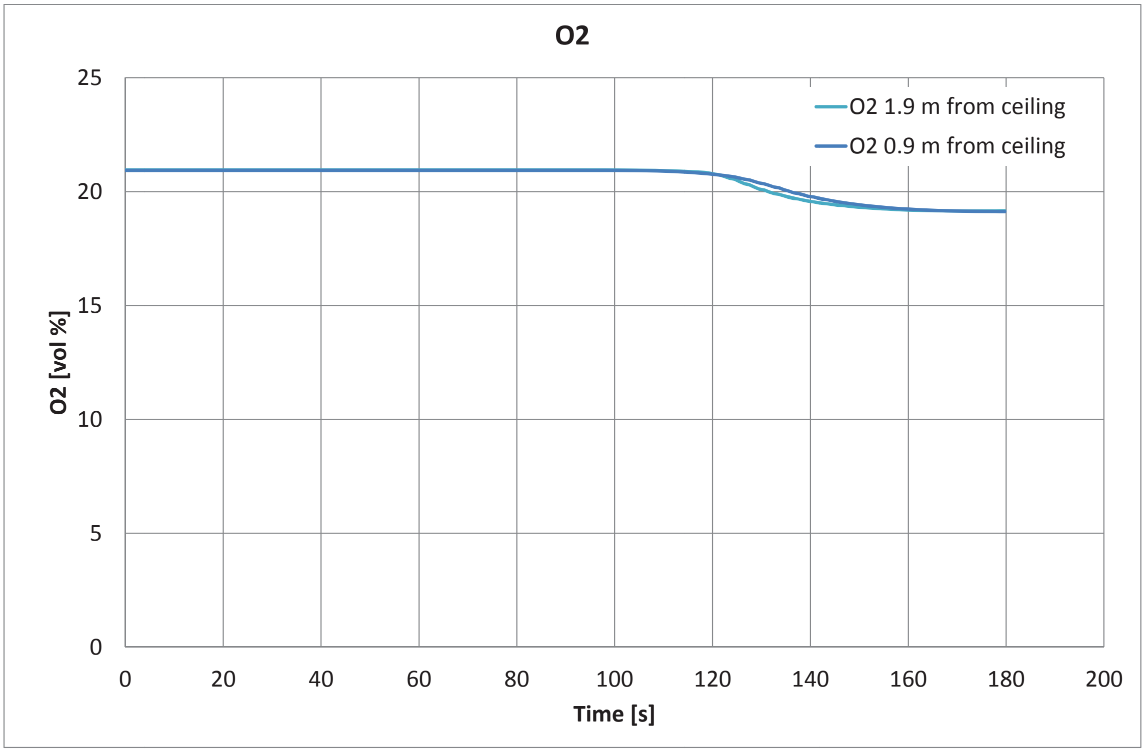

Figure 144. Test 21, O2 level. Not time-adjusted

Test protocol

Test: 22

Date: 2012-02-03

Test engineer: Michael Rahm, Johan Lindström

Type of test	Sand torpedo, drencher system 32 mm/min
Pool fire size (Ø in mm)	1170
Position of pool fire	2 (250 mm from the edge of the torpedo)
Obstruction (% of pool area)	
Amount of diesel (L)	15
Height of freeboard (mm)	25
Water mist nozzle	
Bulkhead nozzle	
Drencher nozzle	LECHLER 460.928
Distance from nozzle to pool area	172 cm
Pressure (bar)	10
Water flow (L/min)	157
Notes:	
Time (s)	
0	Start measuring program and video camera
60	Ignition
90	Activation of drencher system
97	The fire was extinguished

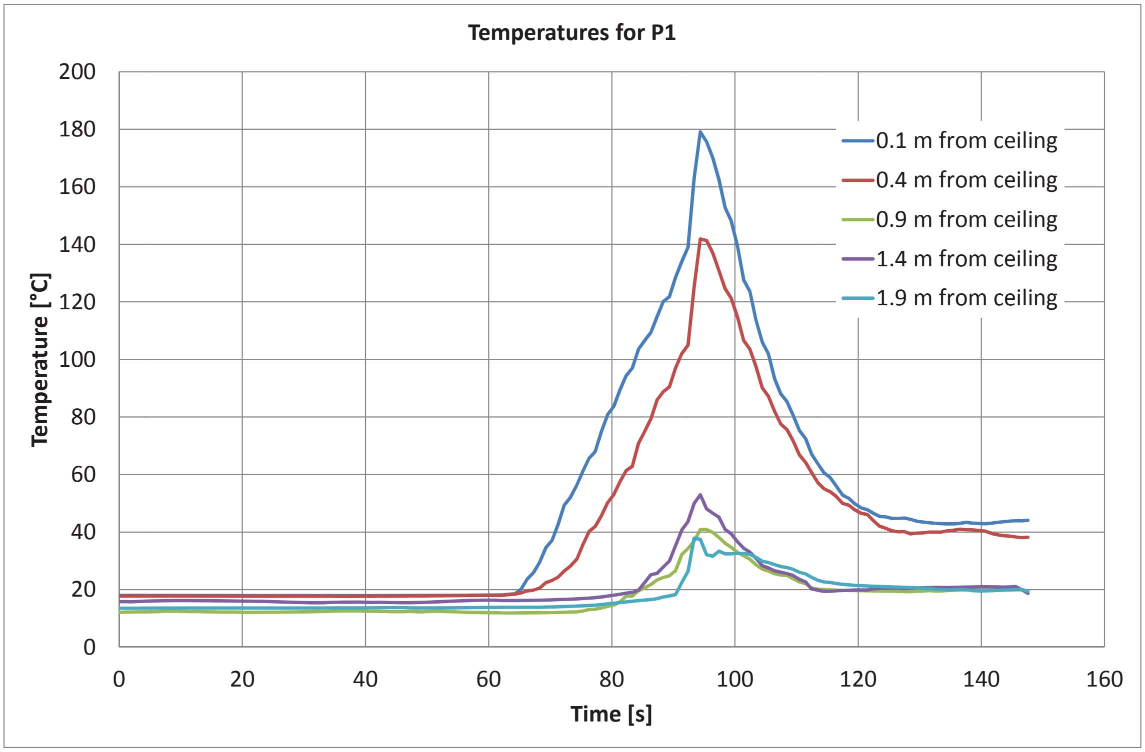

Figure 145. Test 22, Temperatures for P1

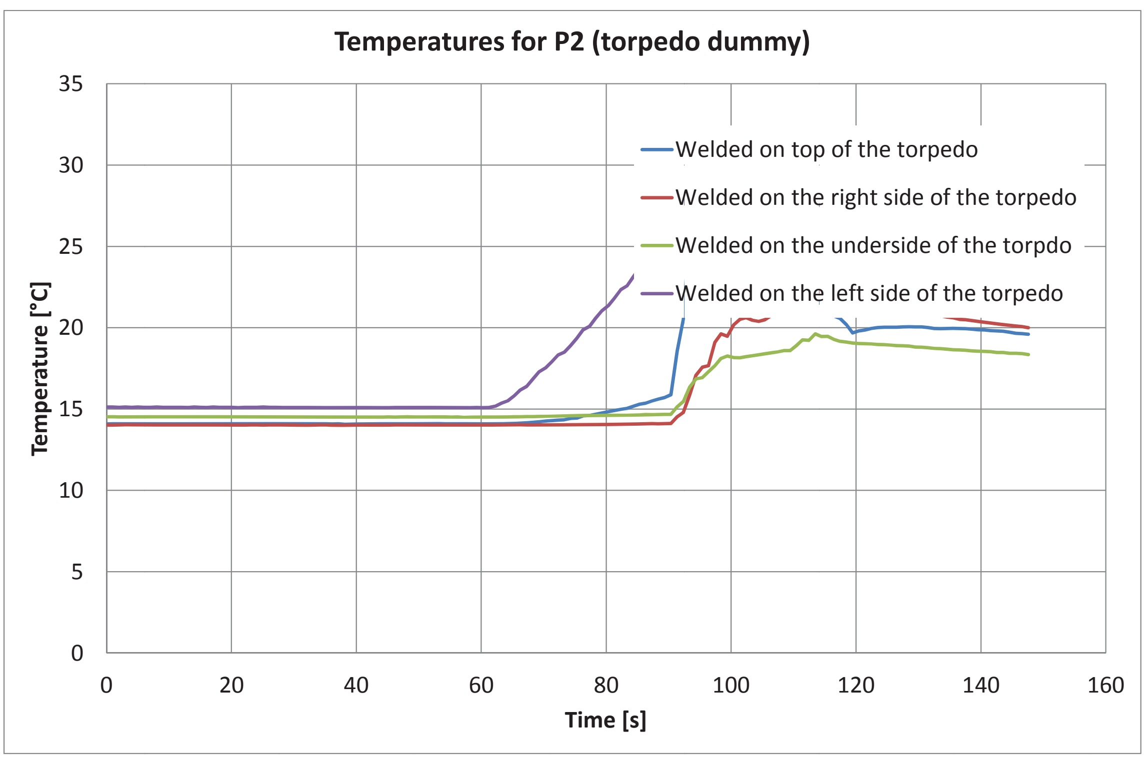

Figure 146. Test 22, Temperatures for P2 (dummy torpedo)

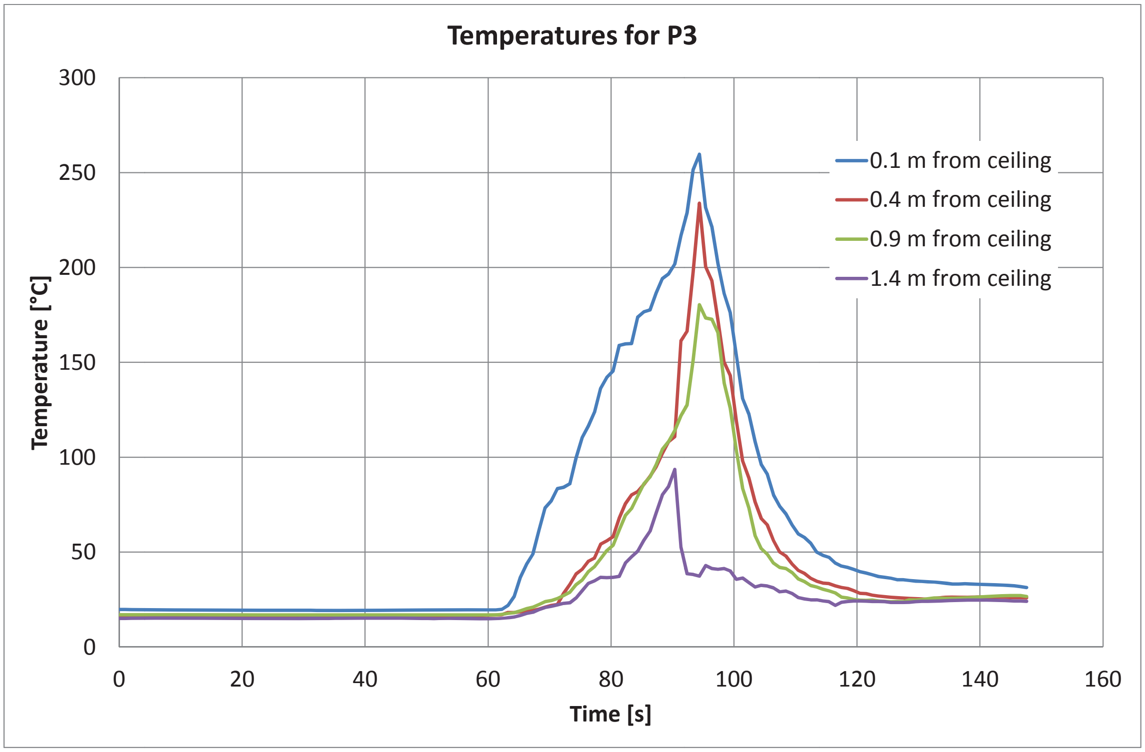

Figure 147. Test 22, Temperatures for P3

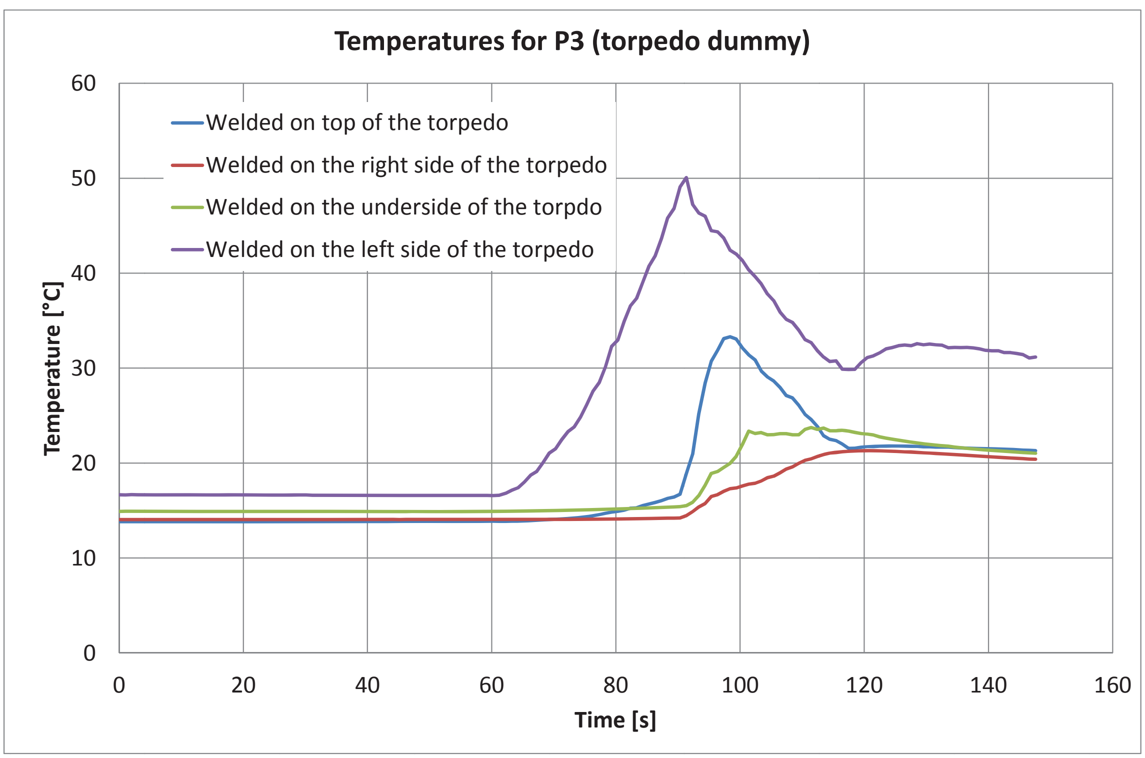

Figure 148. Test 22, Temperatures for P3 (dummy torpedo)

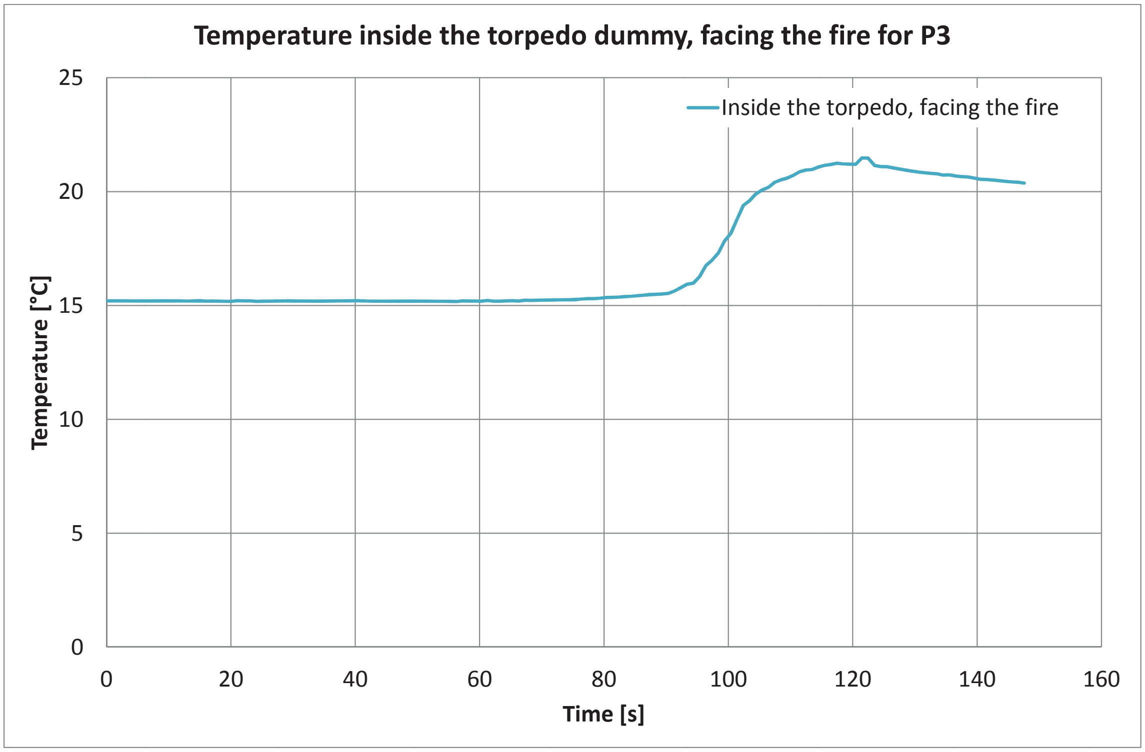

Figure 149. Test 22, Temperature inside the dummy torpedo, facing the fire for P3

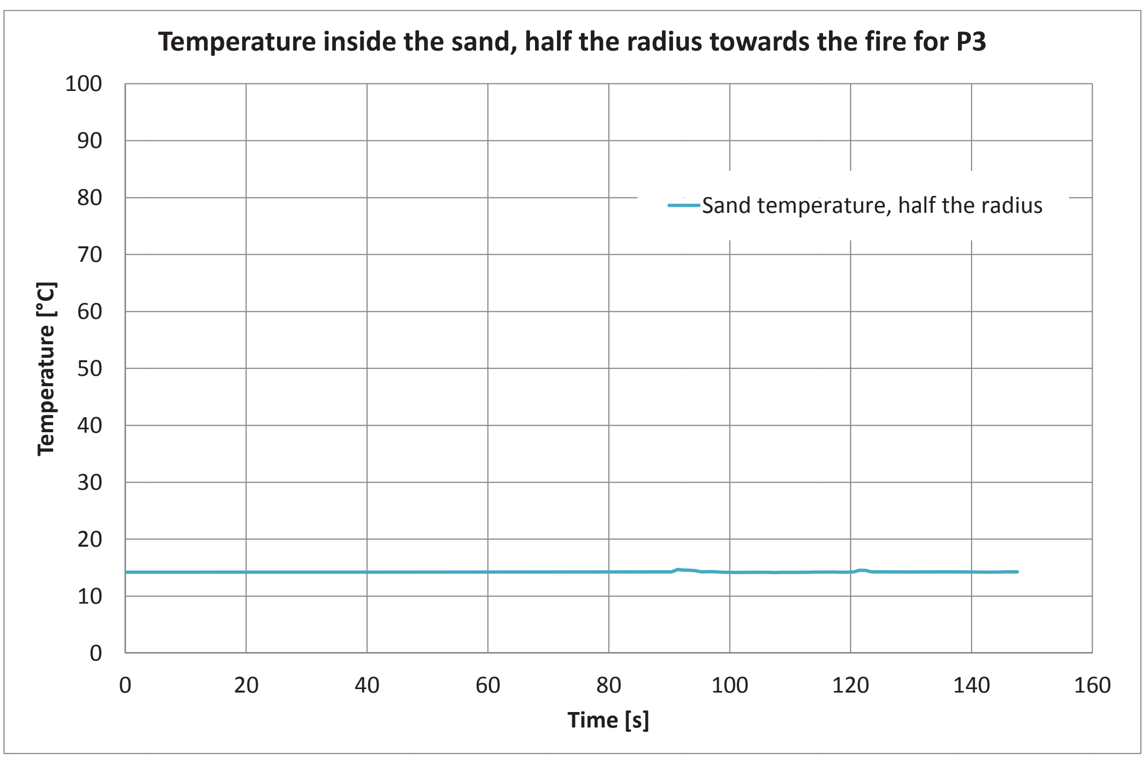

Figure 150. Test 22, Temperature inside the sand, half the radius towards the fire for P3

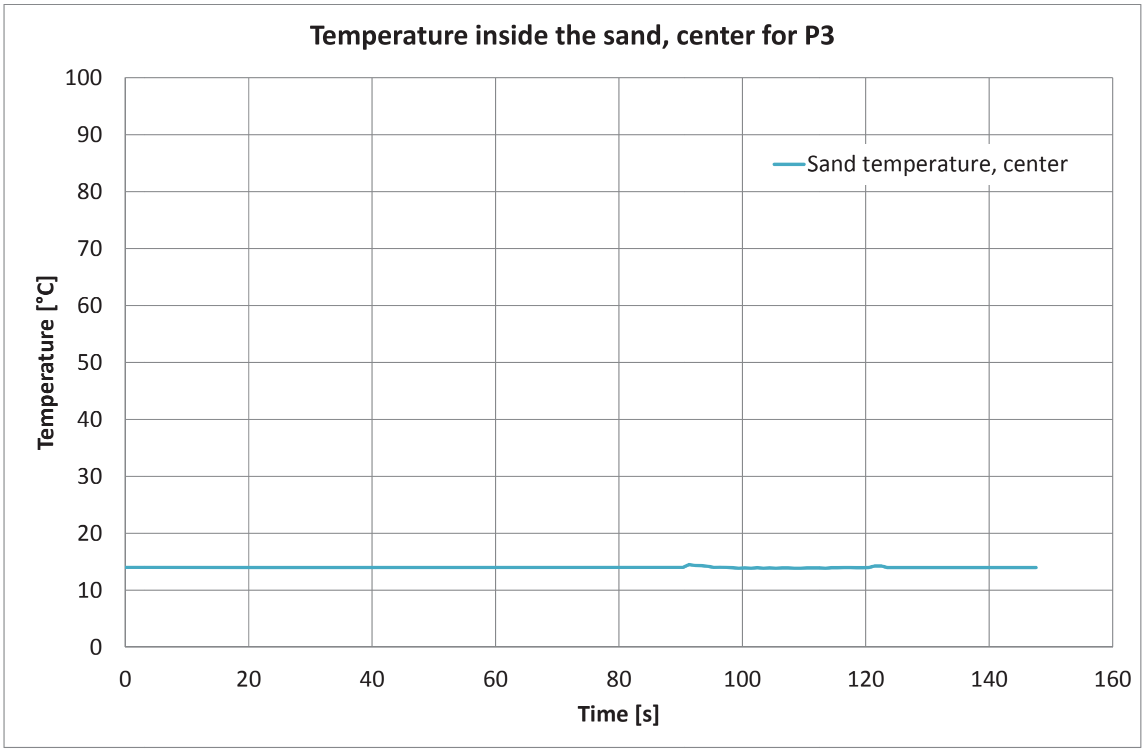

Figure 151. Test 22, Temperature inside the sand, center for P3

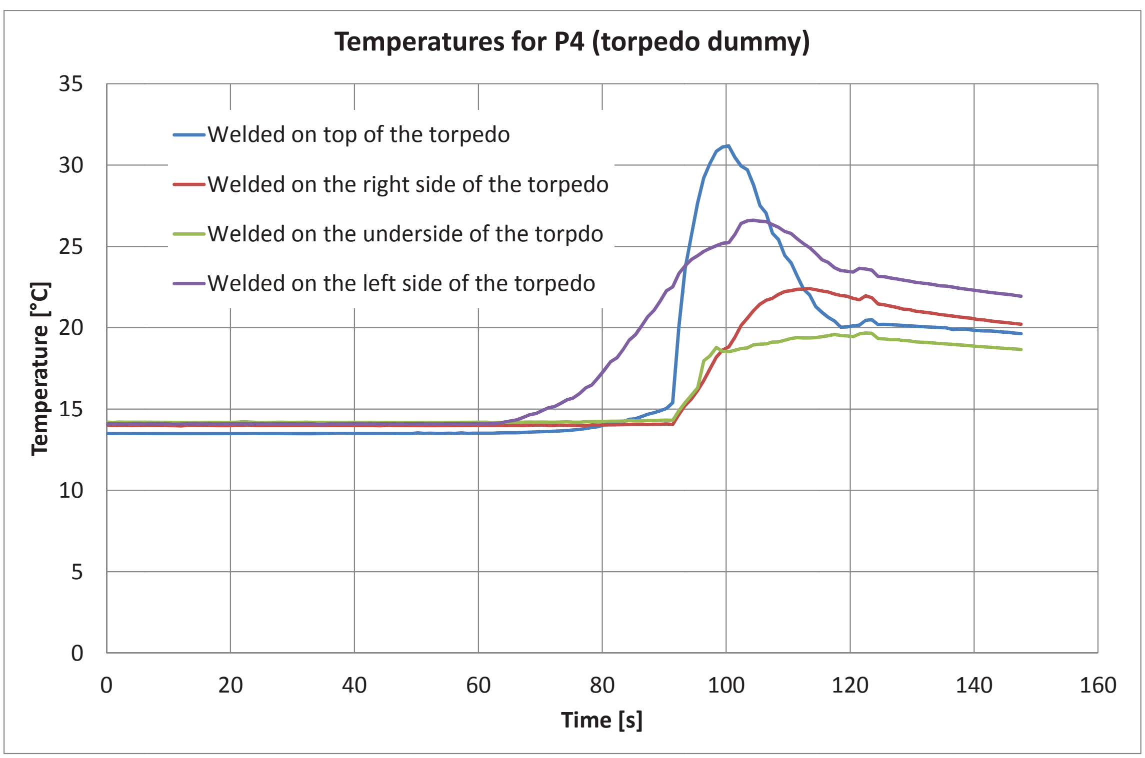

Figure 152. Test 22, Temperatures for P4 (dummy torpedo)

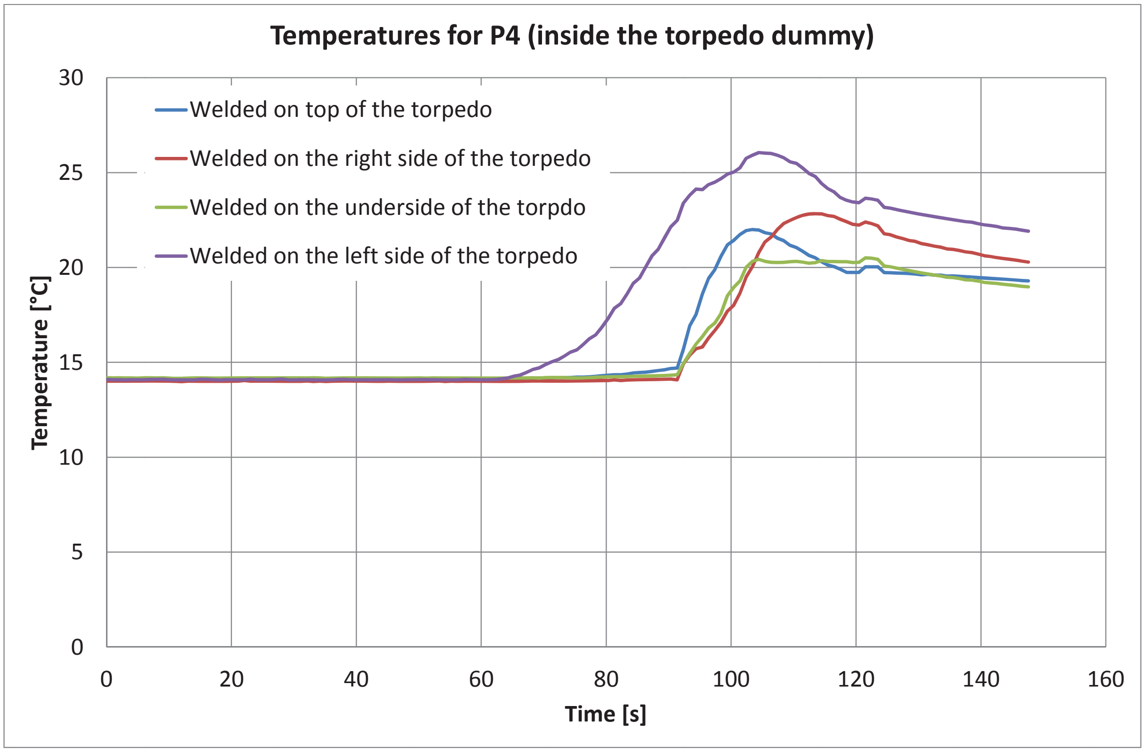

Figure 153. Test 22, Temperatures for P4 (inside the dummy torpedo)

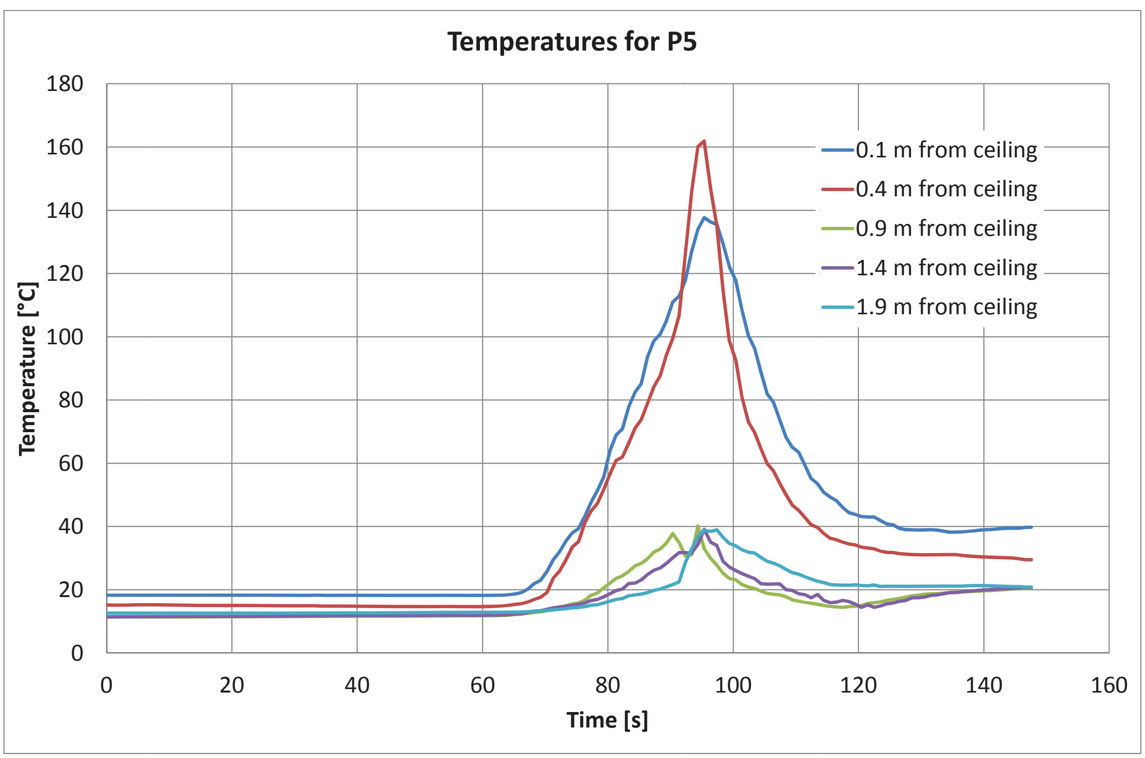

Figure 154. Test 22, Temperatures for P5

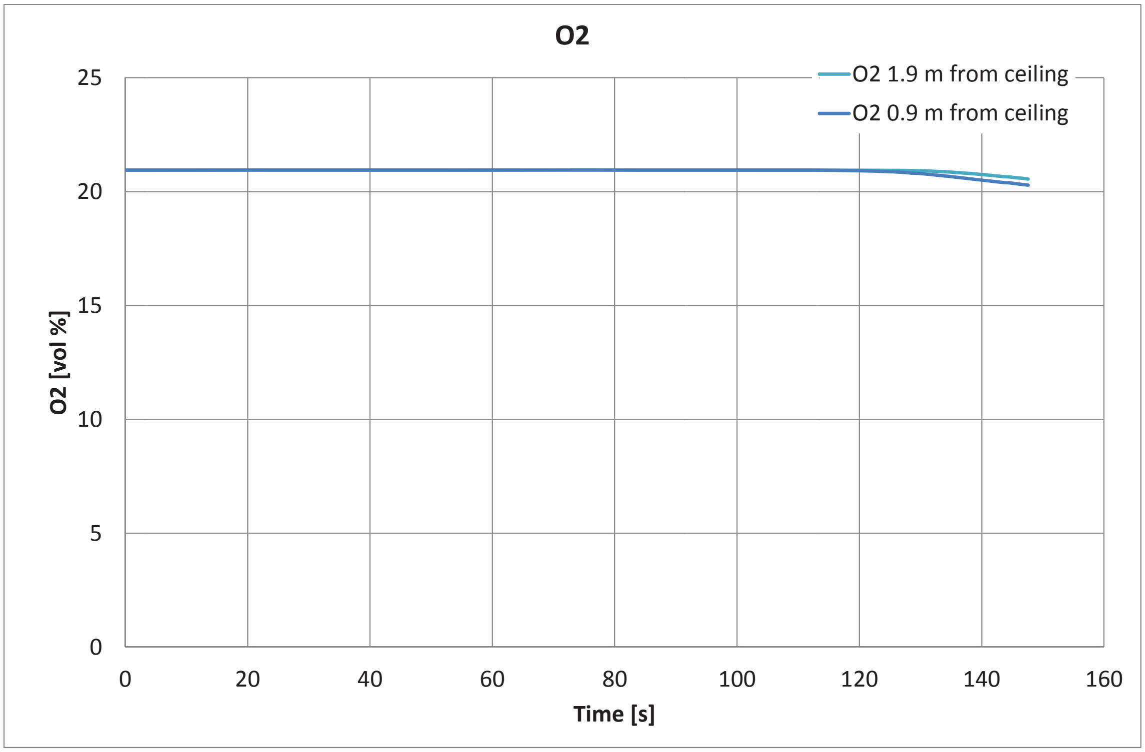

Figure 155. Test 22, O2 level. Not time-adjusted

Appendix 1

Test protocol

Test: 23

Date: 2012-02-03

Test engineer: Michael Rahm, Johan Lindström

Type of test	Sand torpedo, drencher system 32 mm/min
Pool fire size (Ø in mm)	1170
Position of pool fire	2 (250 mm from the edge of the torpedo)
Obstruction (% of pool area)	At the edge of the pool area a vertical (460 mm high Promatect sheet was placed)
Amount of diesel (L)	15
Height of freeboard (mm)	25
Water mist nozzle	
Bulkhead nozzle	
Drencher nozzle	LECHLER 460.928
Distance from nozzle to pool area	172 cm
Pressure (bar)	10
Water flow (L/min)	157
Notes:	
Time (s)	
0	Start measuring program and video camera
60	Ignition
90	Activation of drencher system
100	A small flame behind the Promatect sheet
105	The fire was extinguished

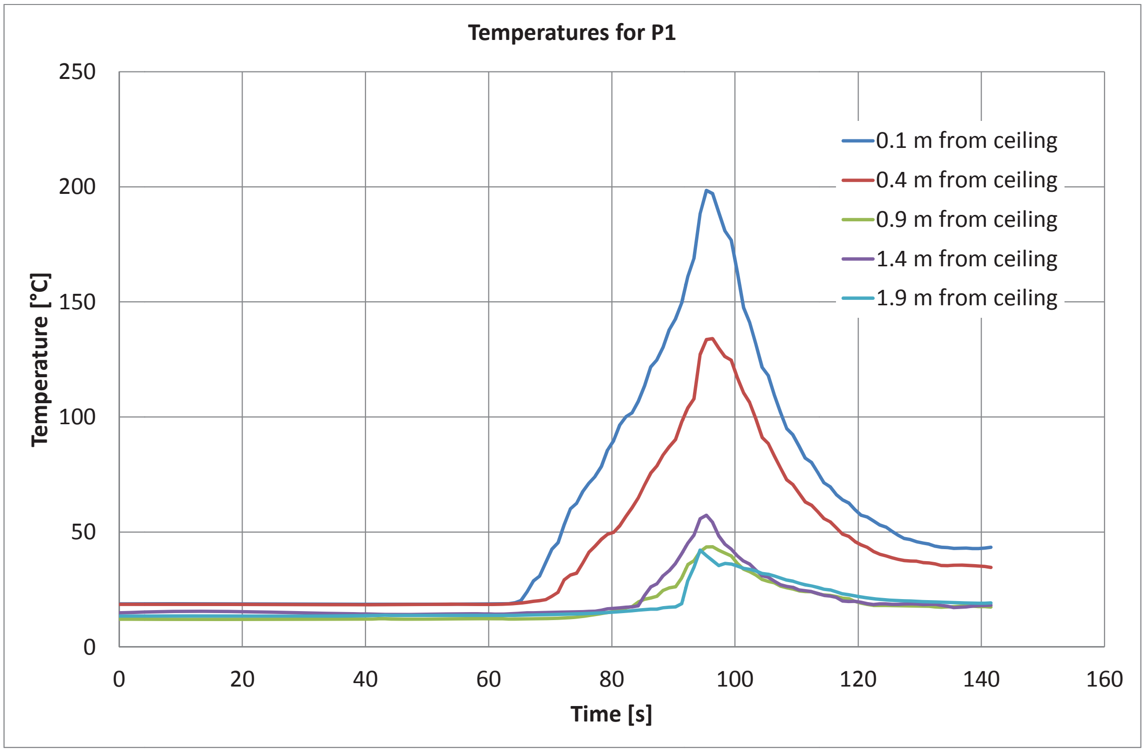

Figure 156. Test 23, Temperatures for P1

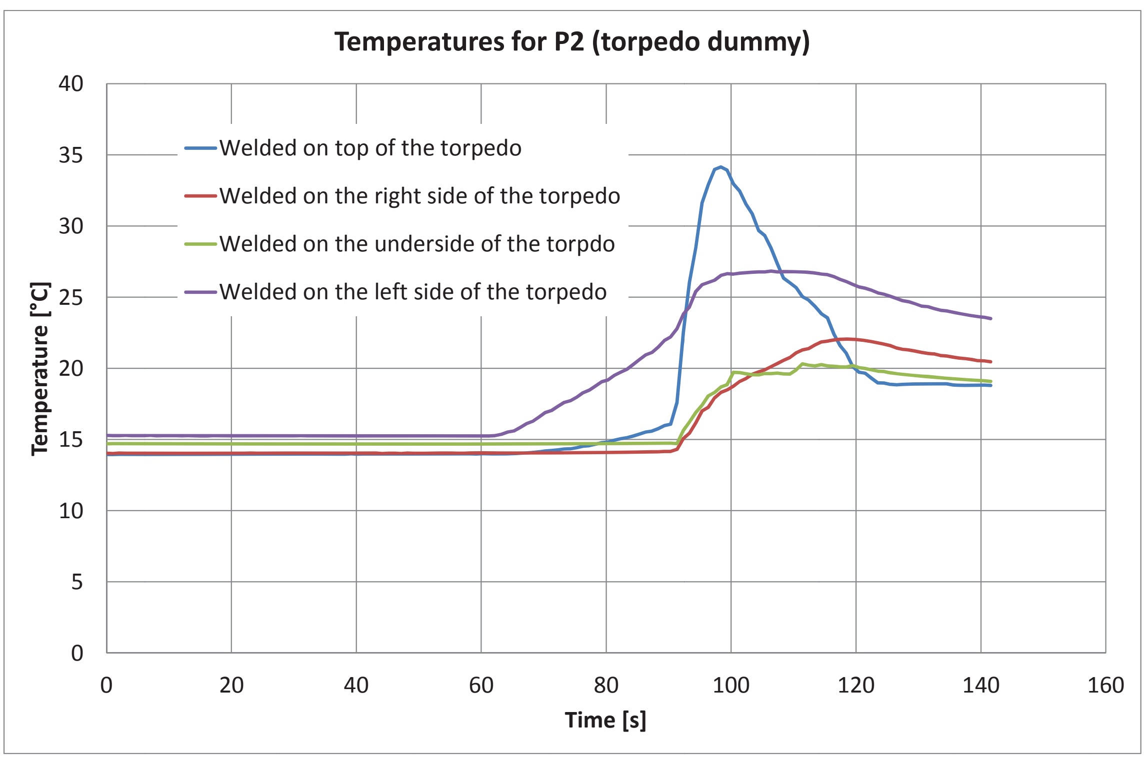

Figure 157. Test 23, Temperatures for P2 (dummy torpedo)

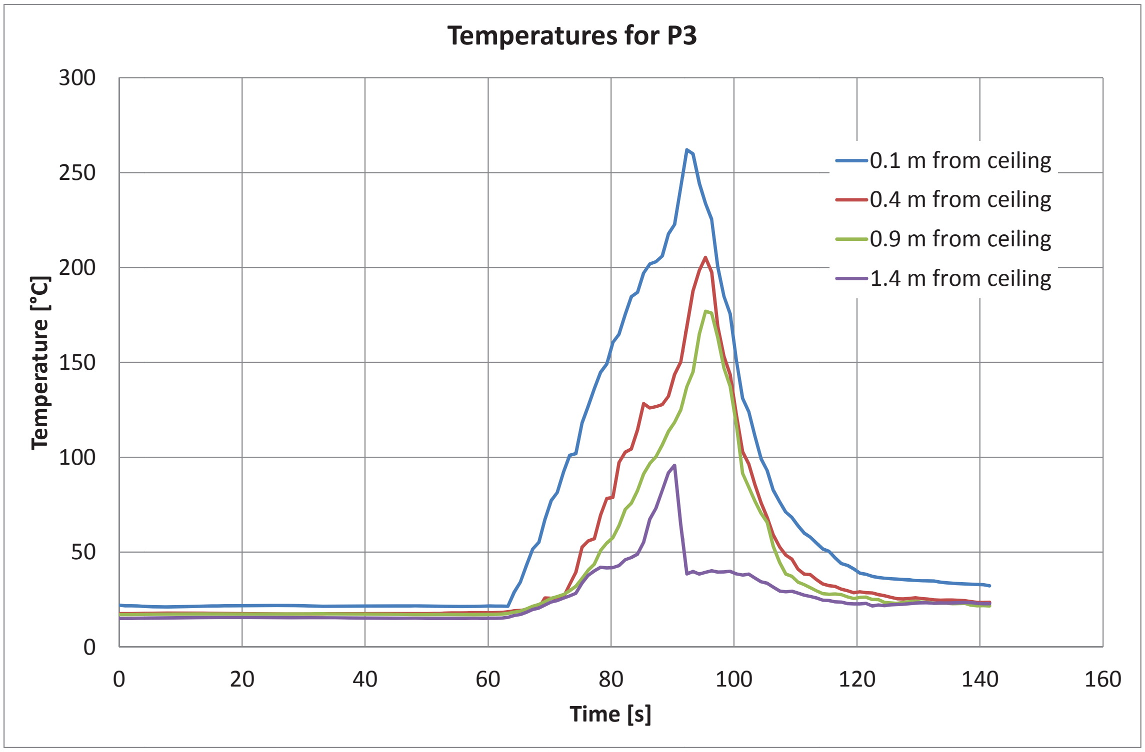

Figure 158. Test 23, Temperatures for P3

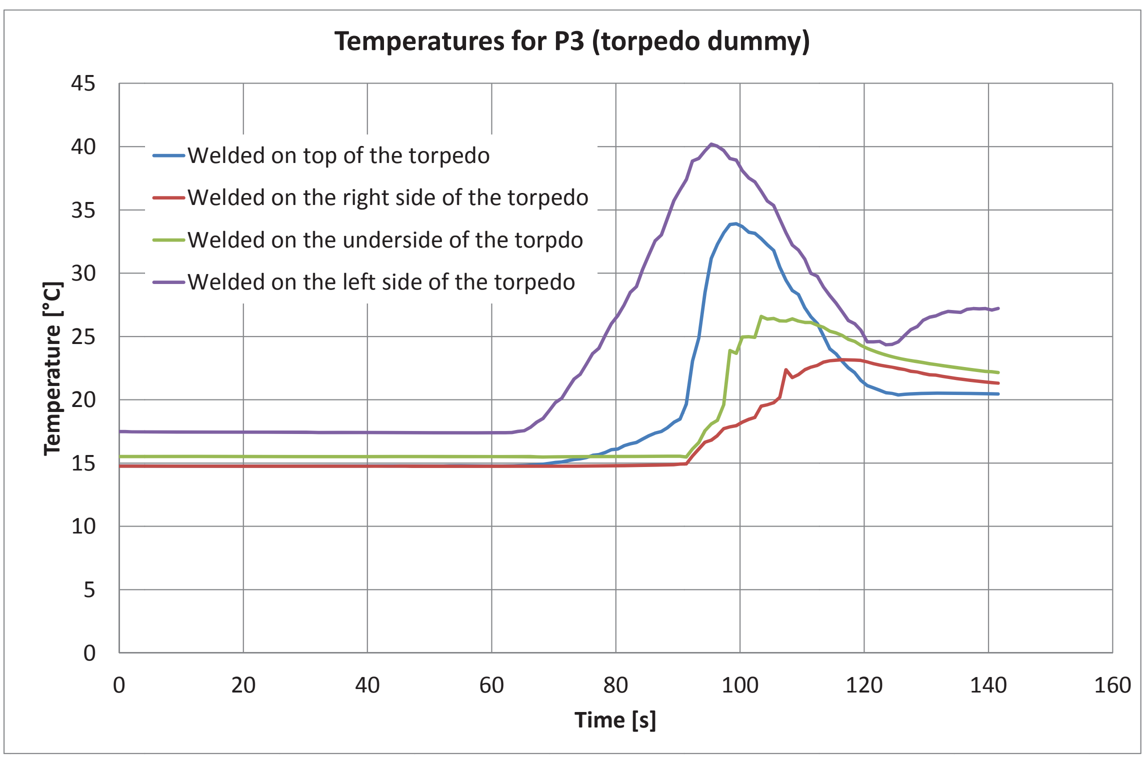

Figure 159. Test 23, Temperatures for P3 (dummy torpedo)

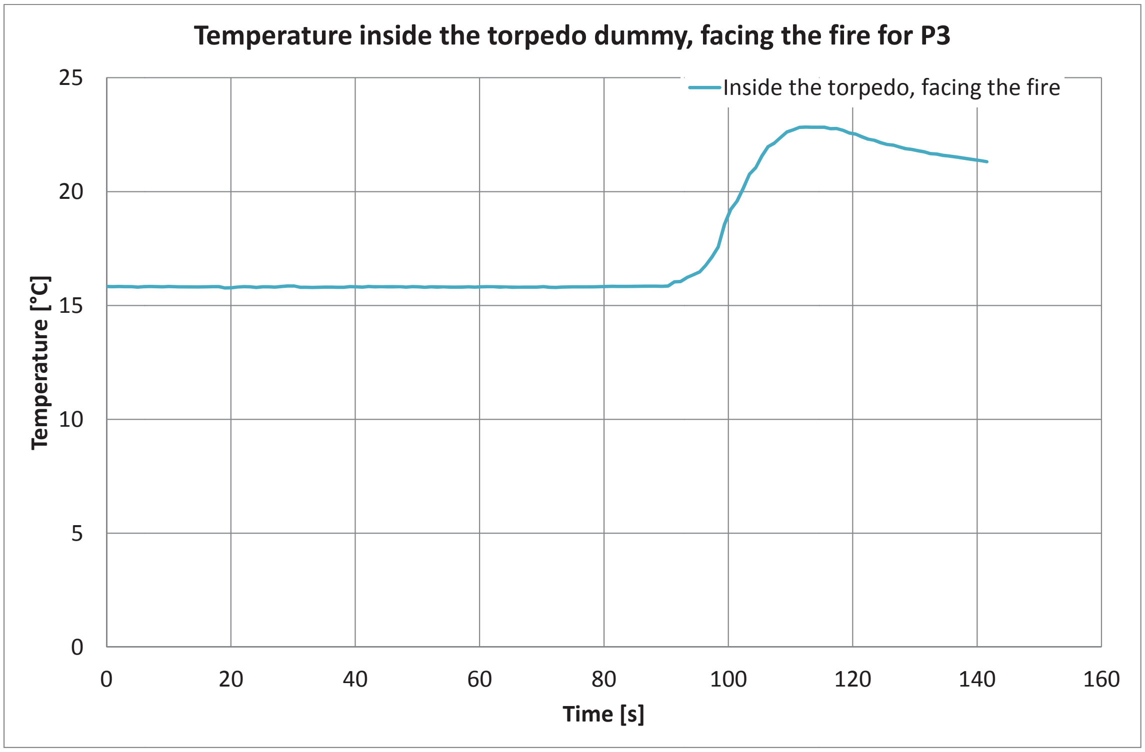

Figure 160. Test 23, Temperature inside the dummy torpedo, facing the fire for P3

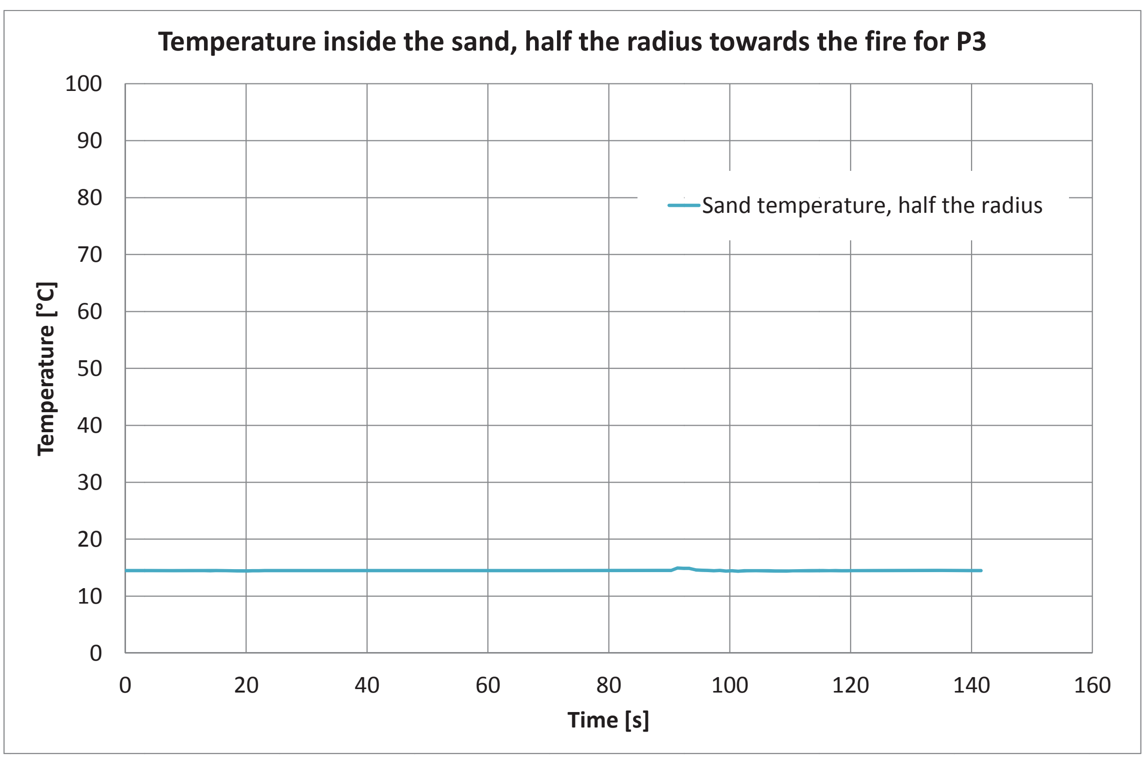

Figure 161. Test 23, Temperature inside the sand, half the radius towards the fire for P3

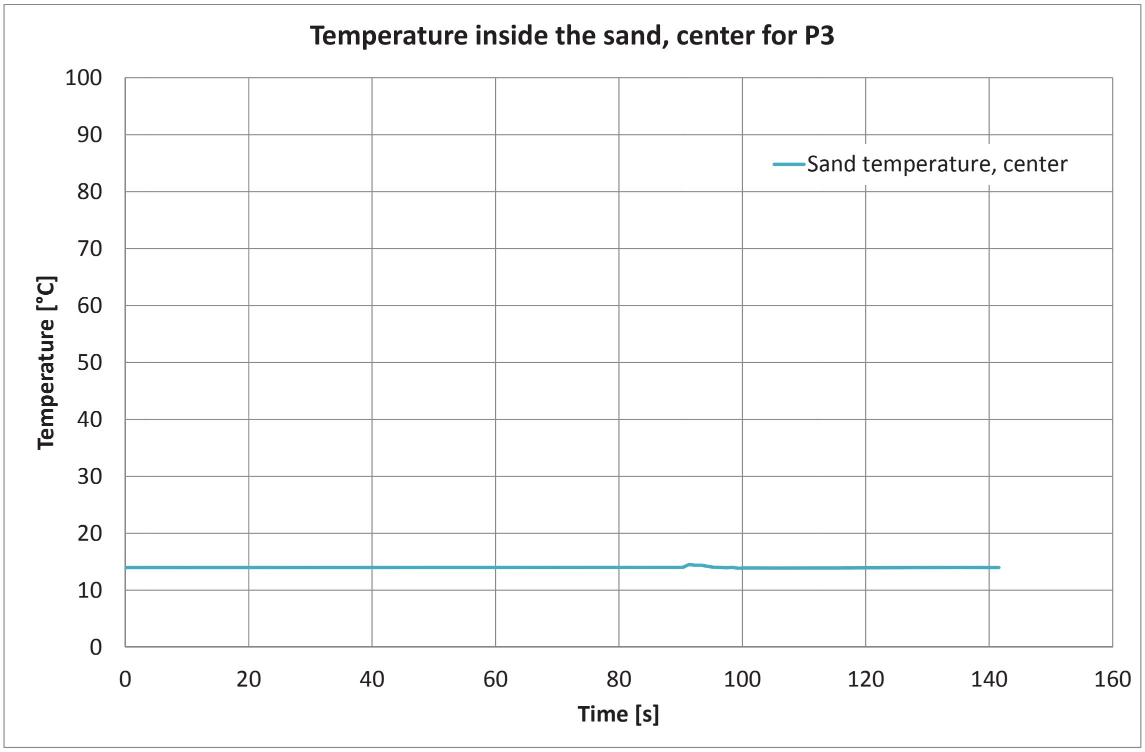

Figure 162. Test 23, Temperature inside the sand, center for P3

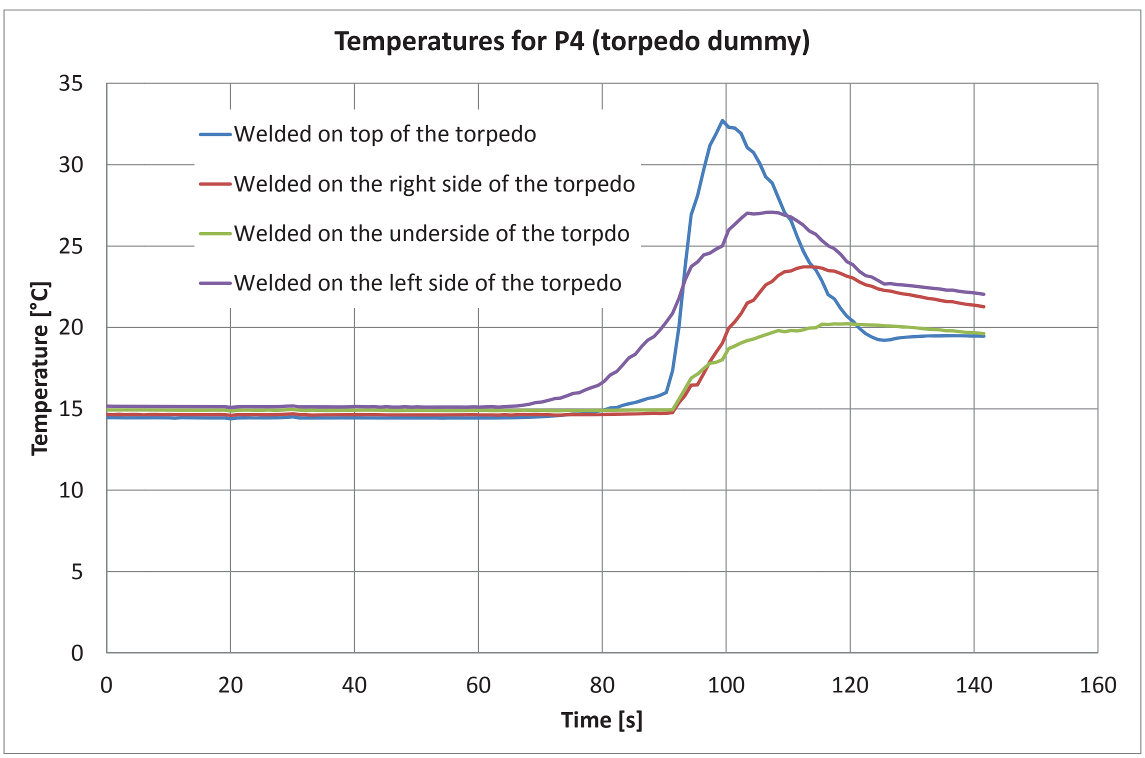

Figure 163. Test 23, Temperatures for P4 (dummy torpedo)

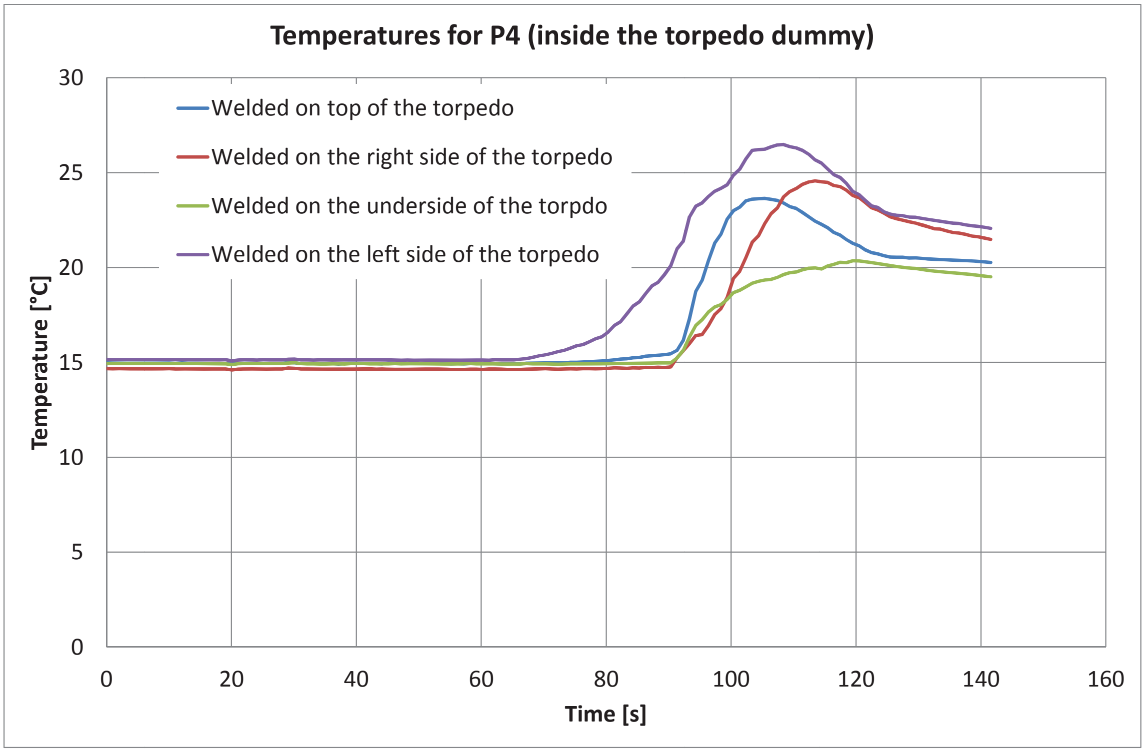

Figure 164. Test 23, Temperatures for P4 (inside the dummy torpedo)

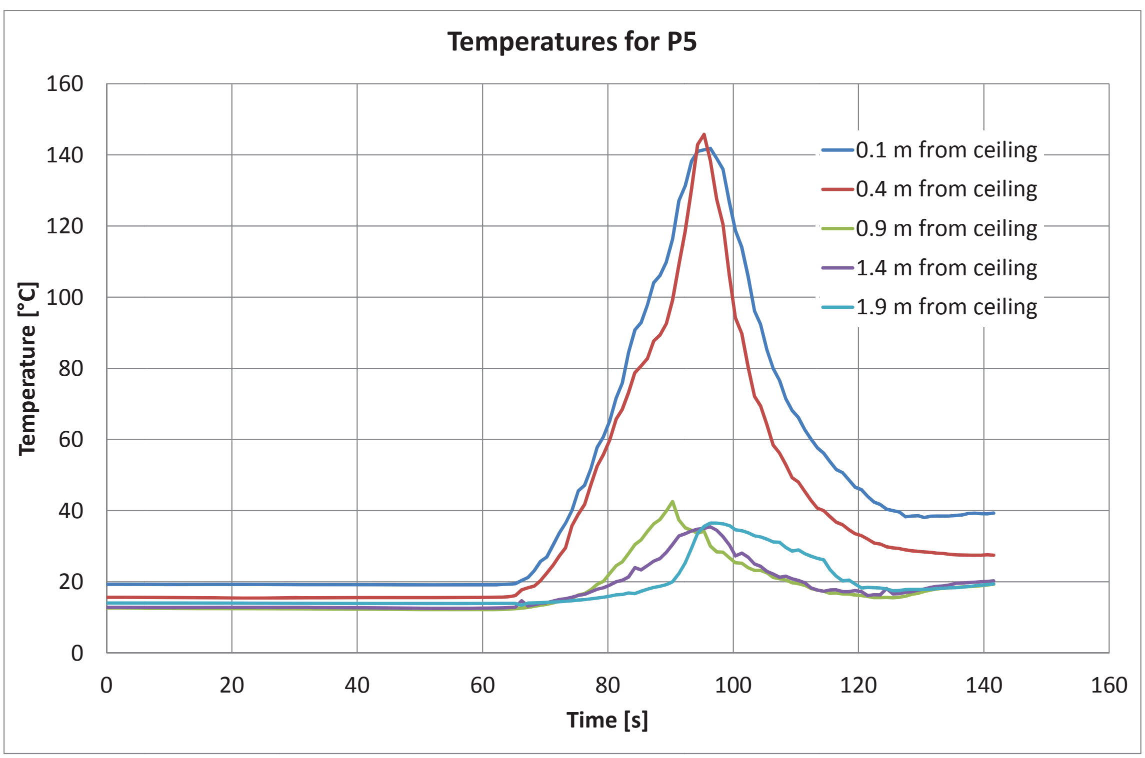

Figure 165. Test 23, Temperatures for P5

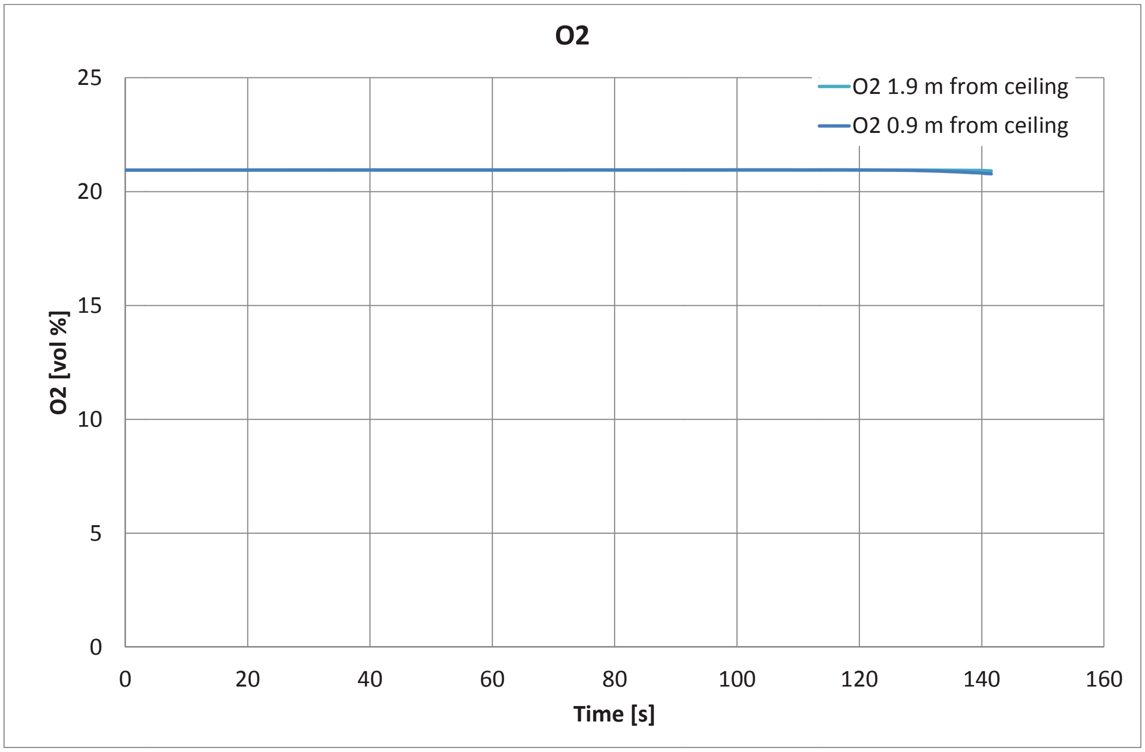

Figure 166. Test 23, O2 level. Not time-adjusted

Test protocol

Test: 24

Date: 2012-02-03

Test engineer: Michael Rahm, Johan Lindström

Type of test	Sand torpedo, drencher system 10 mm/min
Pool fire size (Ø in mm)	1170
Position of pool fire	2 (250 mm from the edge of the torpedo)
Obstruction (% of pool area)	
Amount of diesel (L)	15
Height of freeboard (mm)	25
Water mist nozzle	
Bulkhead nozzle	
Drencher nozzle	LECHLER 460.728
Distance from nozzle to pool area	172 cm
Pressure (bar)	10
Water flow (L/min)	51
Notes:	
Time (s)	
0	Start measuring program and video camera
60	Ignition
90	Activation of drencher system
95	Small flames at the left side pool edge
250	The fire was extinguished

Appendix 1

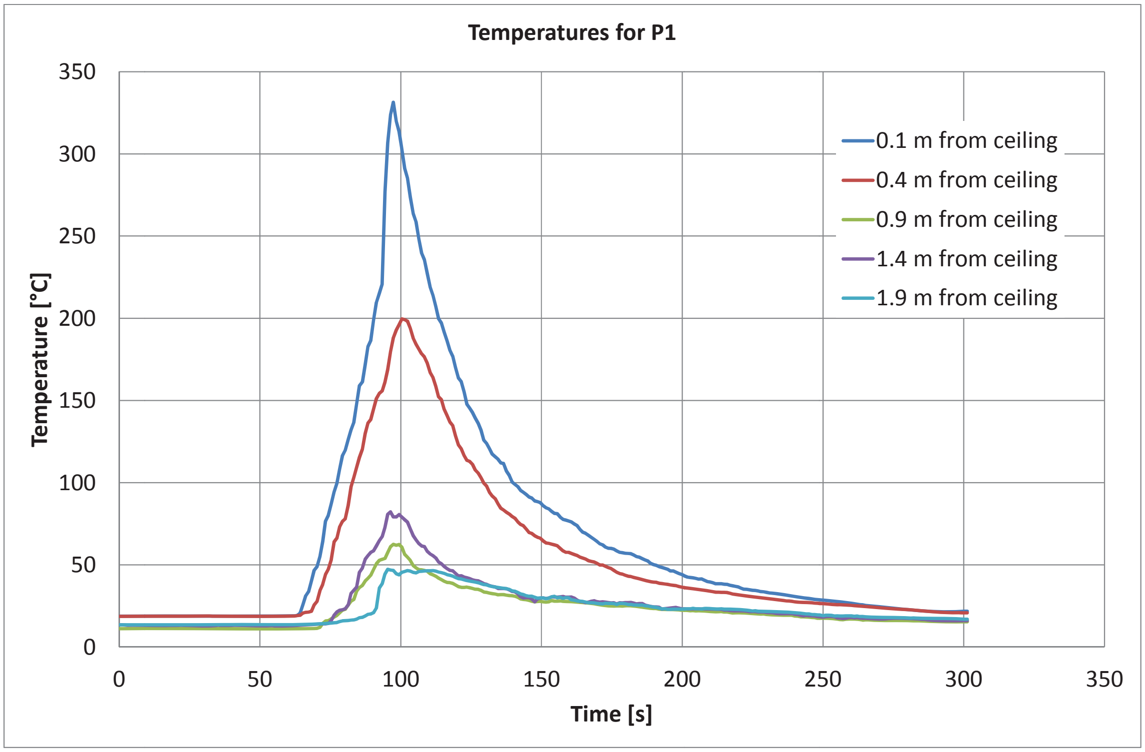

Figure 167. Test 24, Temperatures for P1

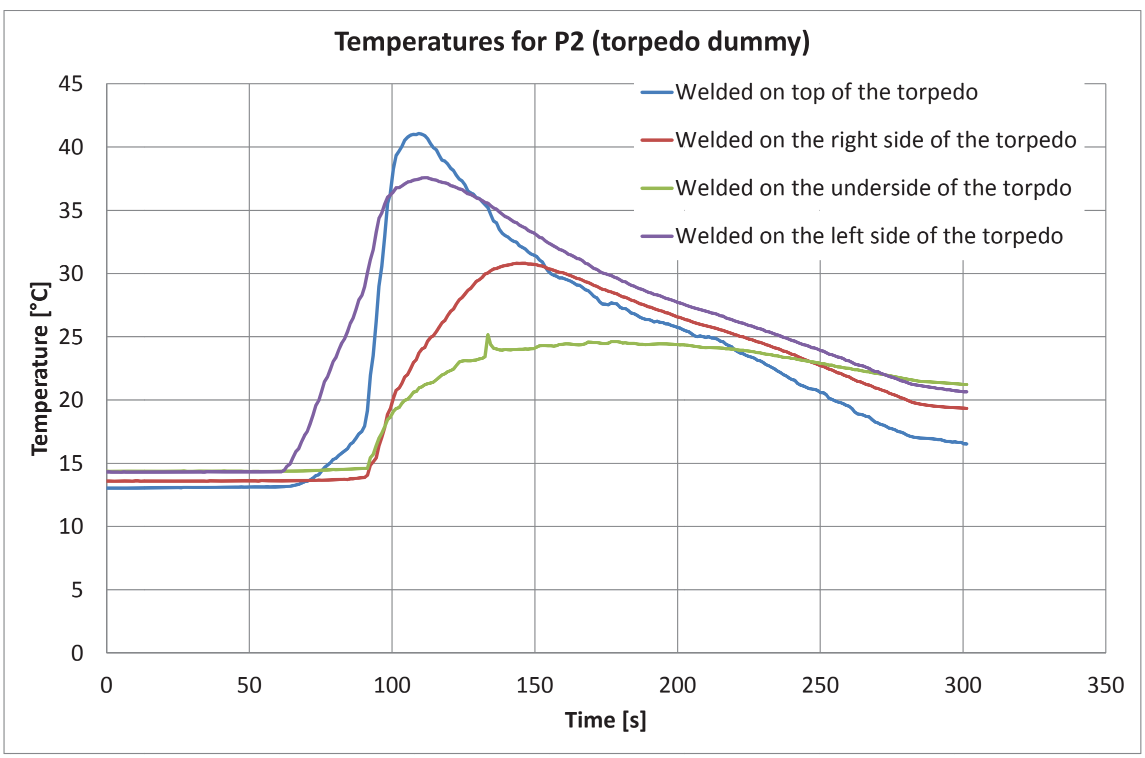

Figure 168. Test 24, Temperatures for P2 (dummy torpedo)

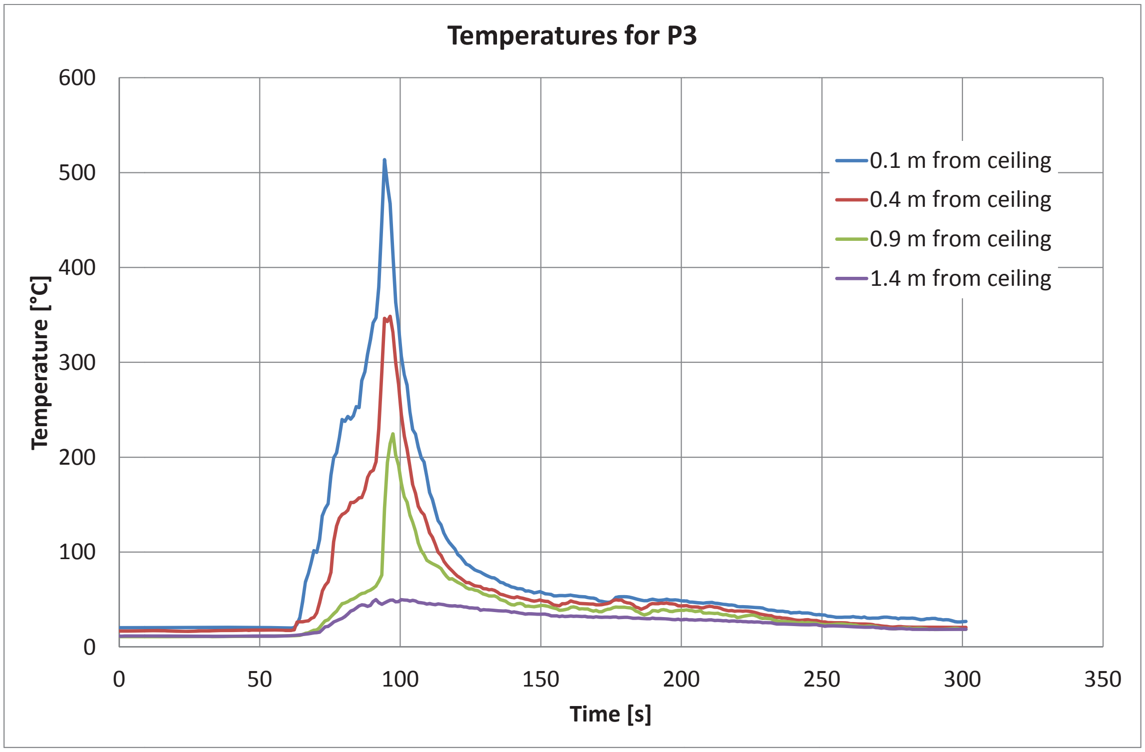

Figure 169. Test 24, Temperatures for P3

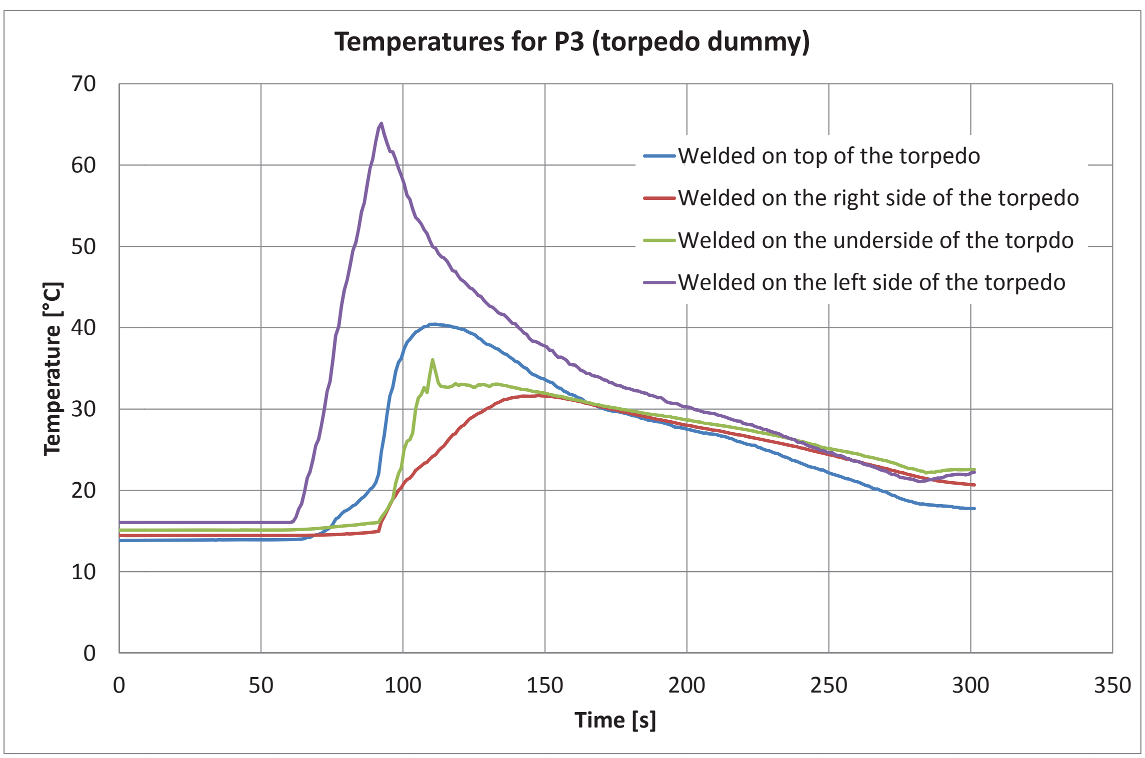

Figure 170. Test 24, Temperatures for P3 (dummy torpedo)

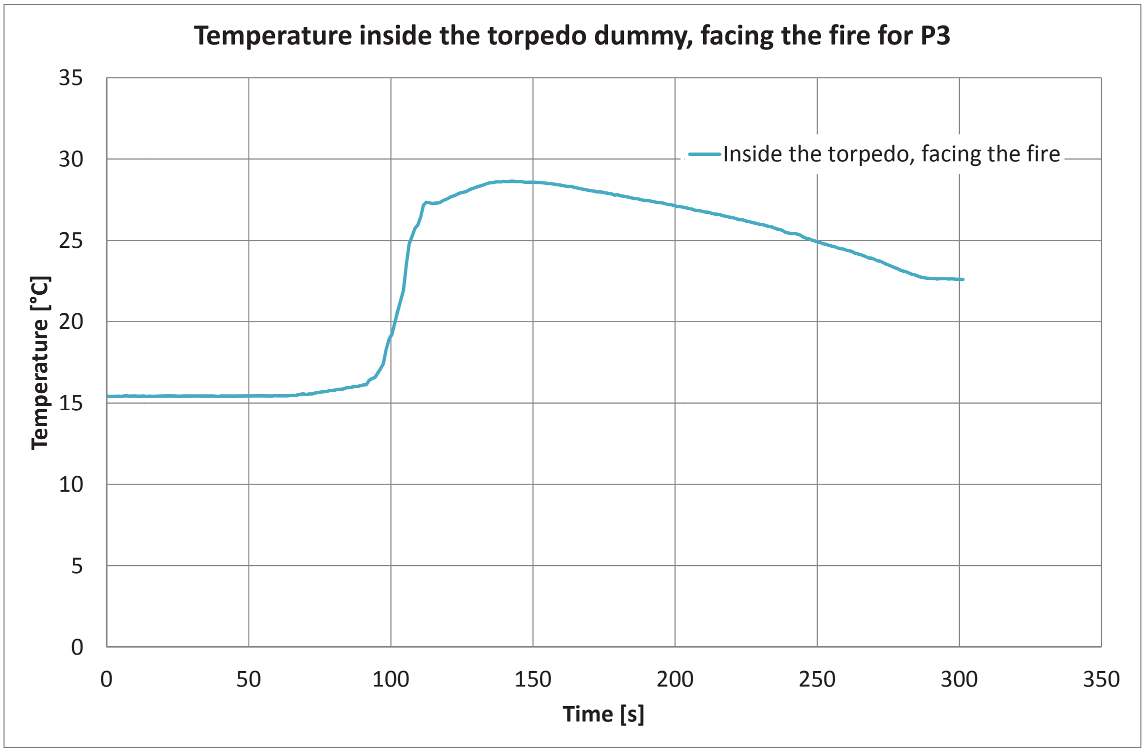

Figure 171. Test 24, Temperature inside the dummy torpedo, facing the fire for P3

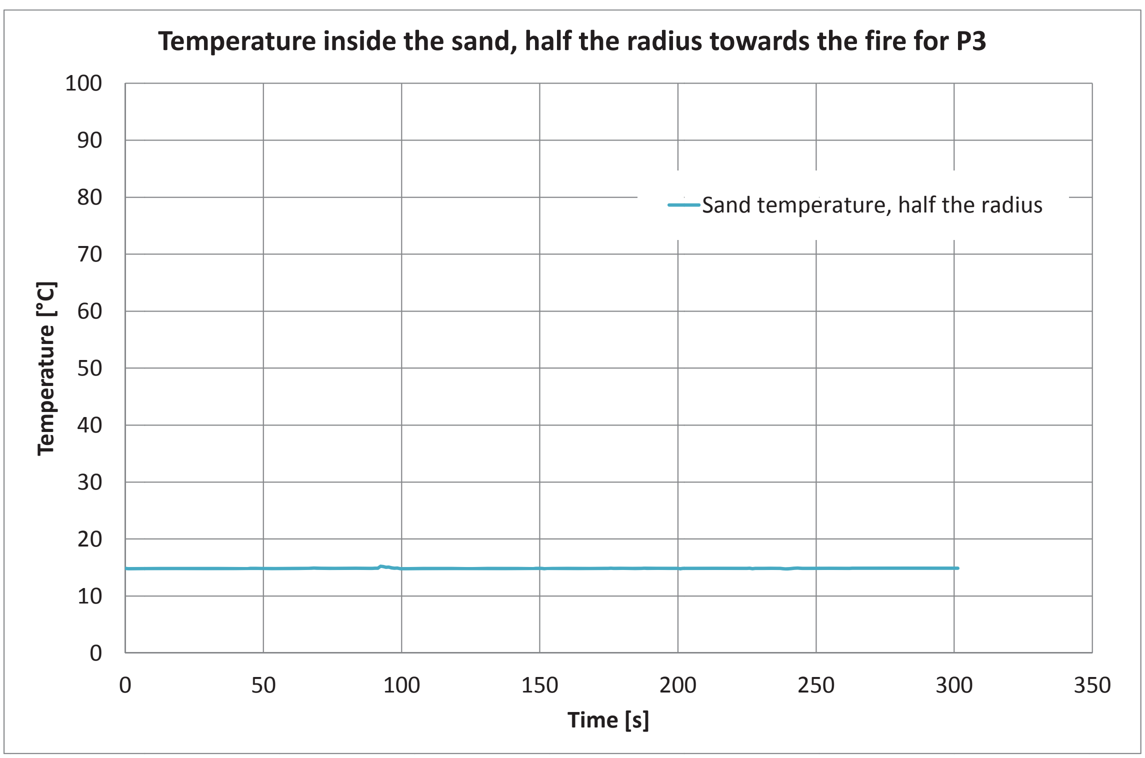

Figure 172. Test 24, Temperature inside the sand, half the radius towards the fire for P3

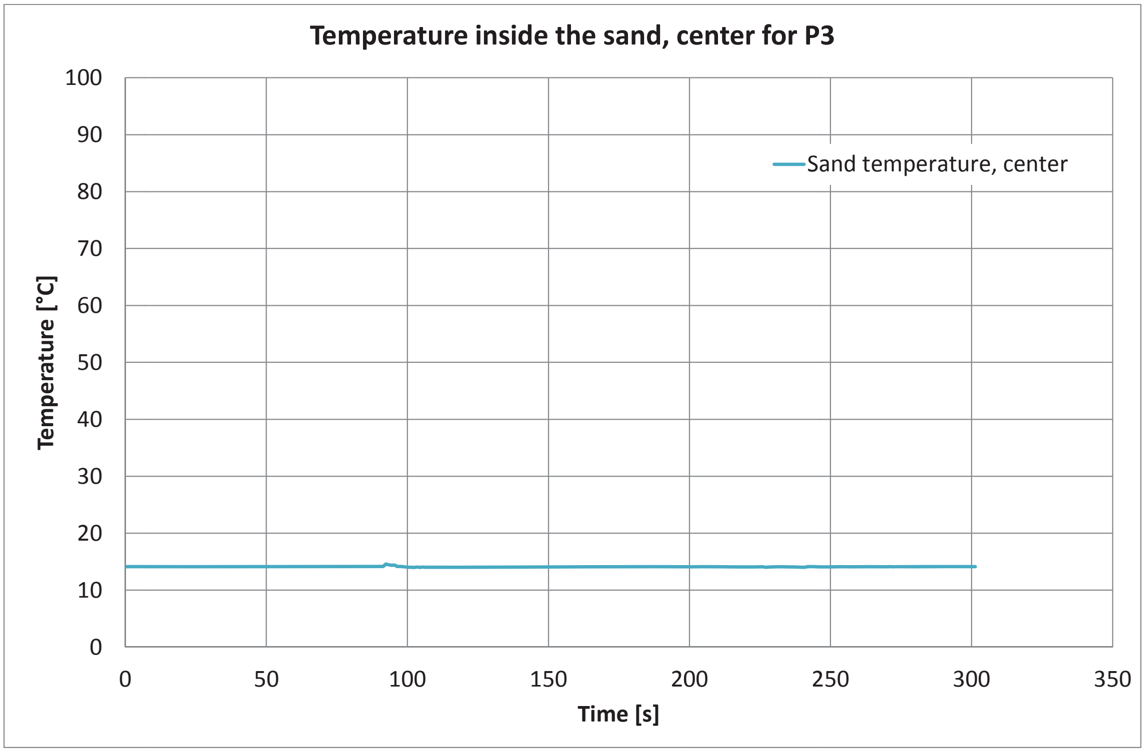

Figure 173. Test 24, Temperature inside the sand, center for P3

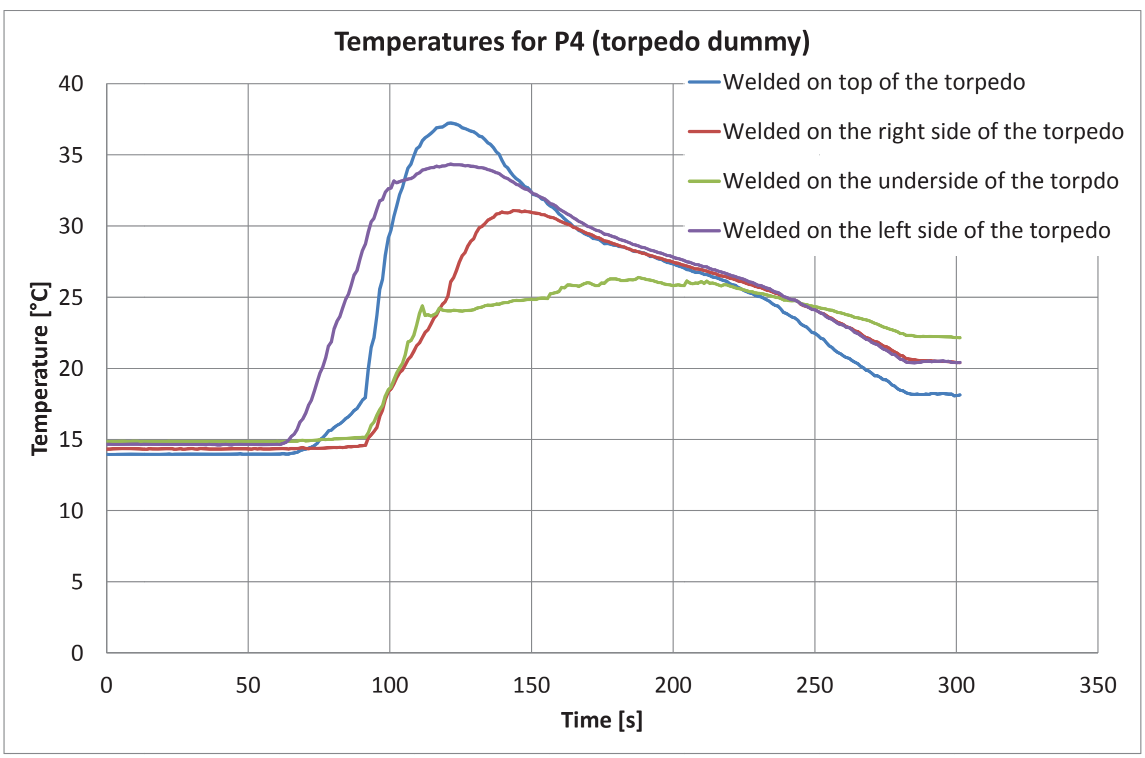

Figure 174. Test 24, Temperatures for P4 (dummy torpedo)

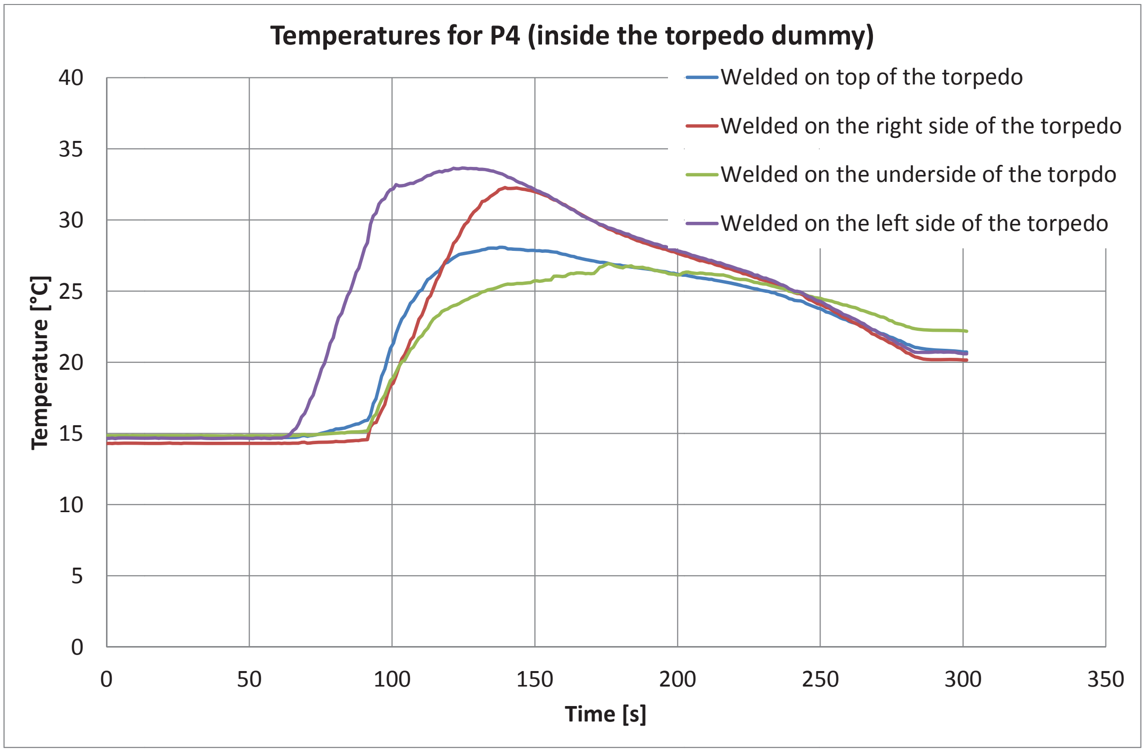

Figure 175. Test 24, Temperatures for P4 (inside the dummy torpedo)

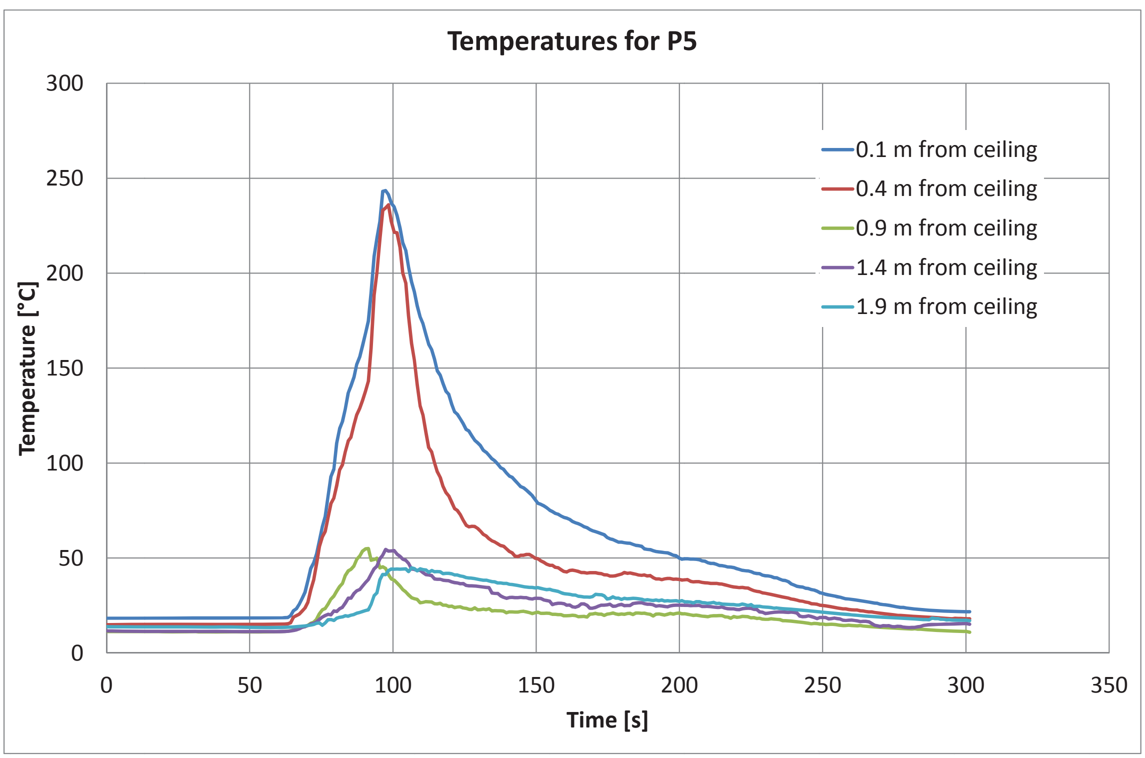

Figure 176. Test 24, Temperatures for P5

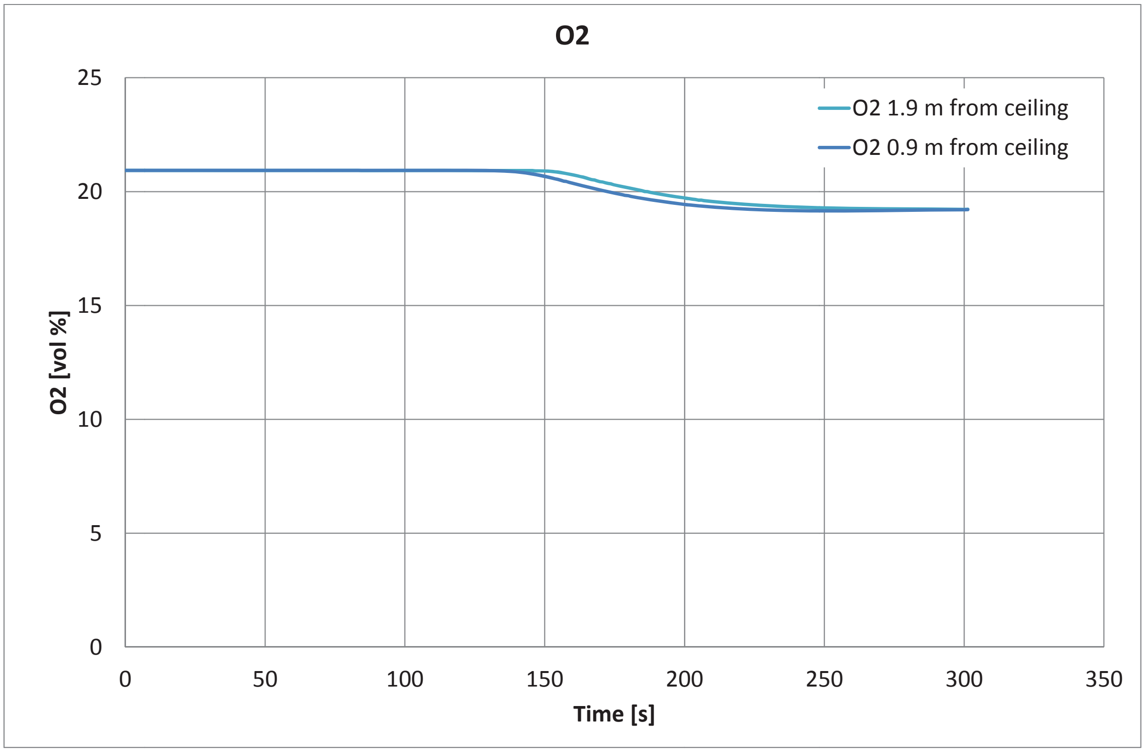

Figure 177. Test 24, O2 level. Not time-adjusted

Test protocol

Test: 25

Date: 2012-02-03

Test engineer: Michael Rahm, Johan Lindström

Type of test	Sand torpedo, drencher system 10 mm/min, obstructed
Pool fire size (Ø in mm)	1170
Position of pool fire	2
Obstruction (% of pool area)	100 (Promatect sheet covering the entire pool area. Placed edge to edge with the torpedo and 425 mm above the pool surface)
Amount of diesel (L)	15
Height of freeboard (mm)	25
Water mist nozzle	
Bulkhead nozzle	
Drencher nozzle	LECHLER 460.728
Distance from nozzle to pool area	172 cm
Pressure (bar)	10
Water flow (L/min)	51
Notes:	
Time (s)	
0	Start measuring program and video camera
60	Ignition
90	Activation of drencher system
110	Suppressed fire (the flames stays mostly under the Promatect sheet)
510	The fire was extinguished with foam

Appendix 1

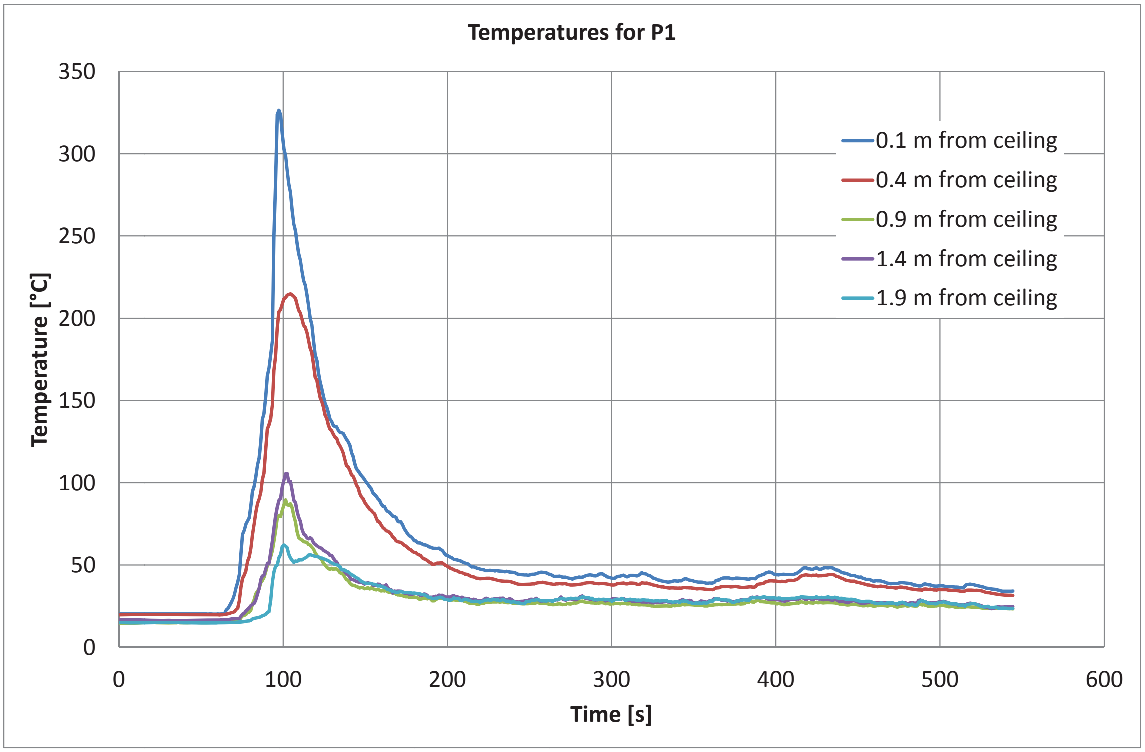

Figure 178. Test 25, Temperatures for P1

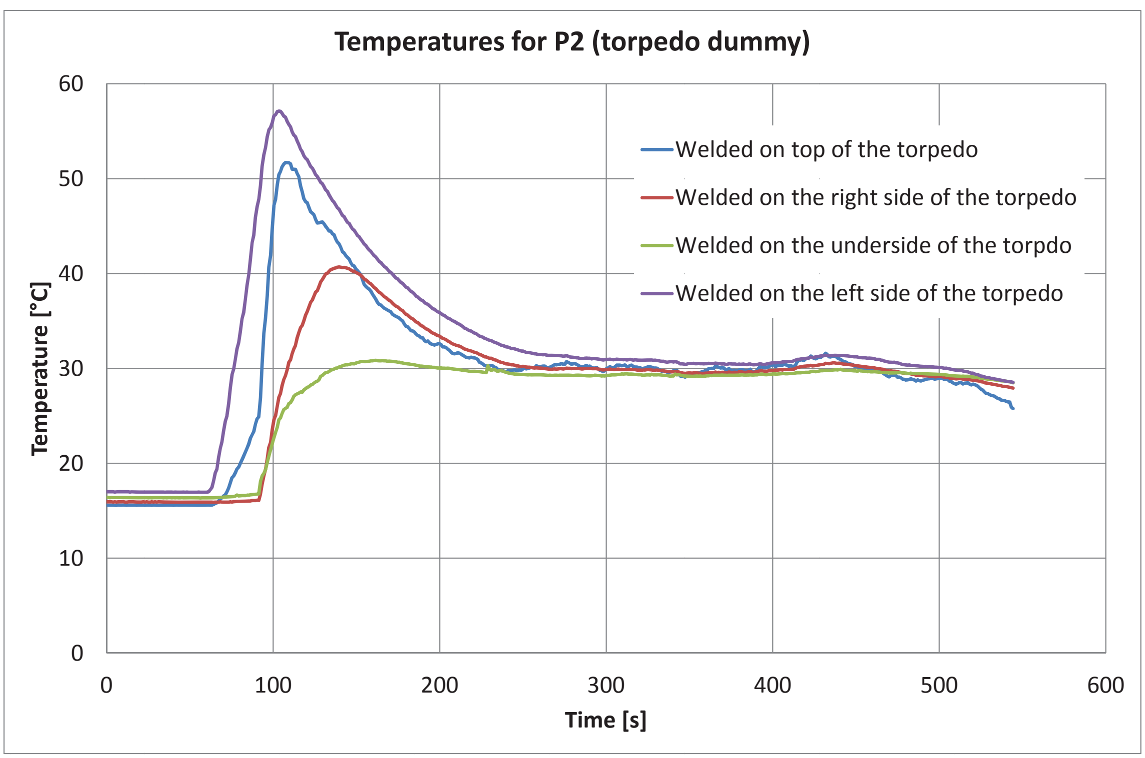

Figure 179. Test 25, Temperatures for P2 (dummy torpedo)

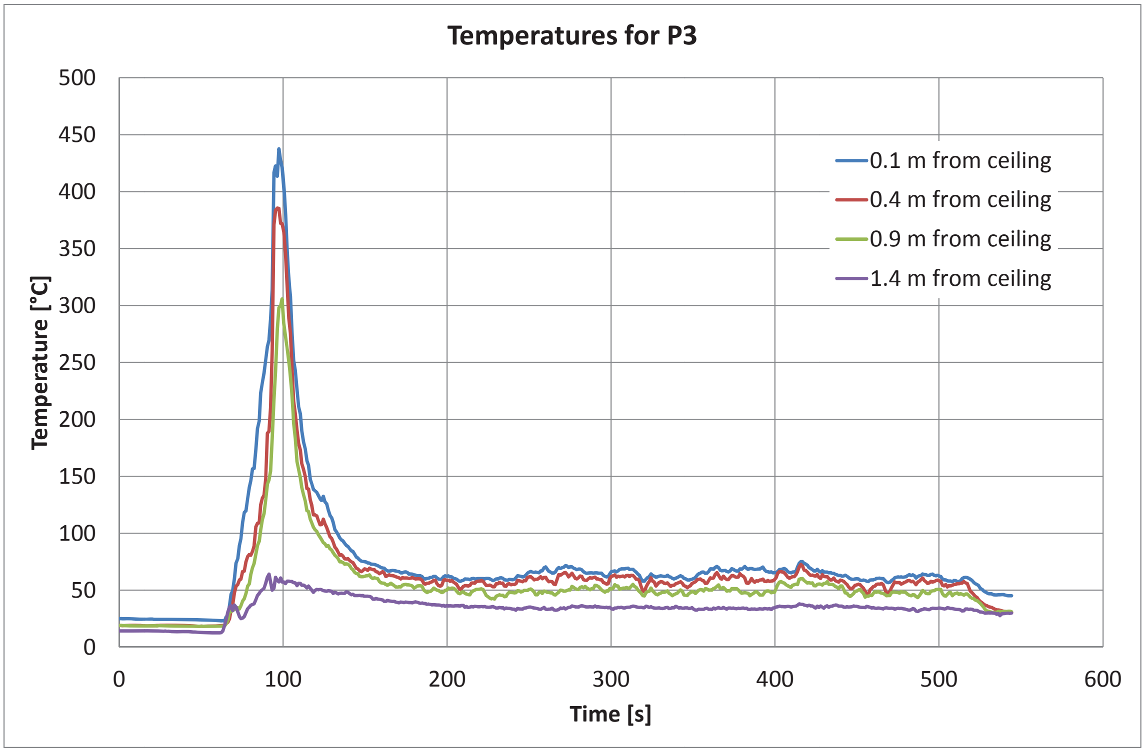

Figure 180. Test 25, Temperatures for P3

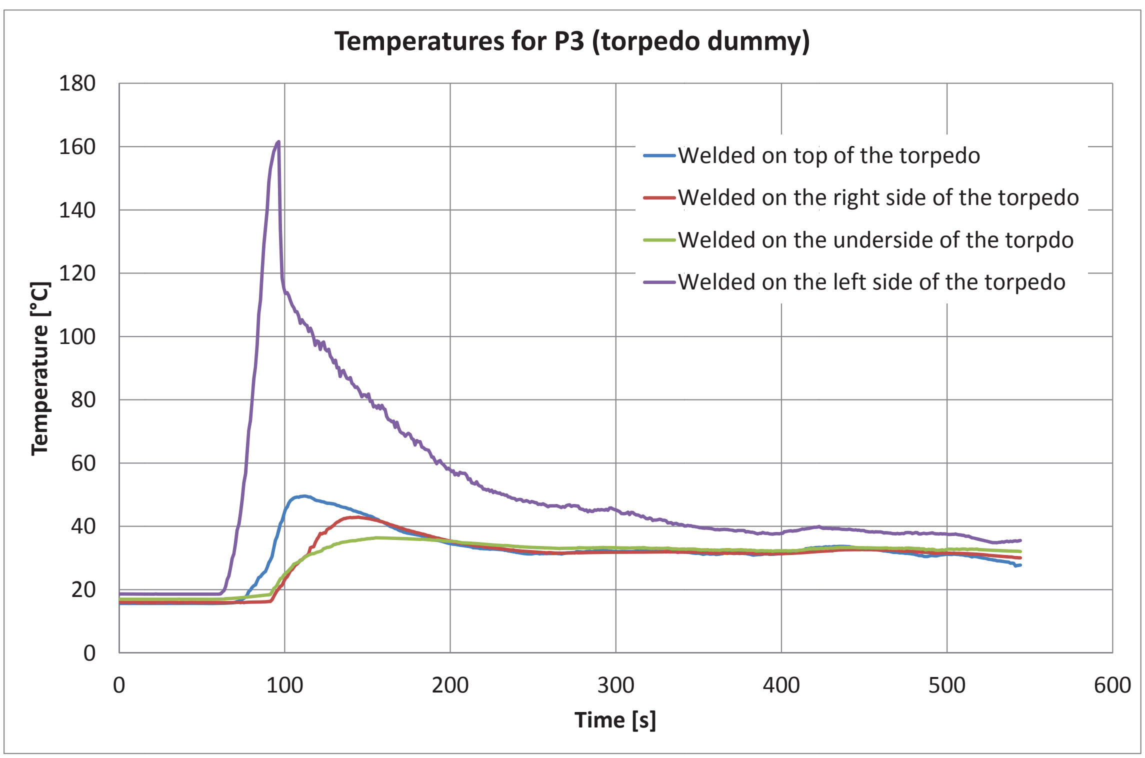

Figure 181. Test 25, Temperatures for P3 (dummy torpedo)

Appendix 1

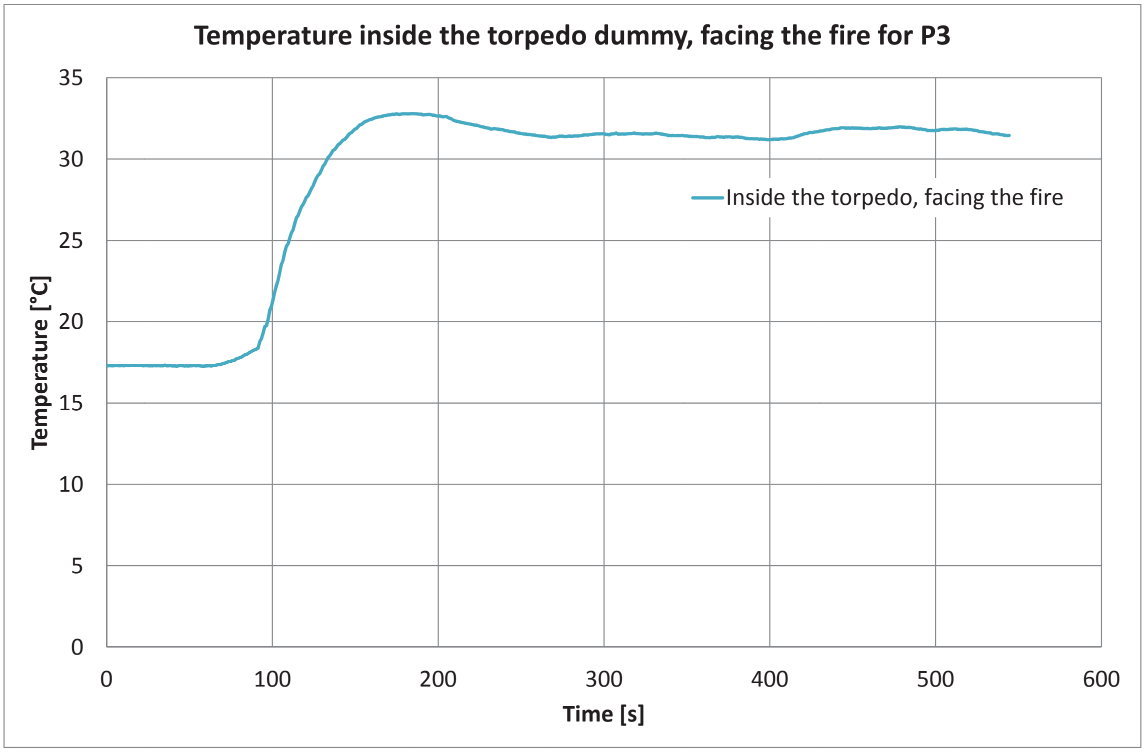

Figure 182. Test 25, Temperature inside the dummy torpedo, facing the fire for P3

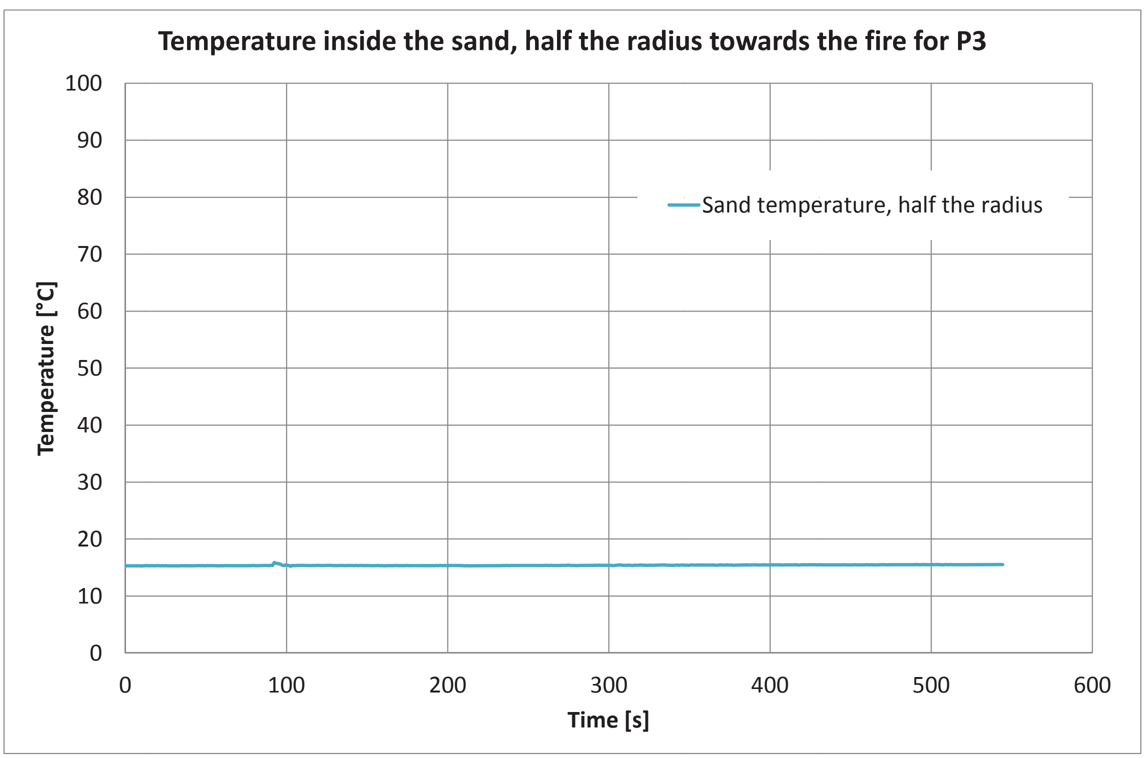

Figure 183. Test 25, Temperature inside the sand, half the radius towards the fire for P3

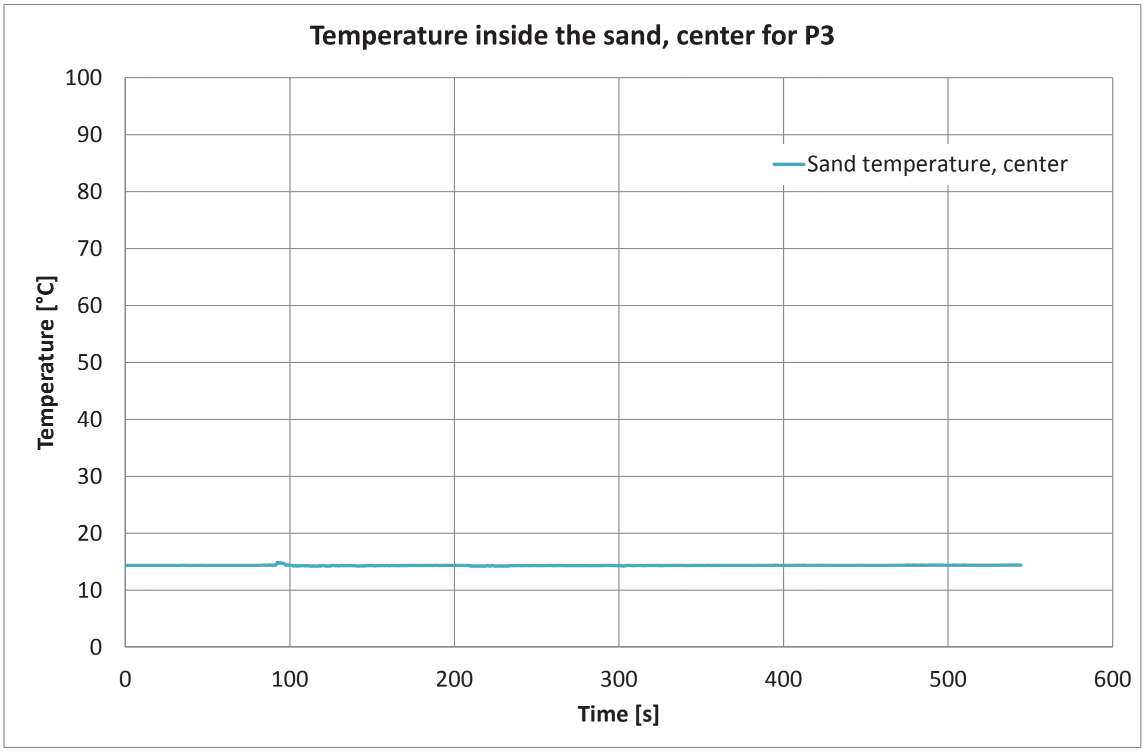

Figure 184. Test 25, Temperature inside the sand, center for P3

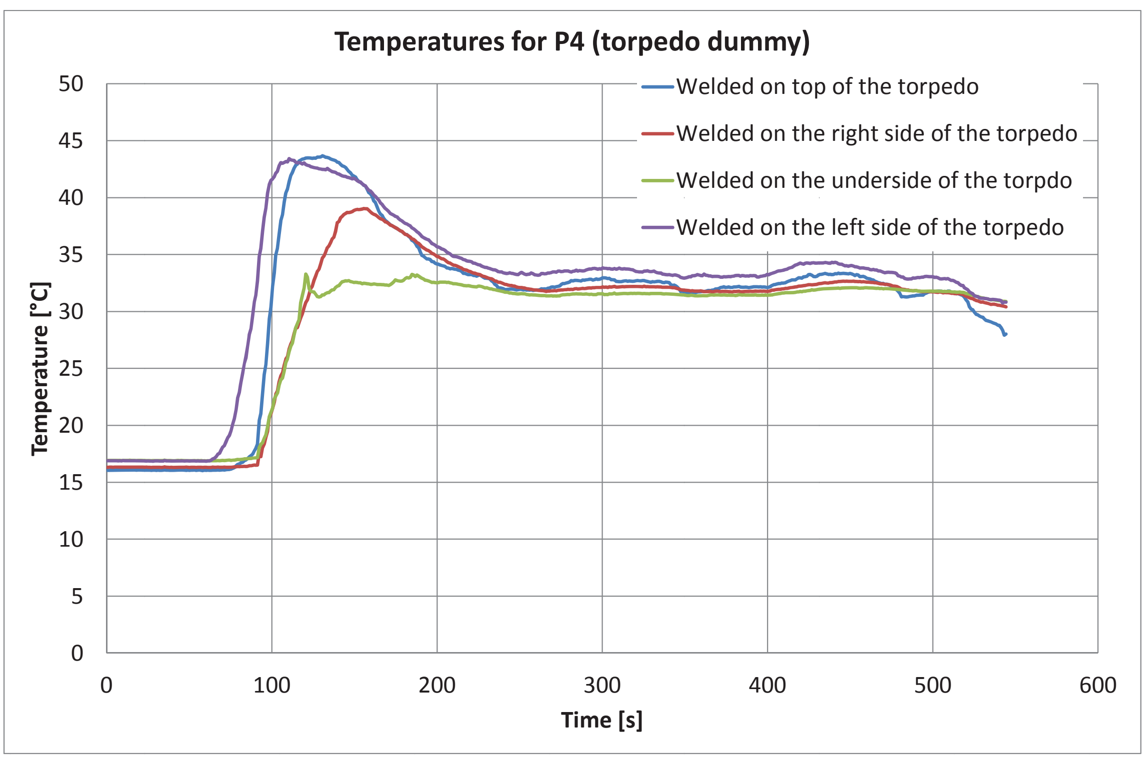

Figure 185. Test 25, Temperatures for P4 (dummy torpedo)

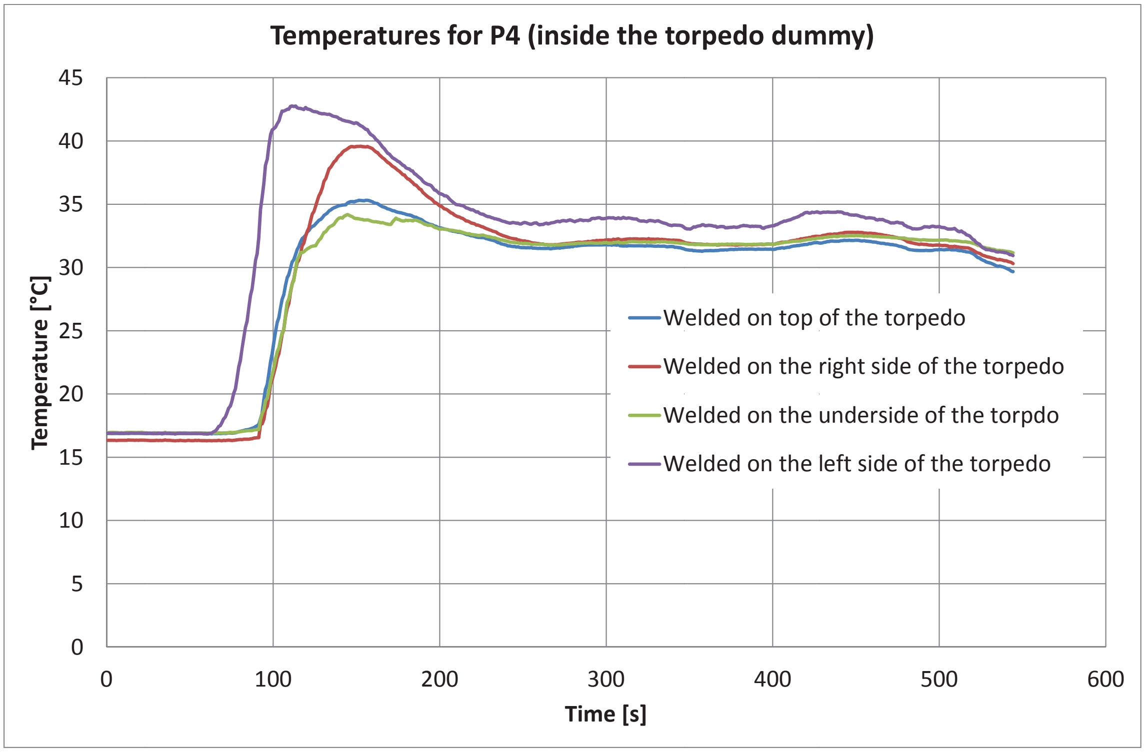

Figure 186. Test 25, Temperatures for P4 (inside the dummy torpedo)

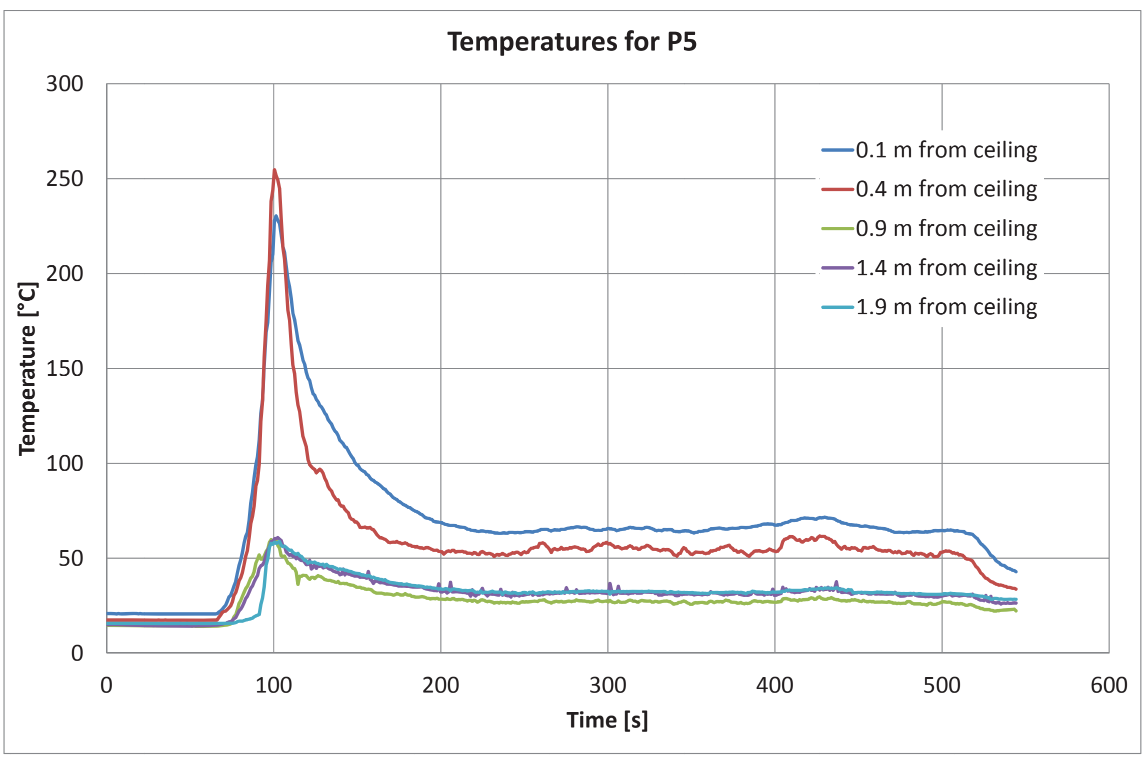

Figure 187. Test 25, Temperatures for P5

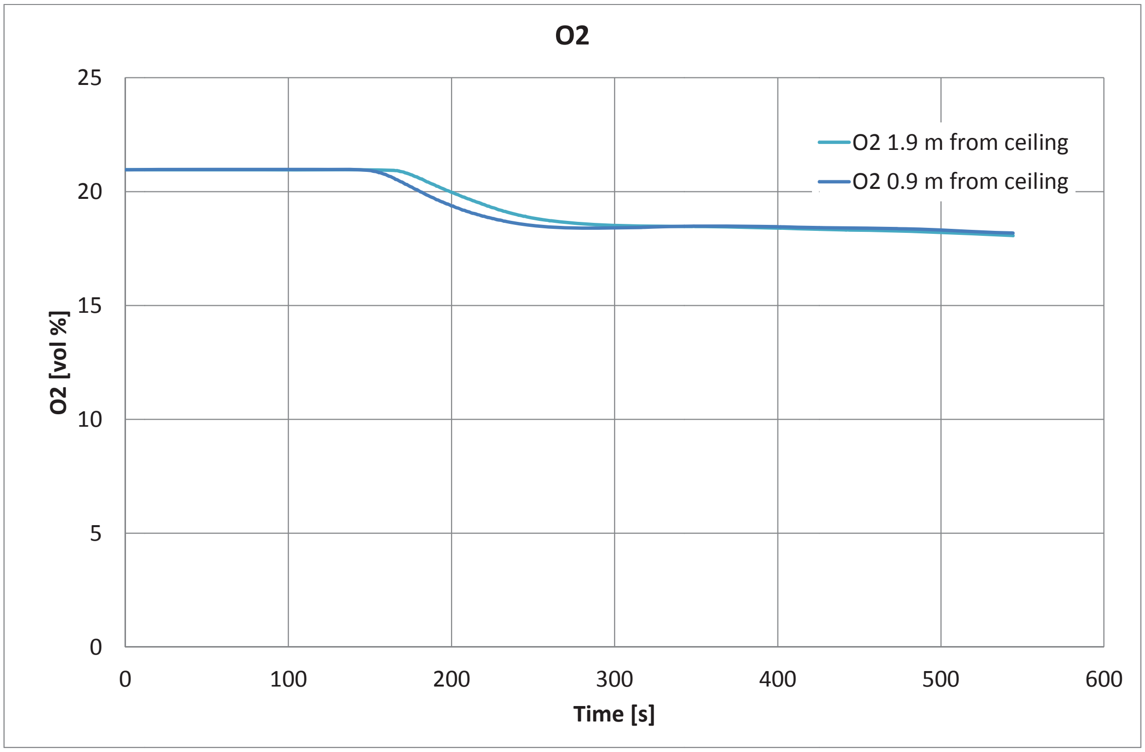

Figure 188. Test 25, O2 level. Not time-adjusted

Test protocol

Test: 26

Date: 2012-02-06

Test engineer: Michael Rahm, Johan Lindström

Type of test	Sand torpedo, drencher system 5 mm/min + water mist, obstructed
Pool fire size (Ø in mm)	1170
Position of pool fire	2
Obstruction (% of pool area)	100 (Promatect sheet covering the entire pool area. Placed edge to edge with the torpedo and 425 mm above the pool surface)
Amount of diesel (L)	15
Height of freeboard (mm)	25
Water mist nozzle	TF 8-170
Bulkhead nozzle	
Drencher nozzle	LECHLER 460.728
Distance from nozzle to pool area	172 cm
Pressure (bar)	10
Water flow (L/min)	24 (drencher system)
Notes:	
Time (s)	
0	Start measuring program and video camera
60	Ignition
90	Activation of drencher and water mist system
100	Suppressed fire (the flames stays mostly under the Promatect sheet)
180	Clear that the air flow at the door opening goes in to the room in the upper part and comes out at the lower part
600	A visible pulsation of the smoke in and out of the door opening
840	Almost extinguished
885	The fire increases
930	Almost extinguished
960	The fire increases
1010	The fire was extinguished with foam

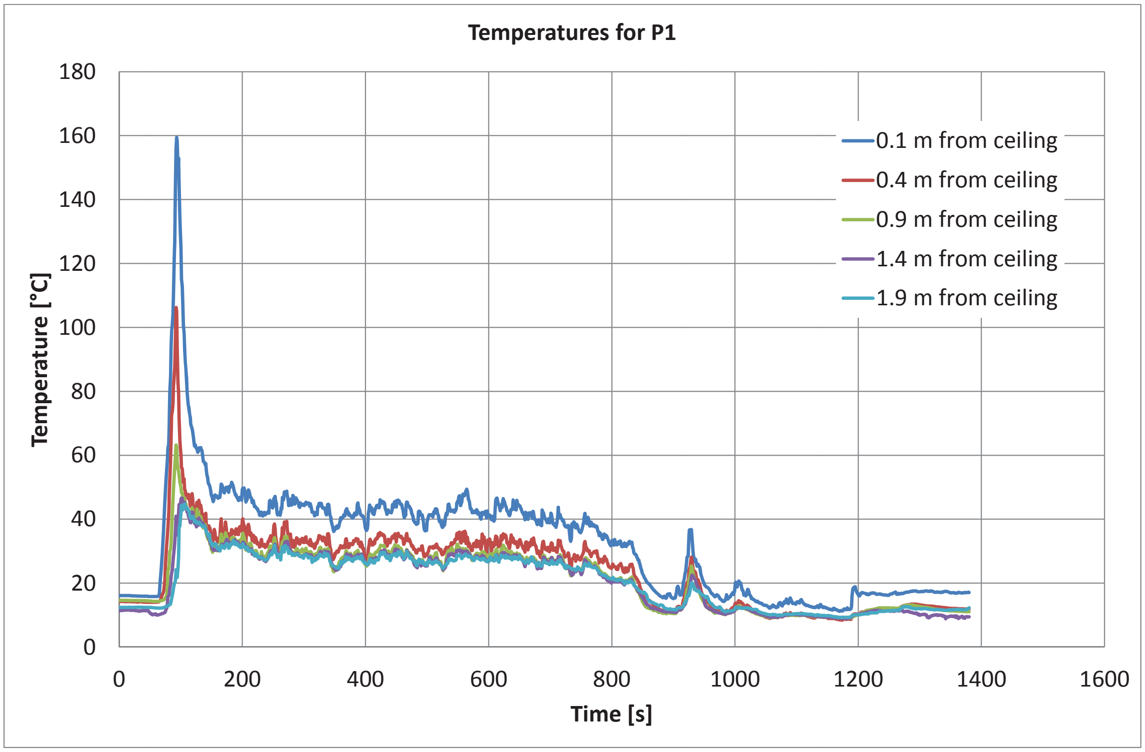

Figure 189. Test 26, Temperatures for P2

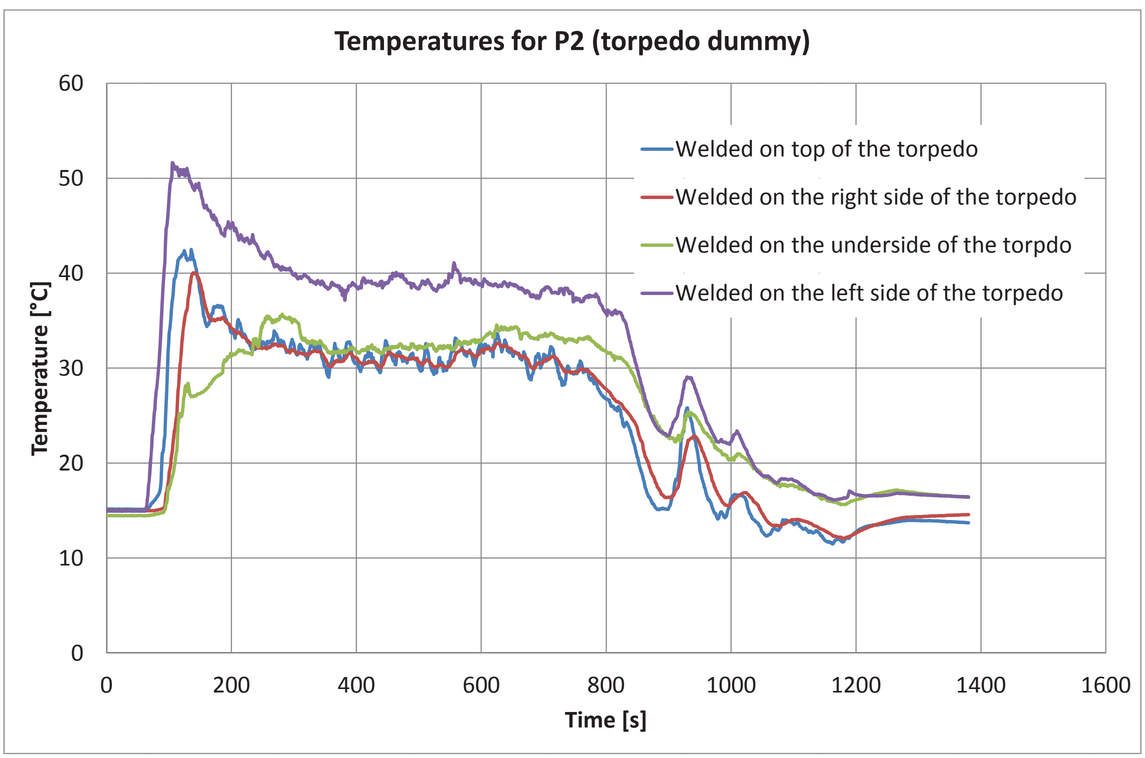

Figure 190. Test 26, Temperatures for P2 (dummy torpedo)

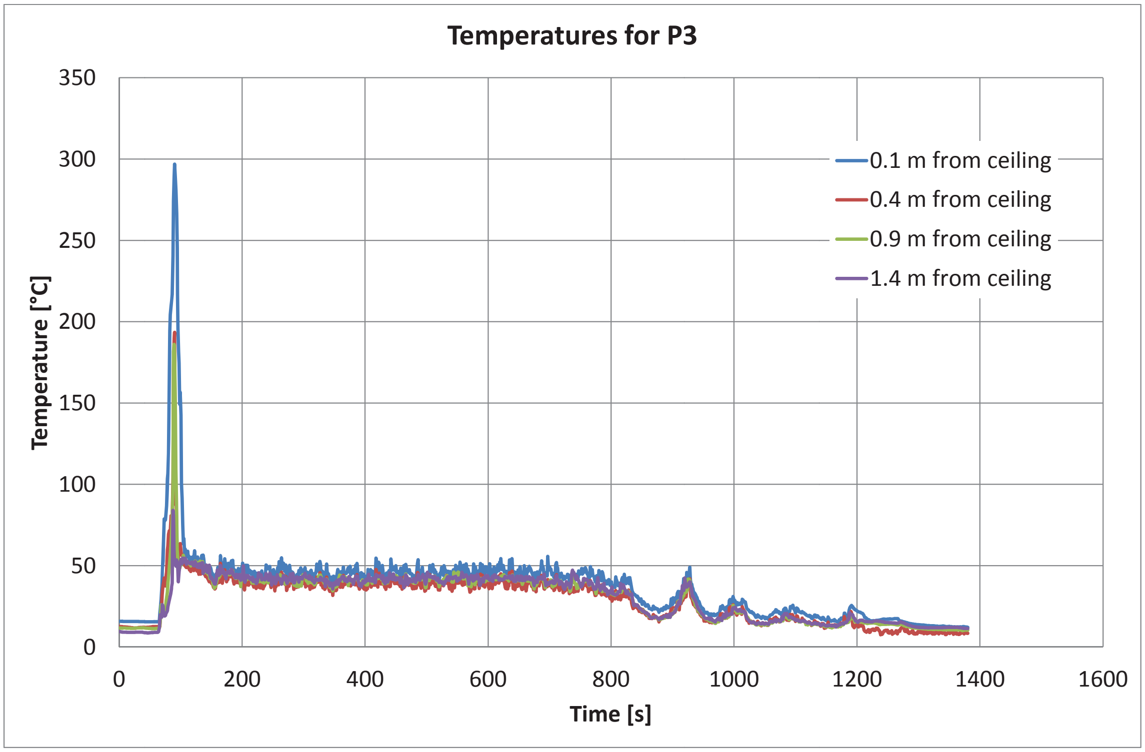

Figure 191. Test 26, Temperatures for P3

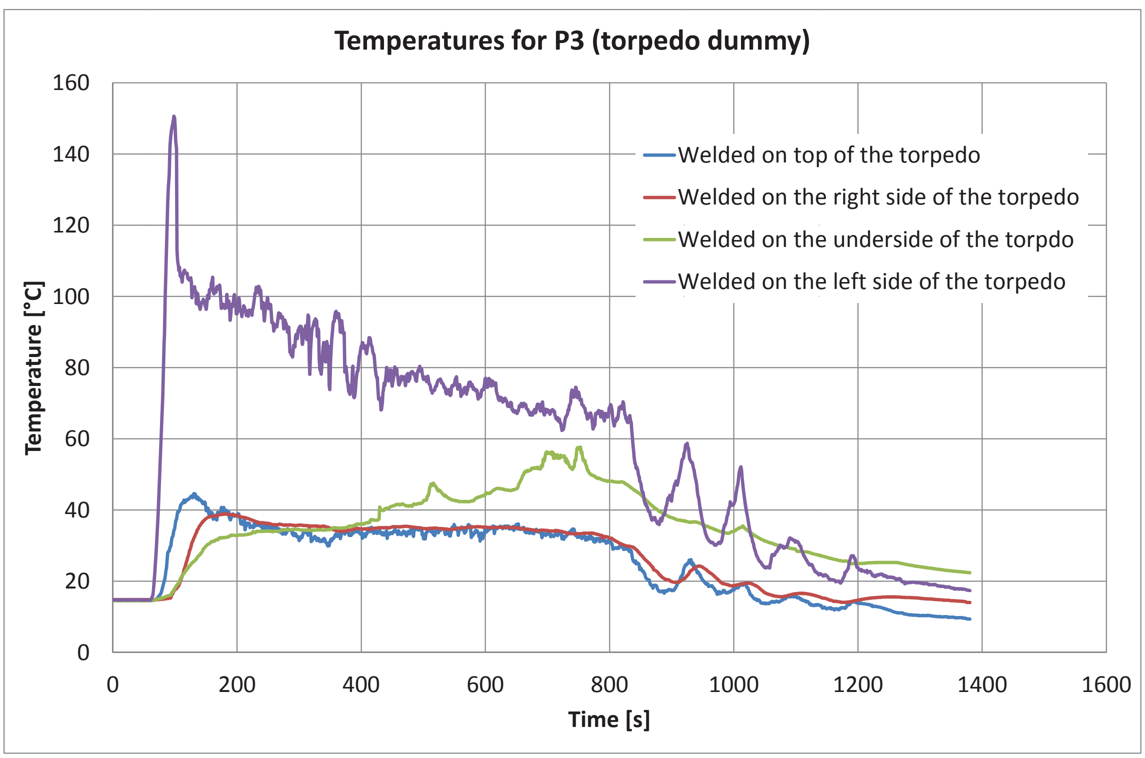

Figure 192. Test 26, Temperatures for P3 (dummy torpedo)

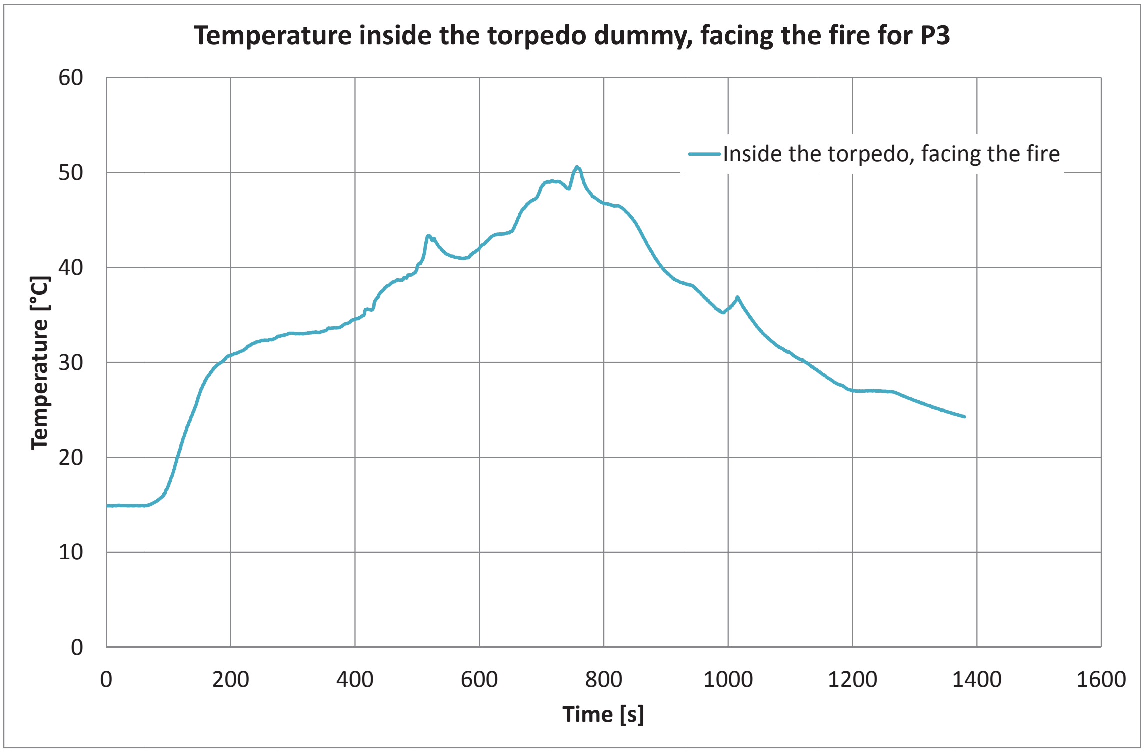

Figure 193. Test 26, Temperature inside the dummy torpedo, facing the fire for P3

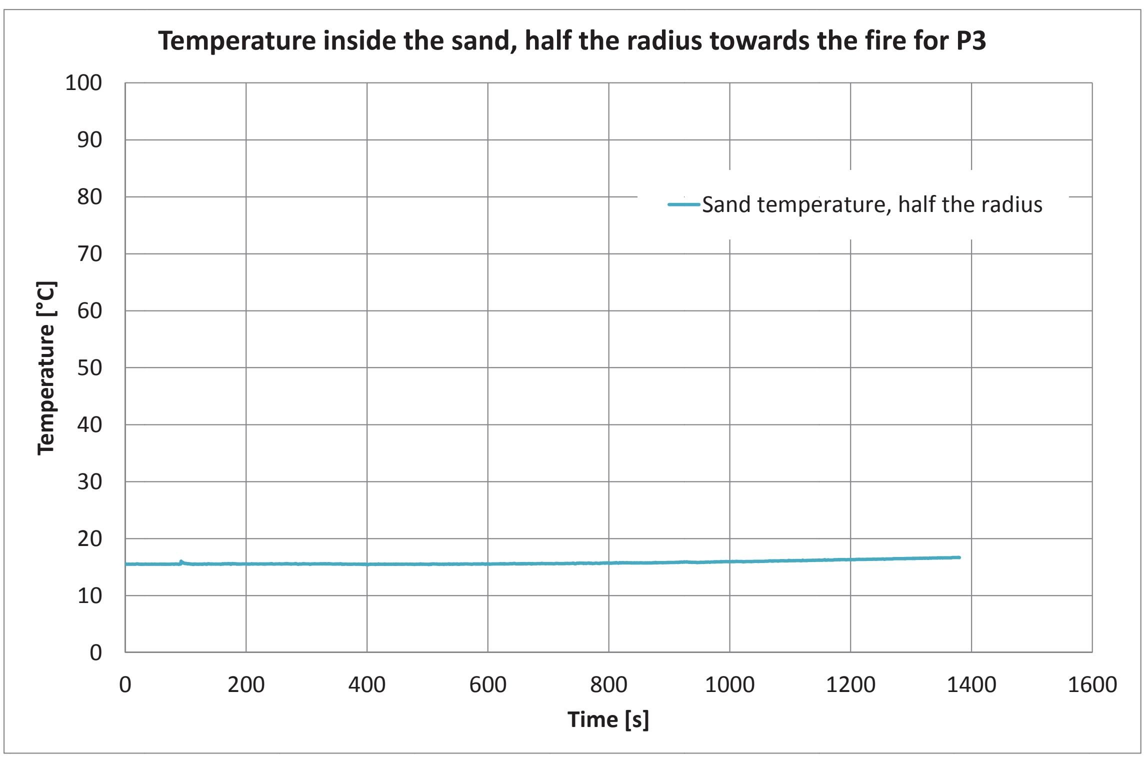

Figure 194. Test 26, Temperature inside the sand, half the radius towards the fire for P3

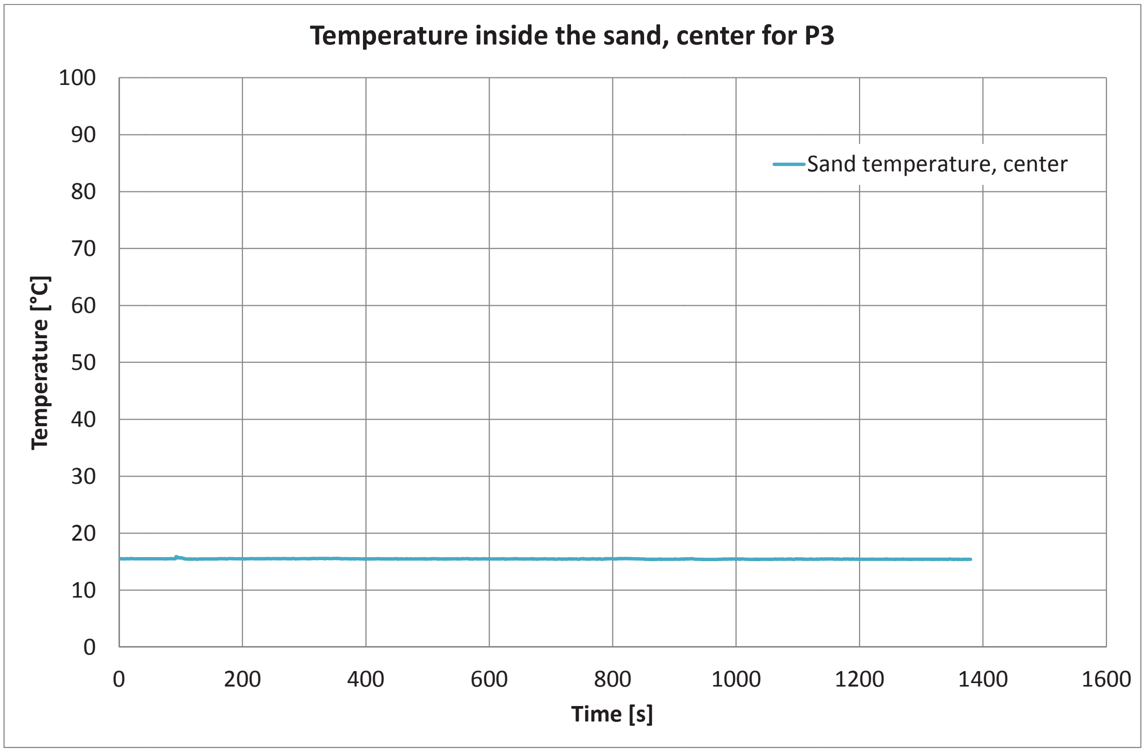

Figure 195. Test 26, Temperature inside the sand, center for P3

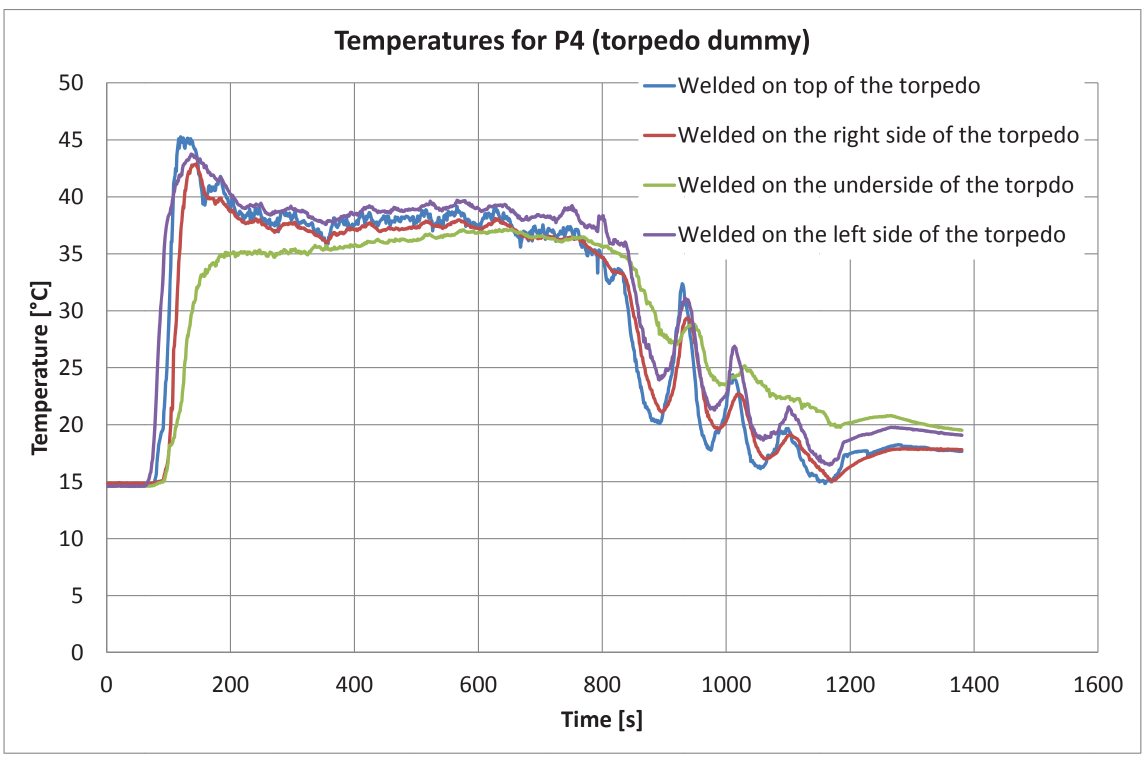

Figure 196. Test 26, Temperatures for P4 (dummy torpedo)

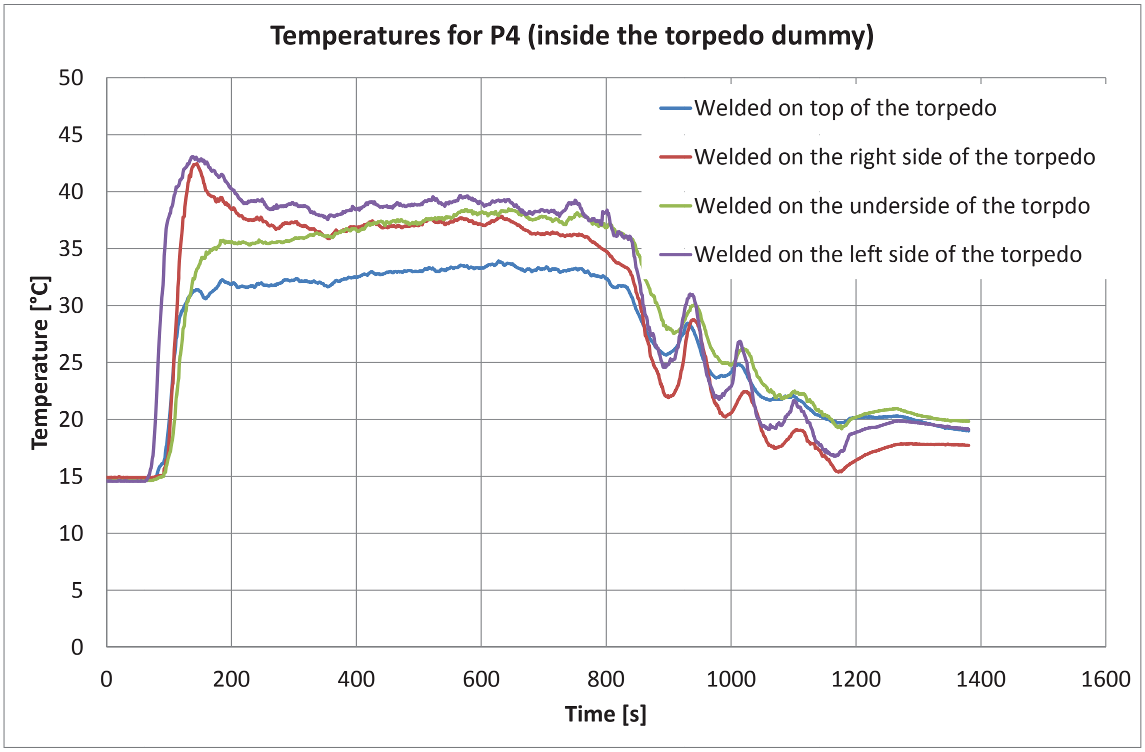

Figure 197. Test 26, Temperatures for P4 (inside the dummy torpedo)

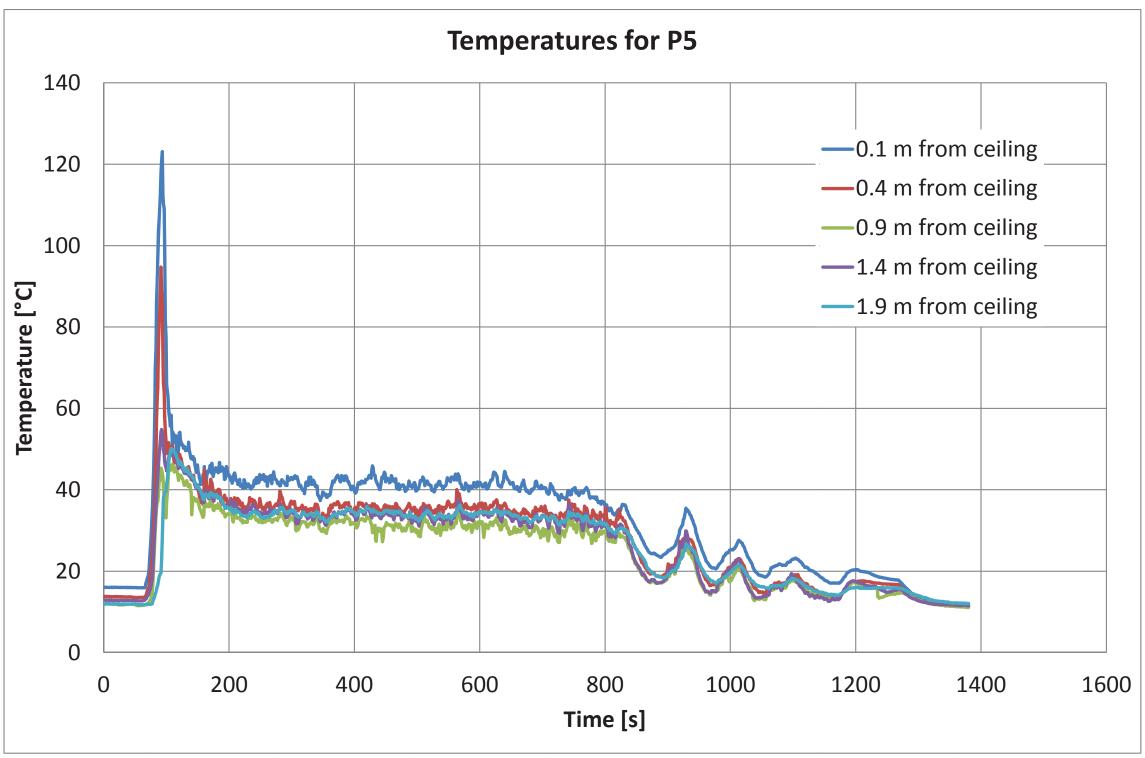

Figure 198. Test 26, Temperatures for P5

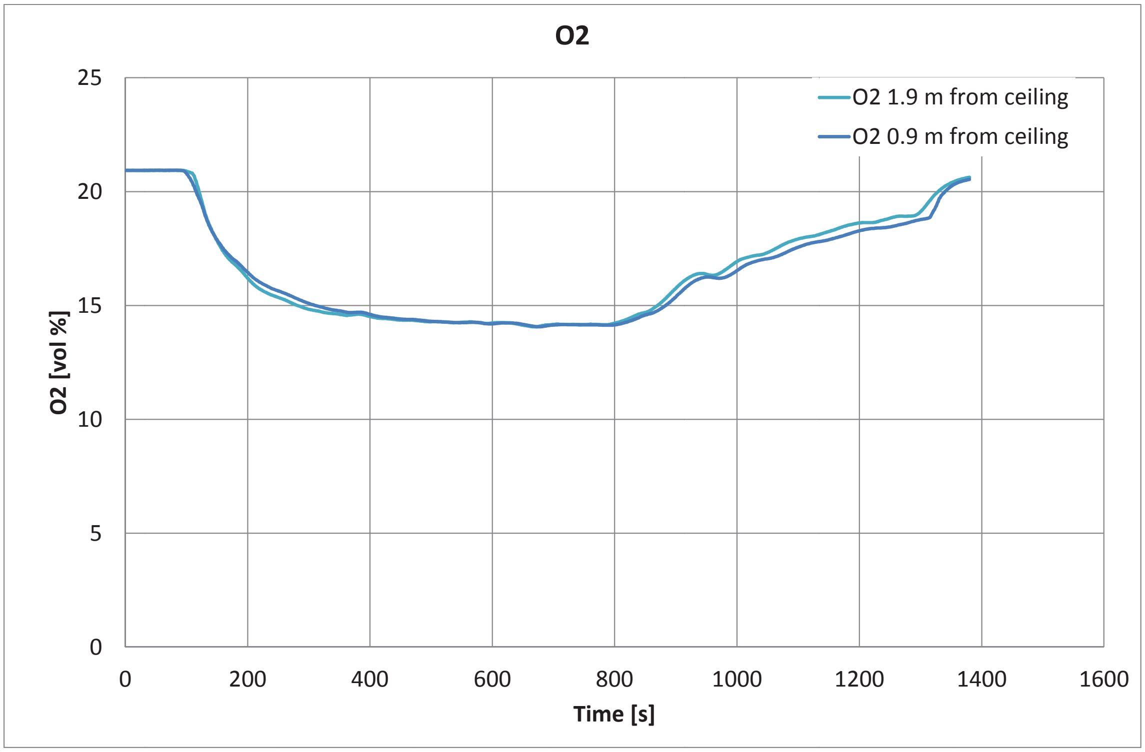

Figure 199. Test 26, O2 level. Not time-adjusted

Appendix 1

Test protocol

Test: 27

Date: 2012-02-02

Test engineer: Michael Rahm, Johan Lindström

Type of test	Sand torpedo, free-burning
Pool fire size (Ø in mm)	1170
Position of pool fire	2
Obstruction (% of pool area)	
Amount of diesel (L)	15
Height of freeboard (mm)	25
Water mist nozzle	BETE TF 8-170 (to extinguish the fire when needed)
Bulkhead nozzle	
Drencher nozzle	
Distance from nozzle to pool area	
Pressure (bar)	10
Water flow (L/min)	
Notes:	
Time (s)	
0	Start measuring program and video camera
60	Ignition
267	Activation of water mist system
280	The fire was extinguished

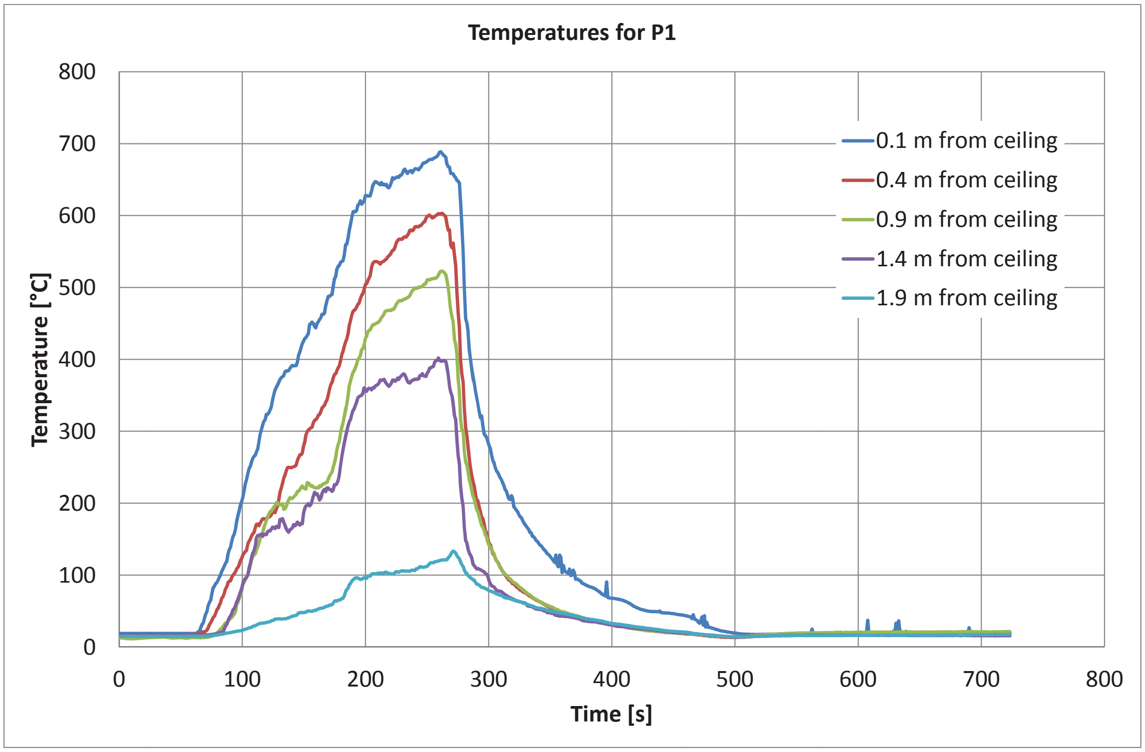

Figure 200. Test 27, Temperatures for P1

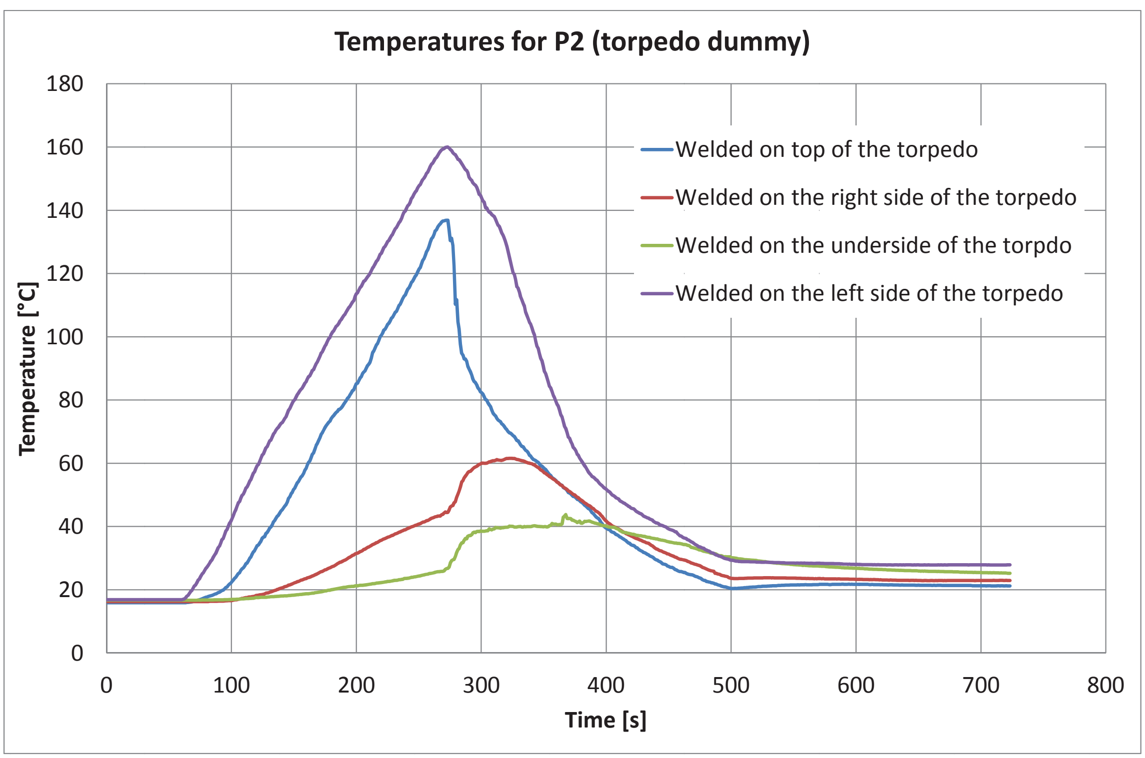

Figure 201. Test 27, Temperatures for P2 (dummy torpedo)

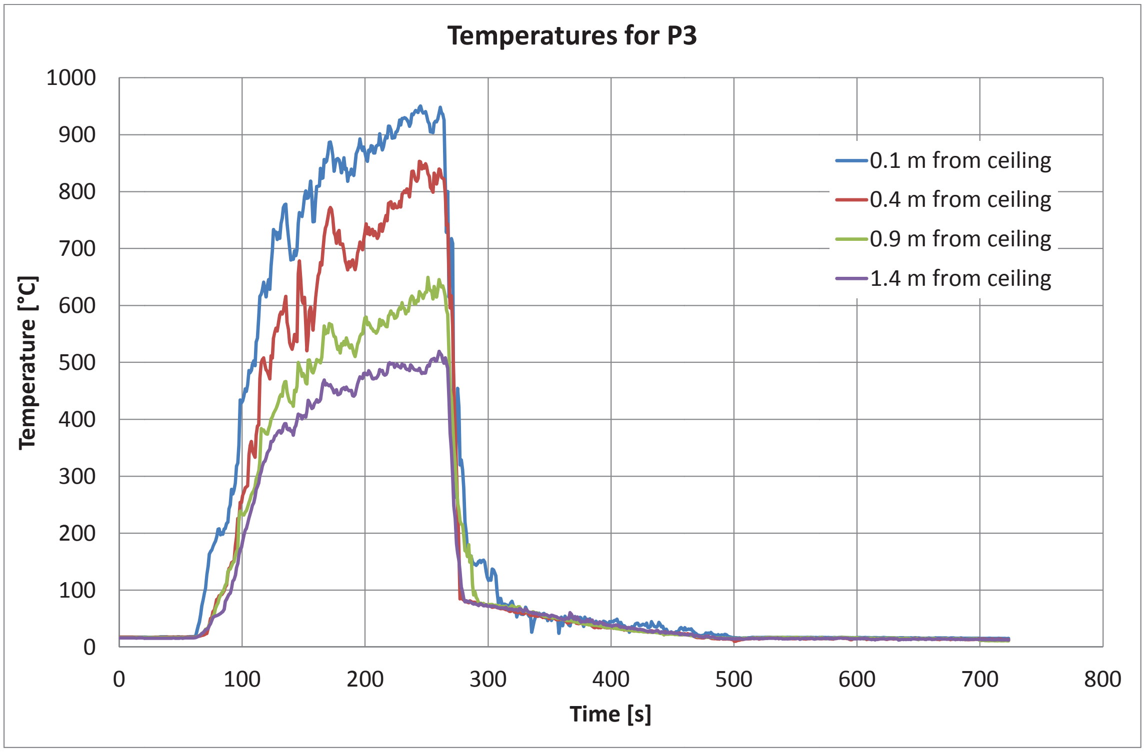

Figure 202. Test 27, Temperatures for P3

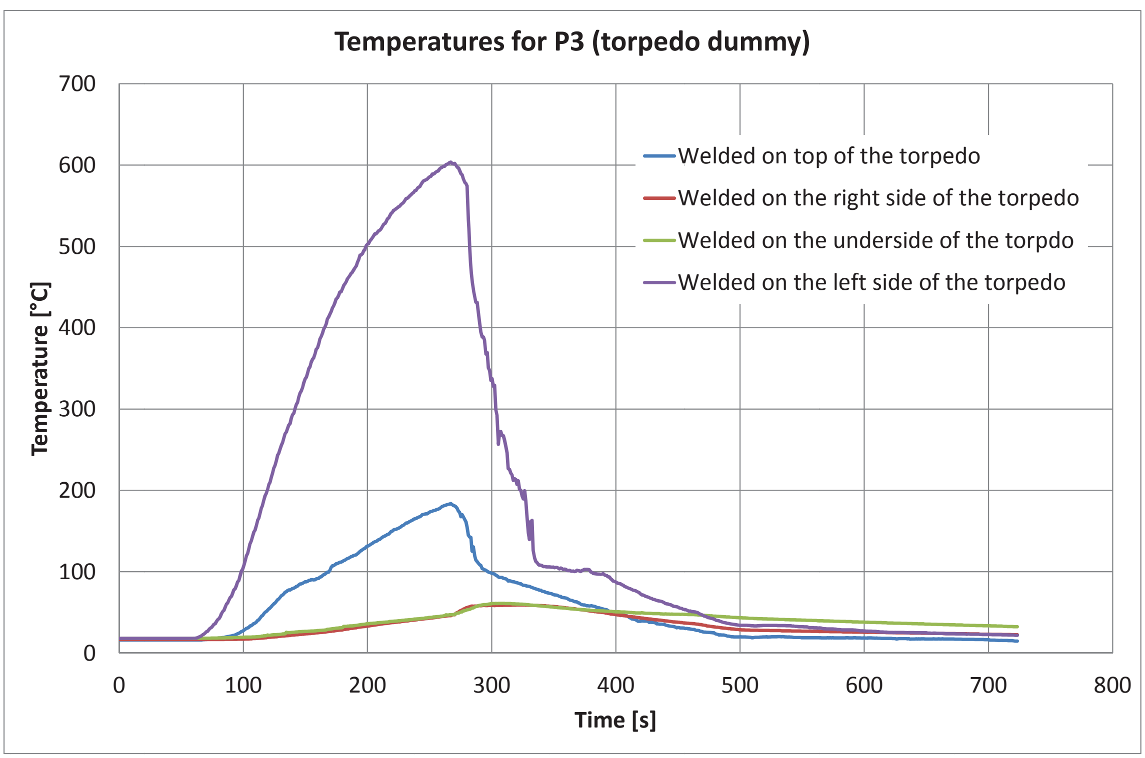

Figure 203. Test 27, Temperatures for P3 (dummy torpedo)

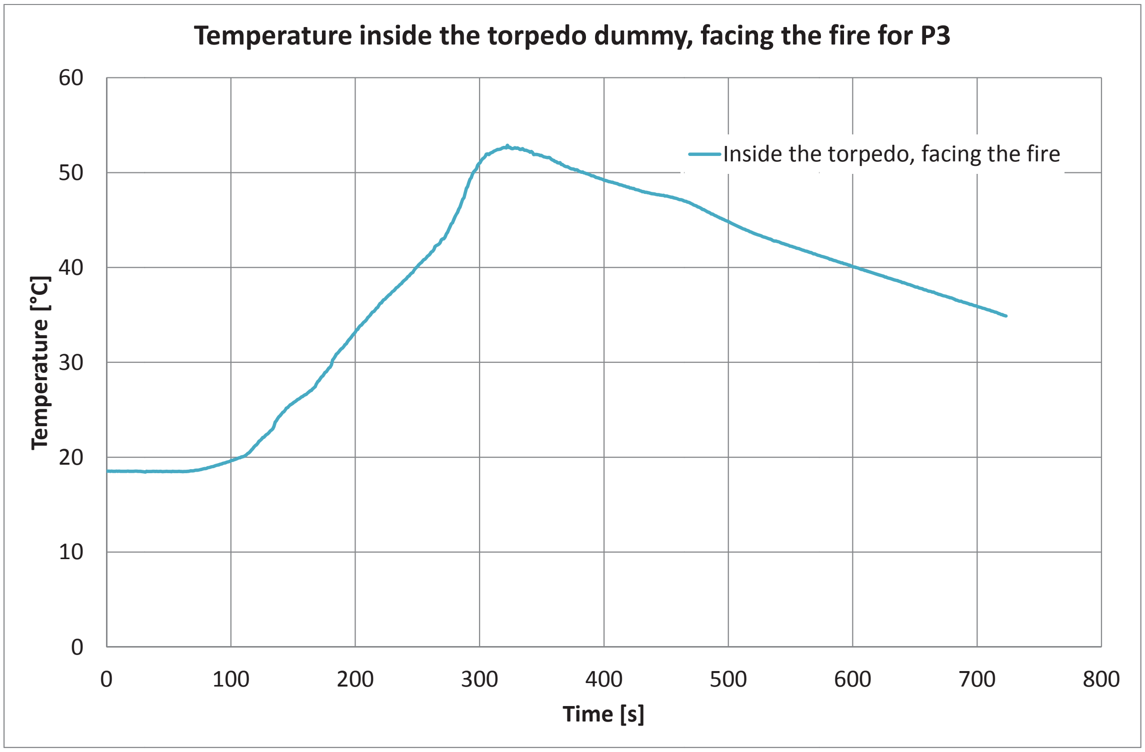

Figure 204. Test 27, Temperature inside the dummy torpedo, facing the fire for P3

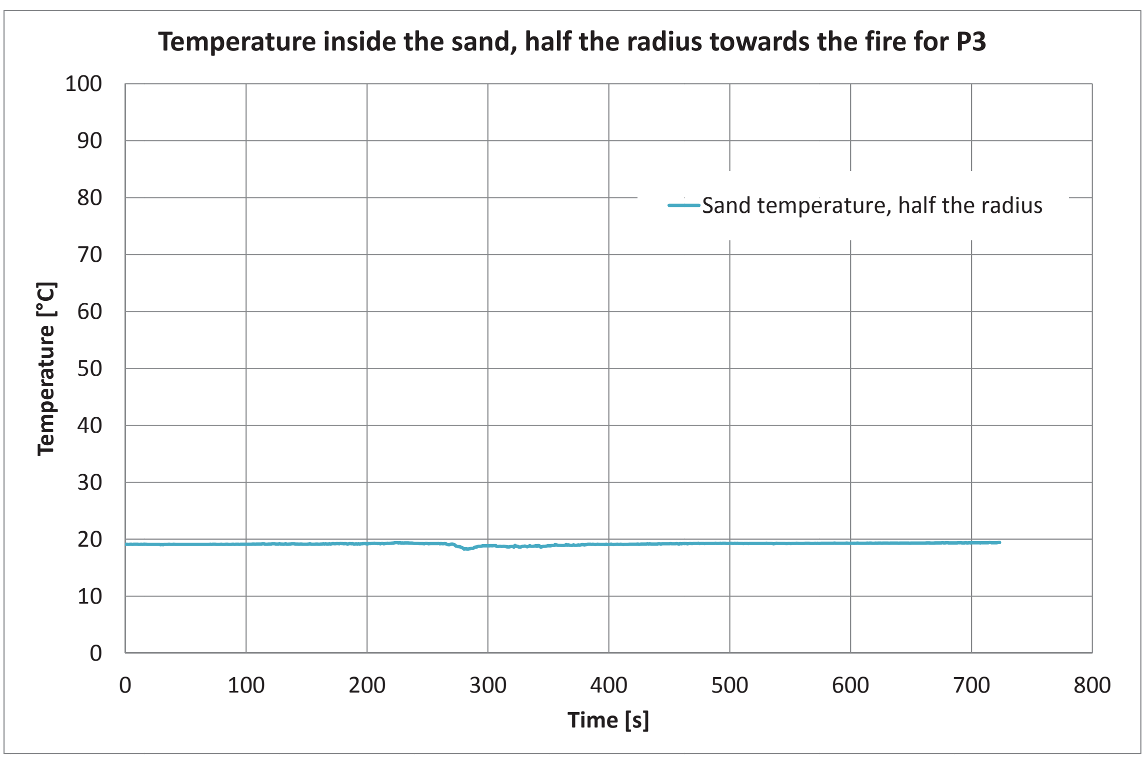

Figure 205. Test 27, Temperature inside the sand, half the radius towards the fire for P3

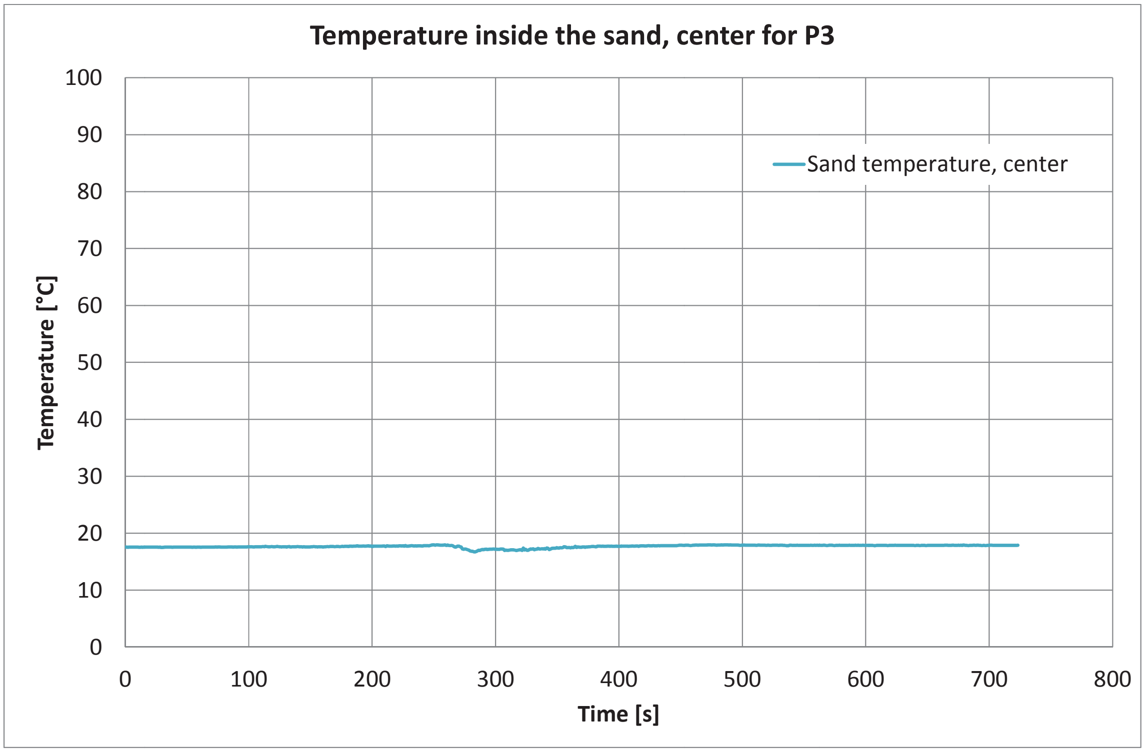

Figure 206. Test 27, Temperature inside the sand, center for P3

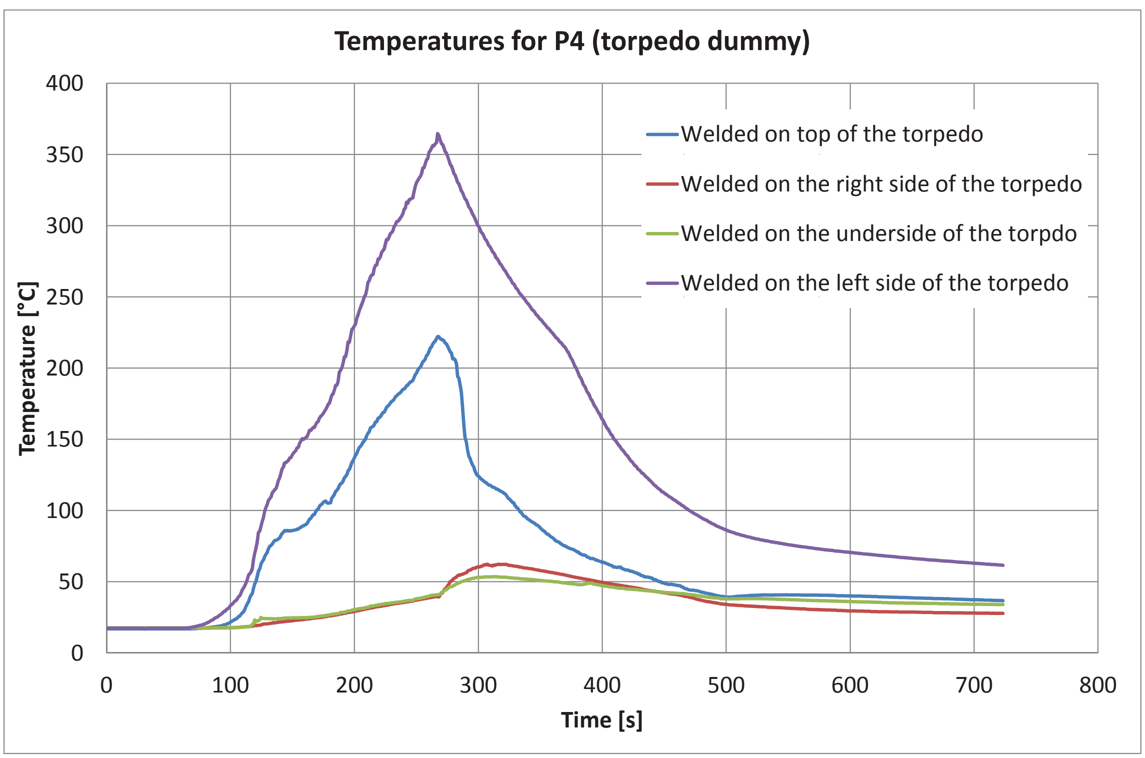

Figure 207. Test 27, Temperatures for P4 (dummy torpedo)

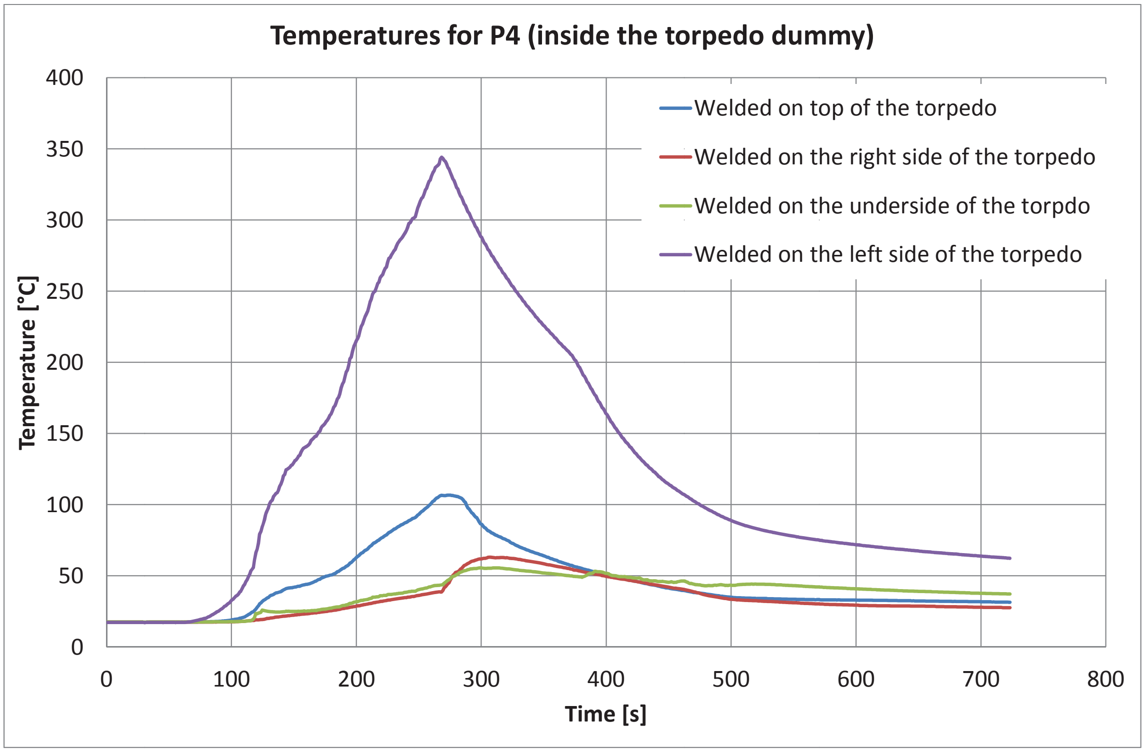

Figure 208. Test 27, Temperatures for P4 (inside the dummy torpedo)

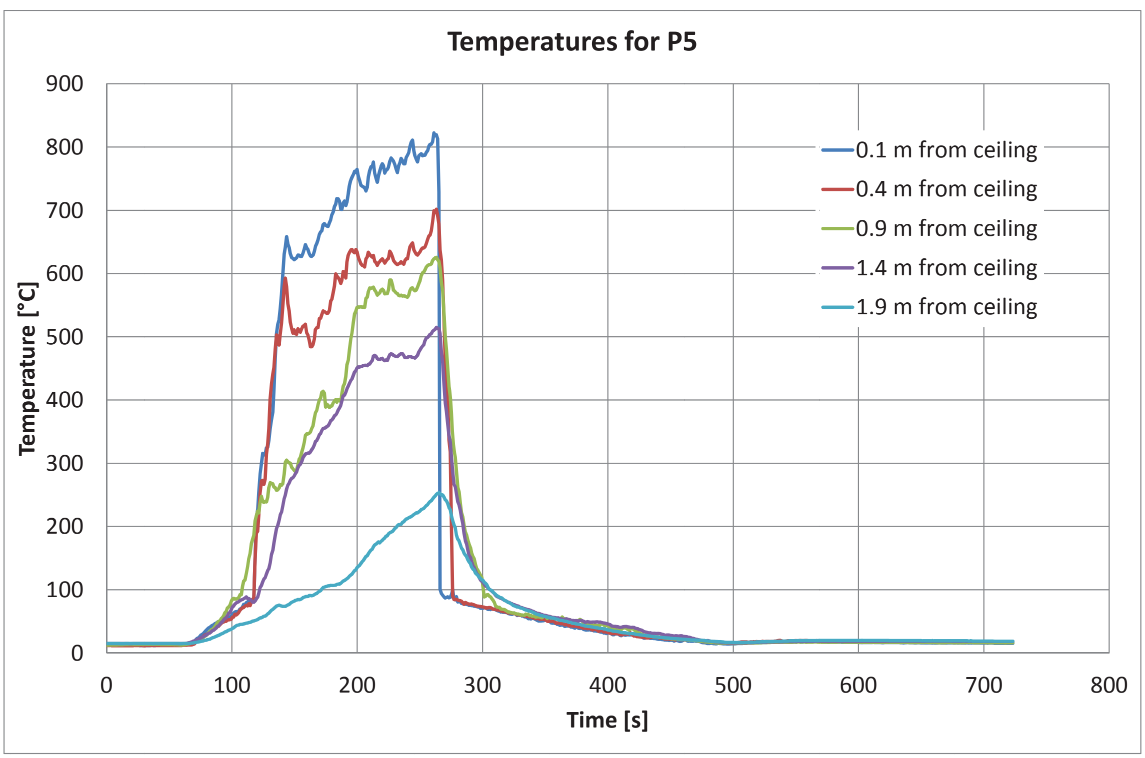

Figure 209. Test 27, Temperatures for P5

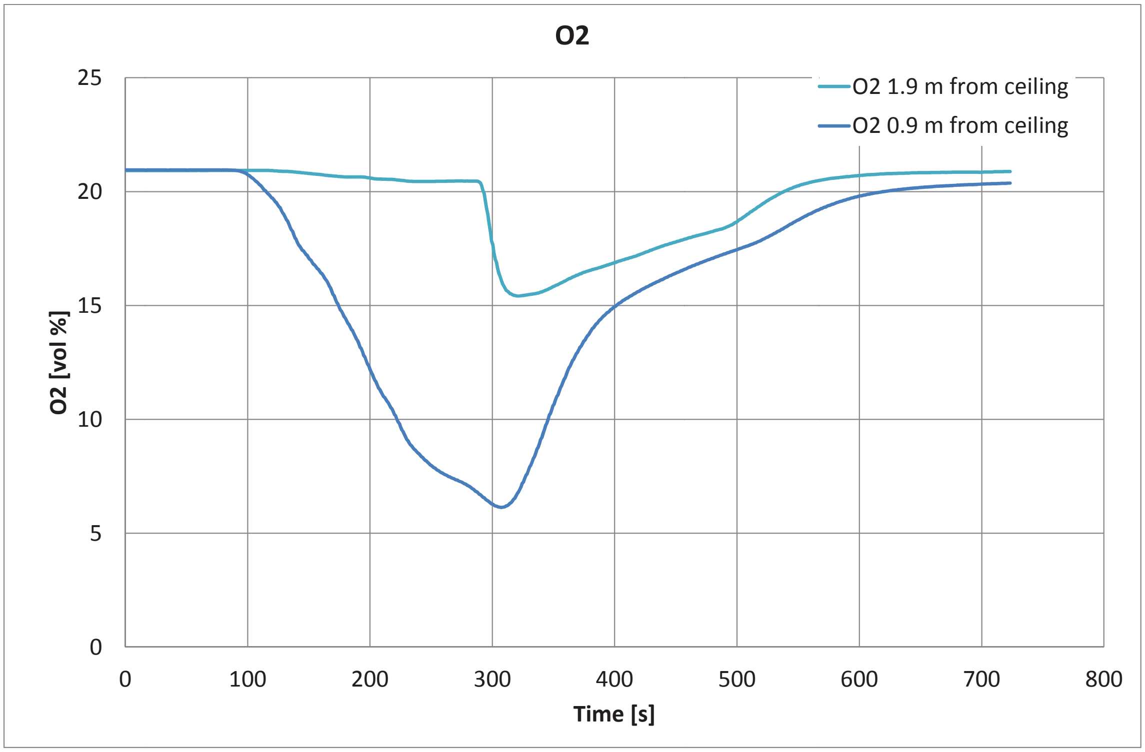

Figure 210. Test 27, O2 level. Not time-adjusted

Test protocol

Test: 28

Date: 2012-02-07

Test engineer: Michael Rahm, Johan Lindström

Type of test	Thin walled torpedo dummy, water mist system
Pool fire size (Ø in mm)	1170
Position of pool fire	1
Obstruction (% of pool area)	Torpedo, placed 50mm above pool surface
Amount of diesel (L)	15
Height of freeboard (mm)	25
Water mist nozzle	BETE TF8-170
Bulkhead nozzle	
Drencher nozzle	BETE 460.928 (used as a backup)
Distance from nozzle to pool area	
Pressure (bar)	10
Water flow (L/min)	
Notes:	
Time (s)	
0	Start measuring program and video camera
60	Ignition
90	Activation of water mist system
102	Suppressed fire (approximately 1 m high flames around the torpedo dummy)
120	Flames underneath the torpedo
570	Activates the drencher system (32 mm/min) to extinguish the fire
589	The fire was extinguished
	Channel 26 may not work

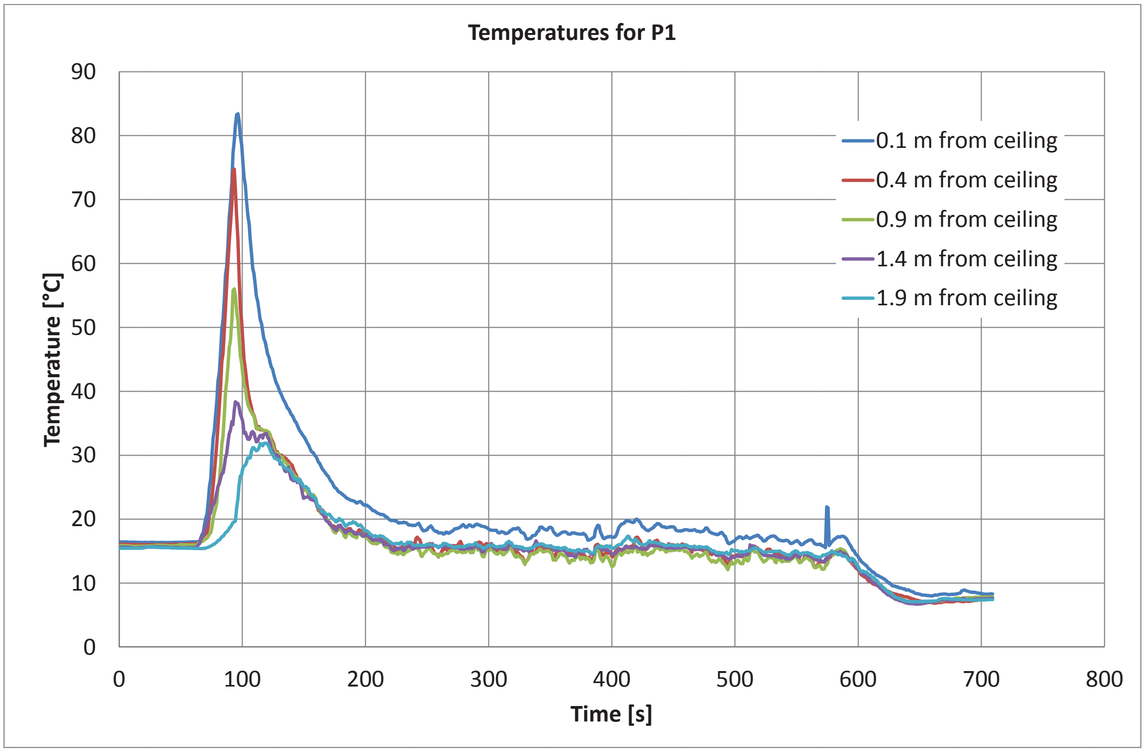

Figure 211. Test 28, Temperatures for P1

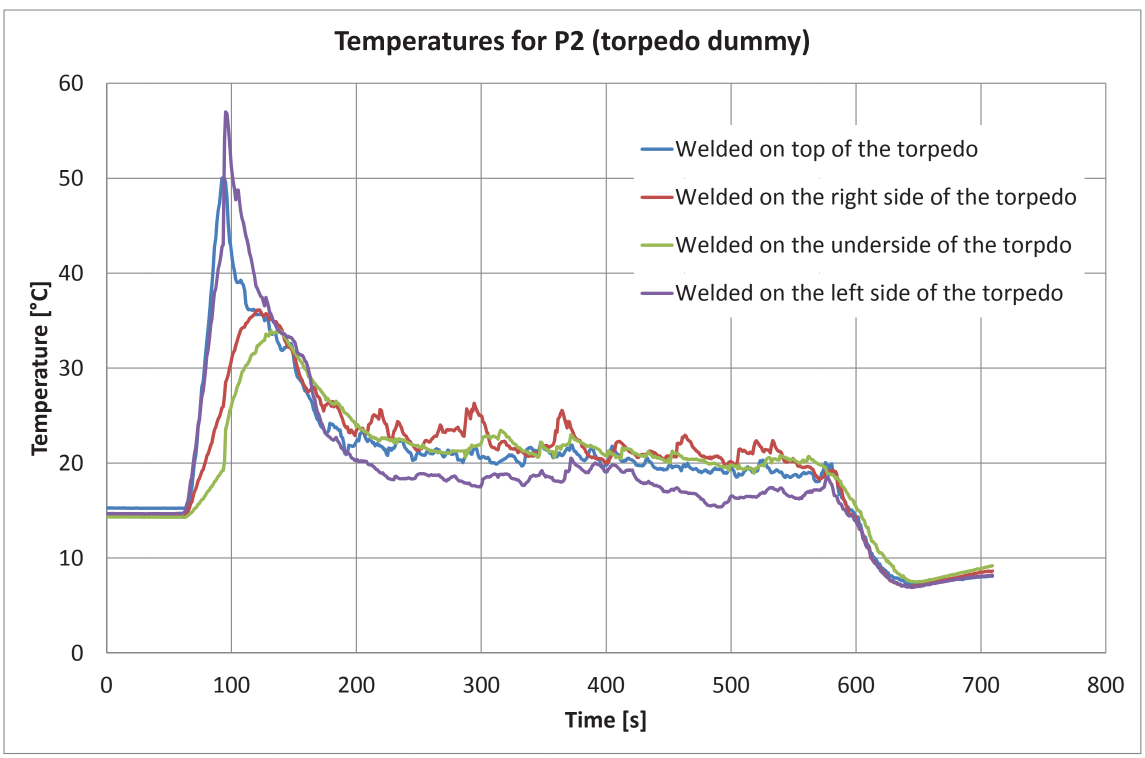

Figure 212. Test 28, Temperatures for P2 (dummy torpedo)

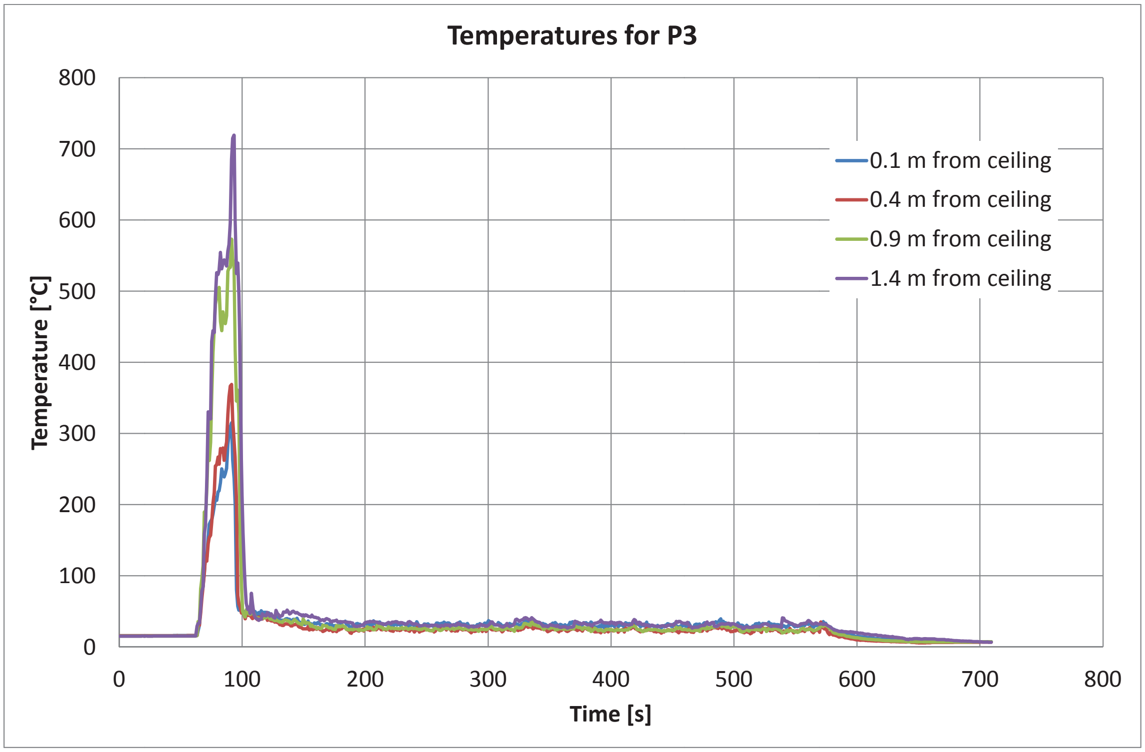

Figure 213. Test 28, Temperatures for P3

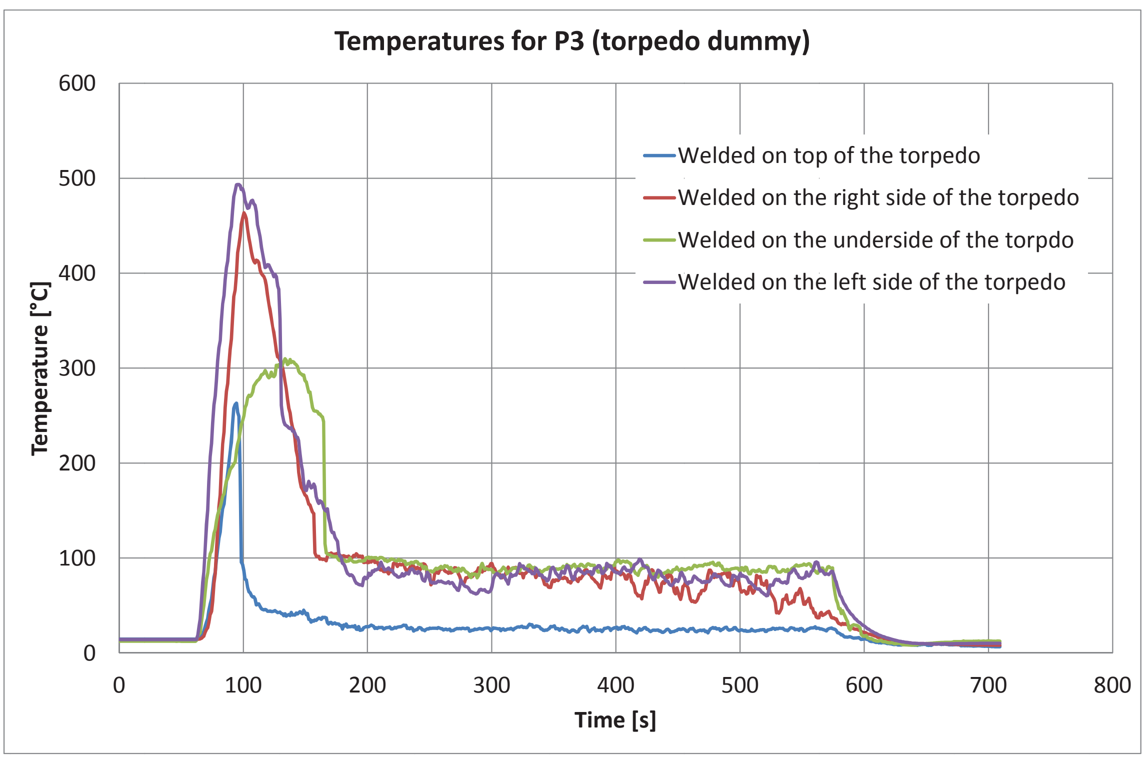

Figure 214. Test 28, Temperatures for P3 (dummy torpedo)

Appendix 1

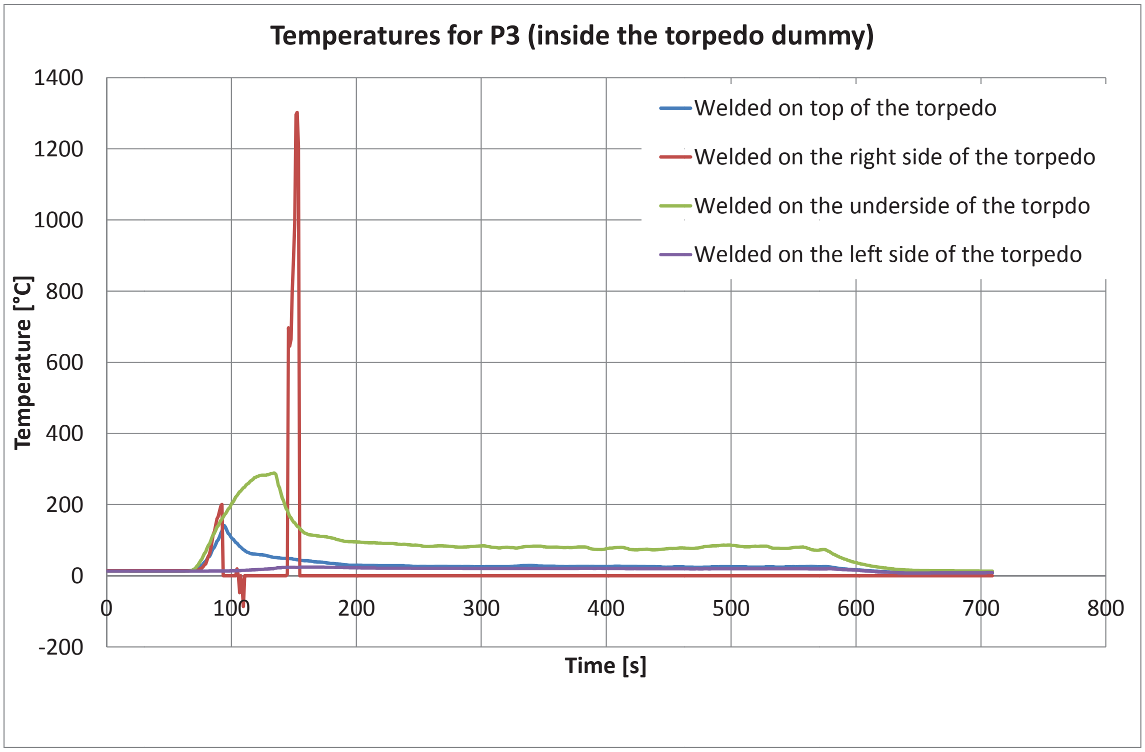

Figure 215. Test 28, Temperatures for P3 (inside the dummy torpedo)

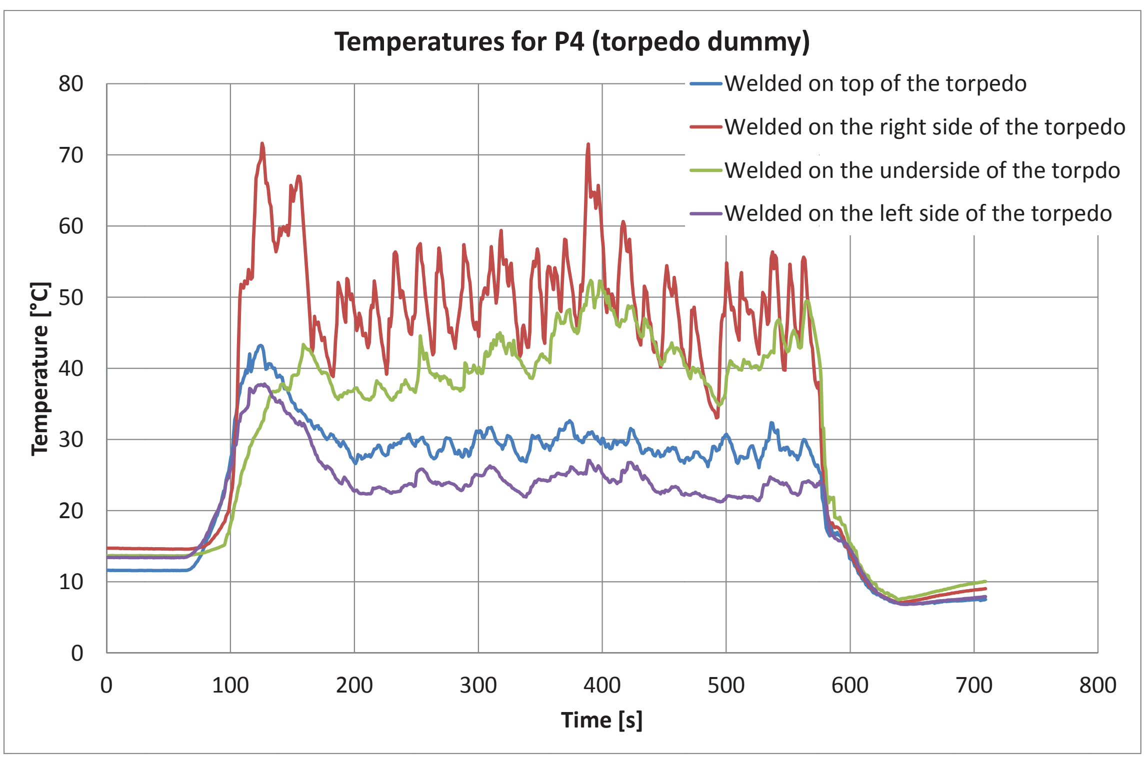

Figure 216. Test 28, Temperatures for 4 (dummy torpedo)

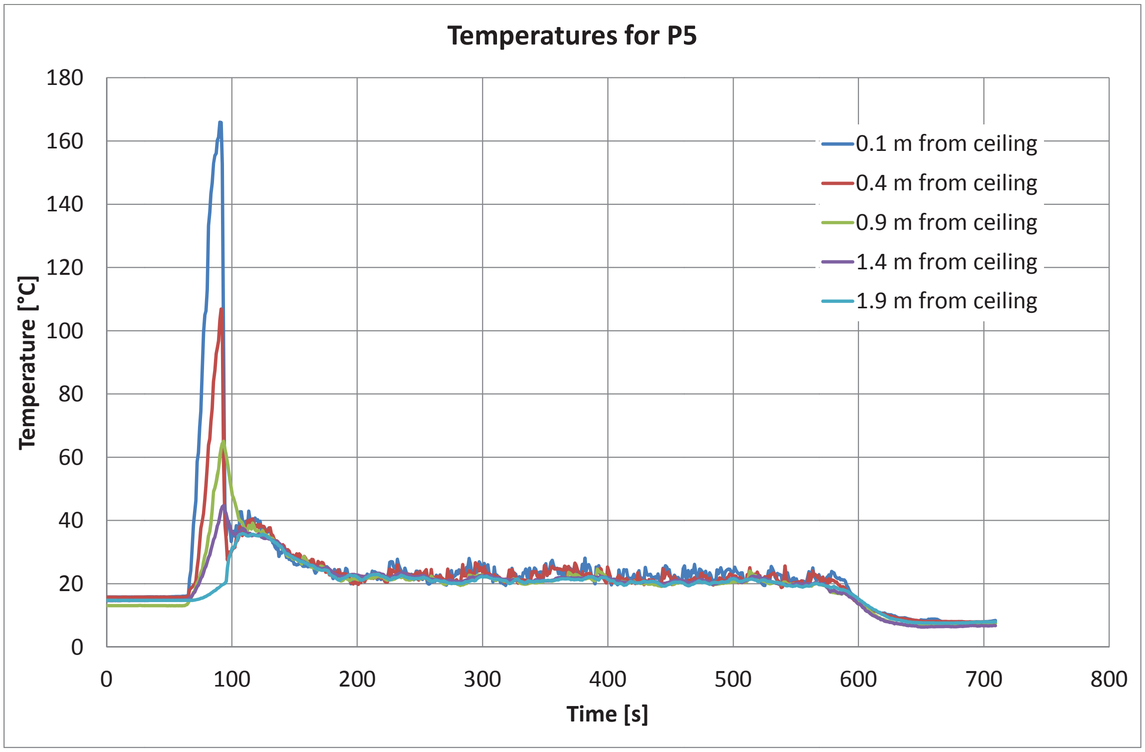

Figure 217. Test 28, Temperatures for P5

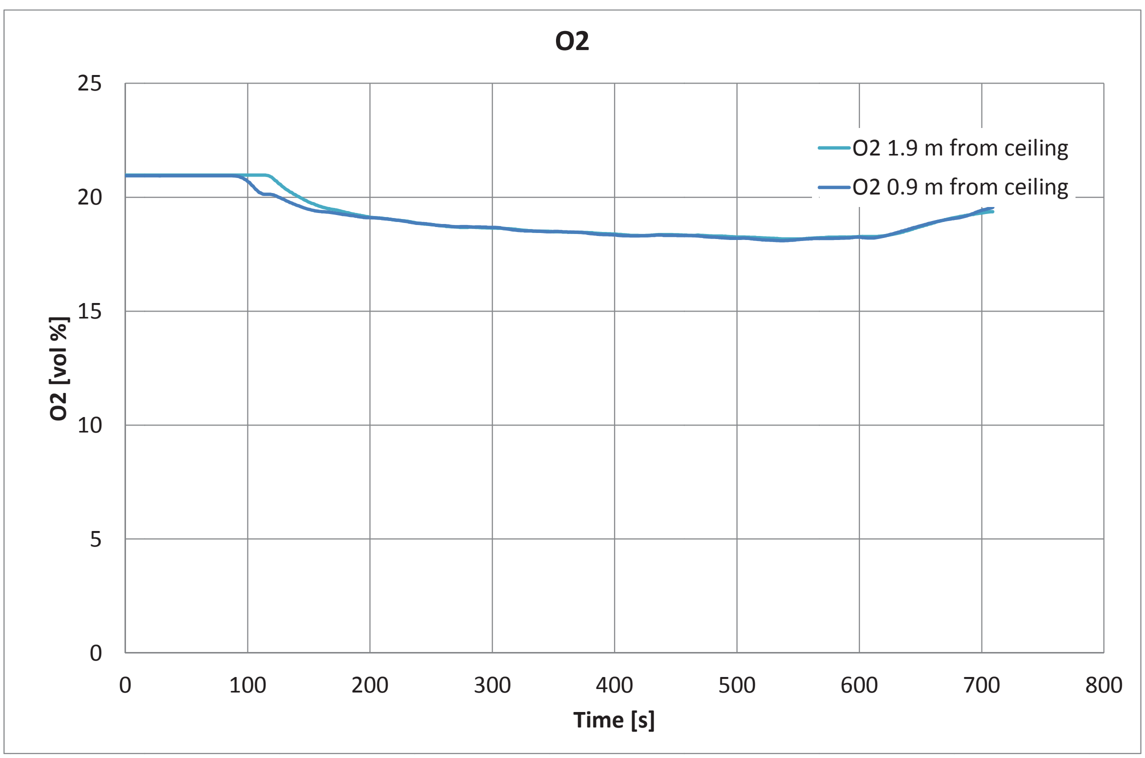

Figure 218. Test 28, O2 level. Not time-adjusted

Appendix 1

Test protocol

Test: 29

Date: 2012-02-07

Test engineer: Michael Rahm, Johan Lindström

Type of test	Thin walled torpedo, drencher system 32 mm/min
Pool fire size (Ø in mm)	1170
Position of pool fire	1
Obstruction (% of pool area)	Torpedo, placed 50mm above pool surface
Amount of diesel (L)	10
Hight of freeboard (mm)	25
Water mist nozzle	
Bulkhead nozzle	
Drencher nozzle	BETE 460.928
Distance from nozzle to pool area	
Pressure (bar)	10
Water flow (L/min)	
Notes:	
Time (s)	
0	Start measuring program and video camera
60	Ignition
90	Activation of drencher system
	Instants fire suppression
110	The fire was extinguished
180	The water flow to the drencher nozzles was stopped

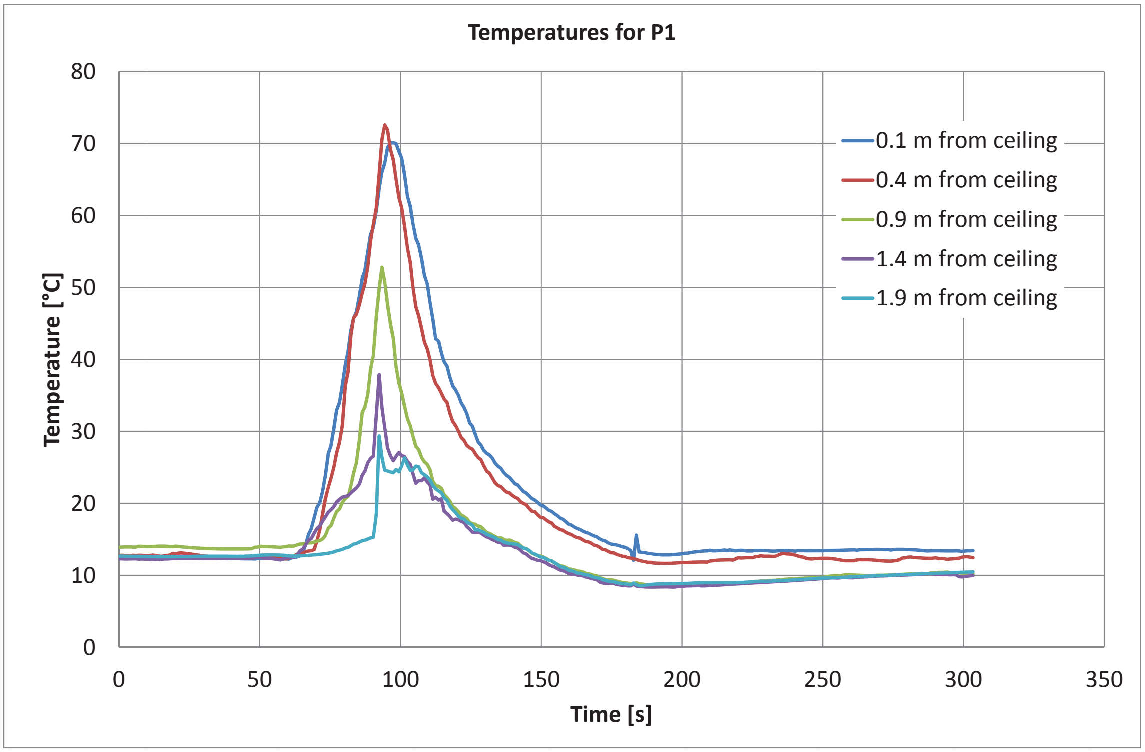

Figure 219. Test 29, Temperatures for P1

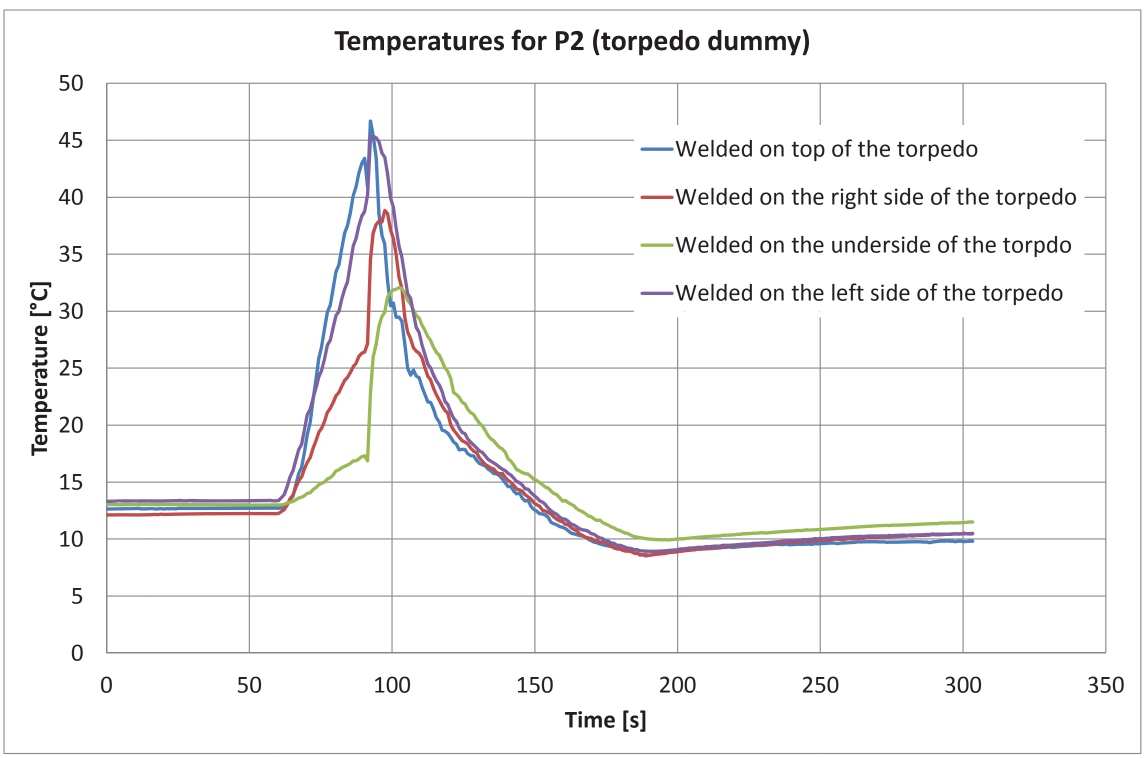

Figure 220. Test 29, Temperatures for P2 (dummy torpedo)

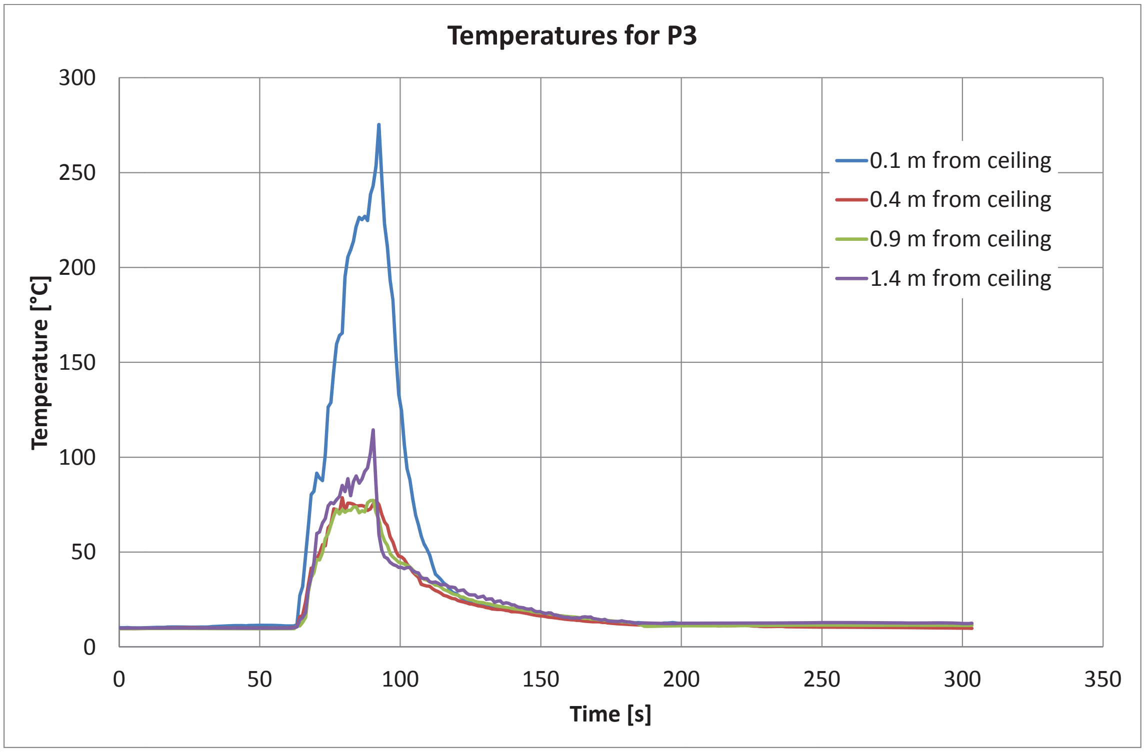

Figure 221. Test 29, Temperatures for P3

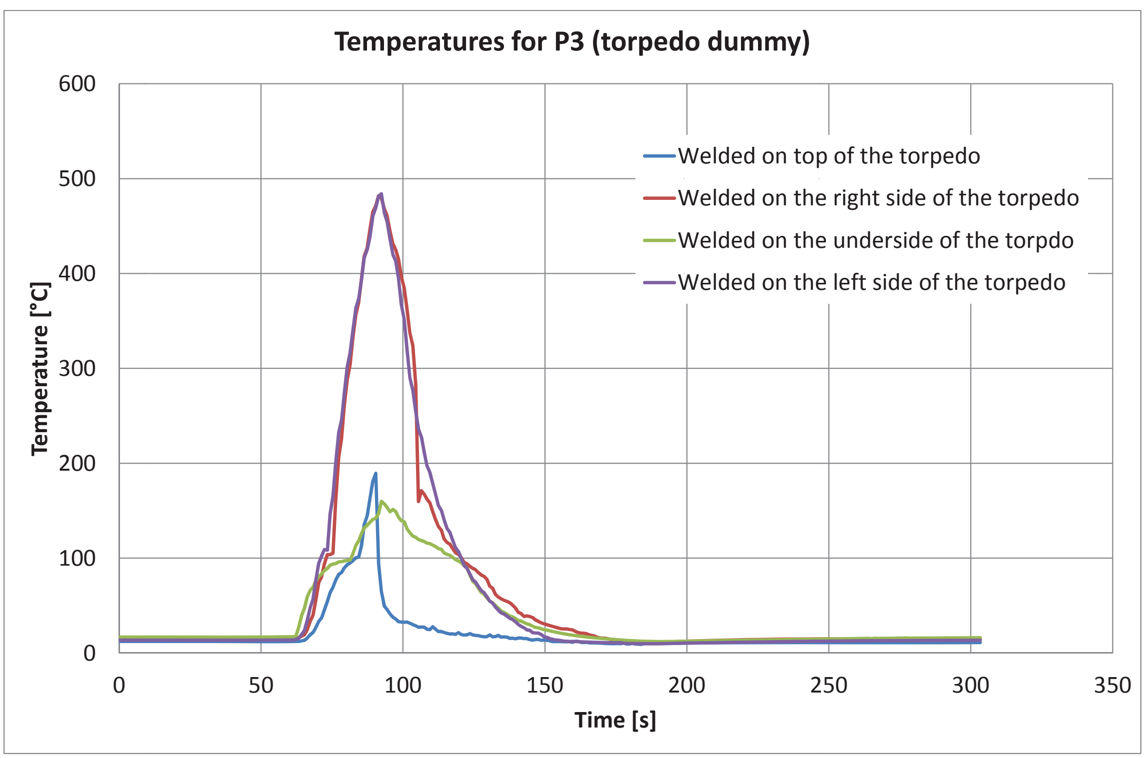

Figure 222. Test 29, Temperatures for P3 (dummy torpedo)

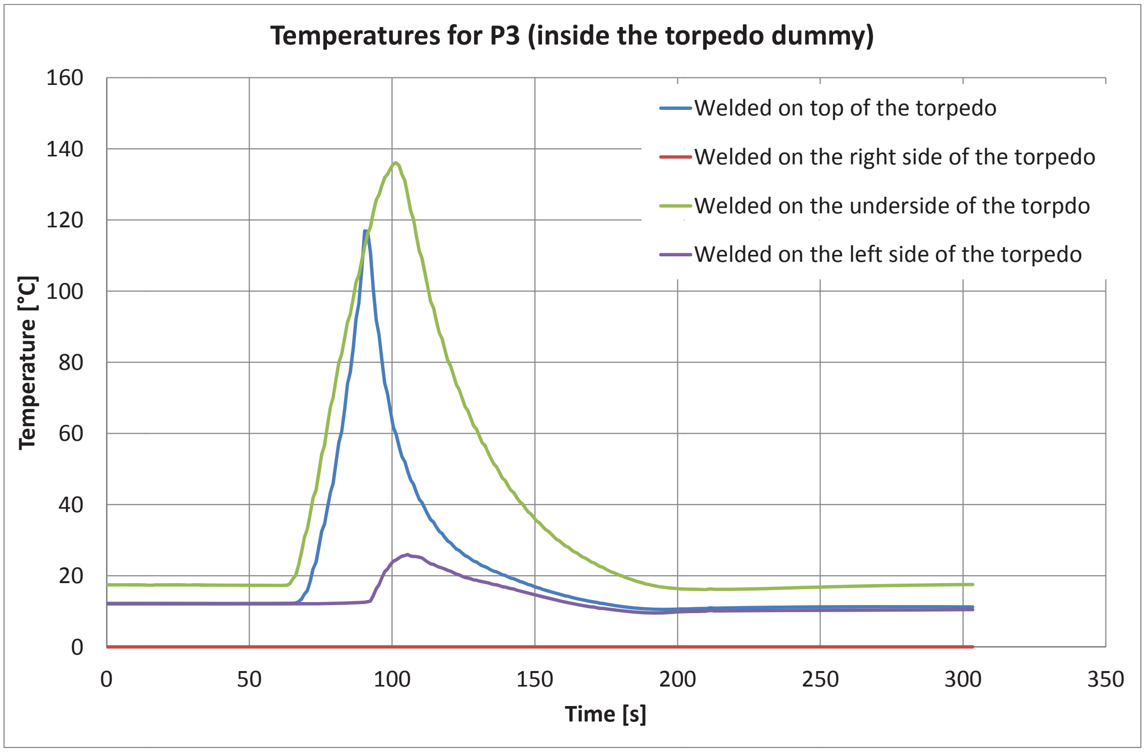

Figure 223. Test 29, Temperatures for P3 (inside the dummy torpedo

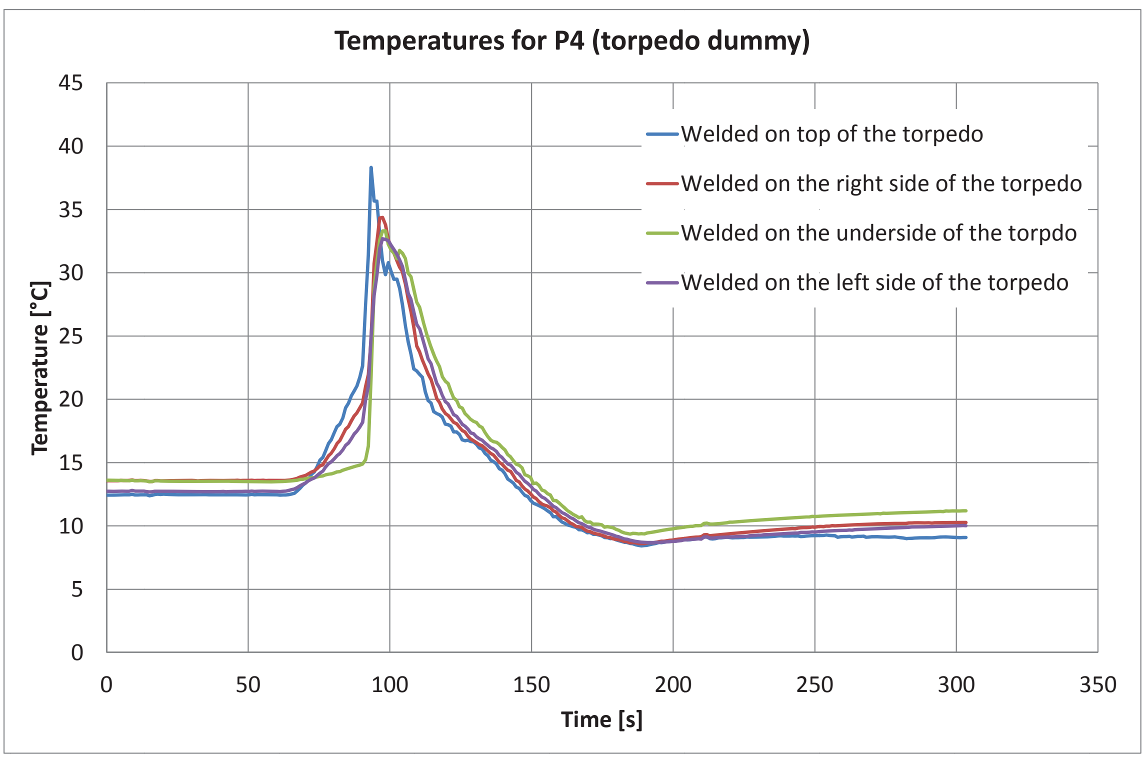

Figure 224. Test 29, Temperatures for P4 (dummy torpedo)

Appendix 1

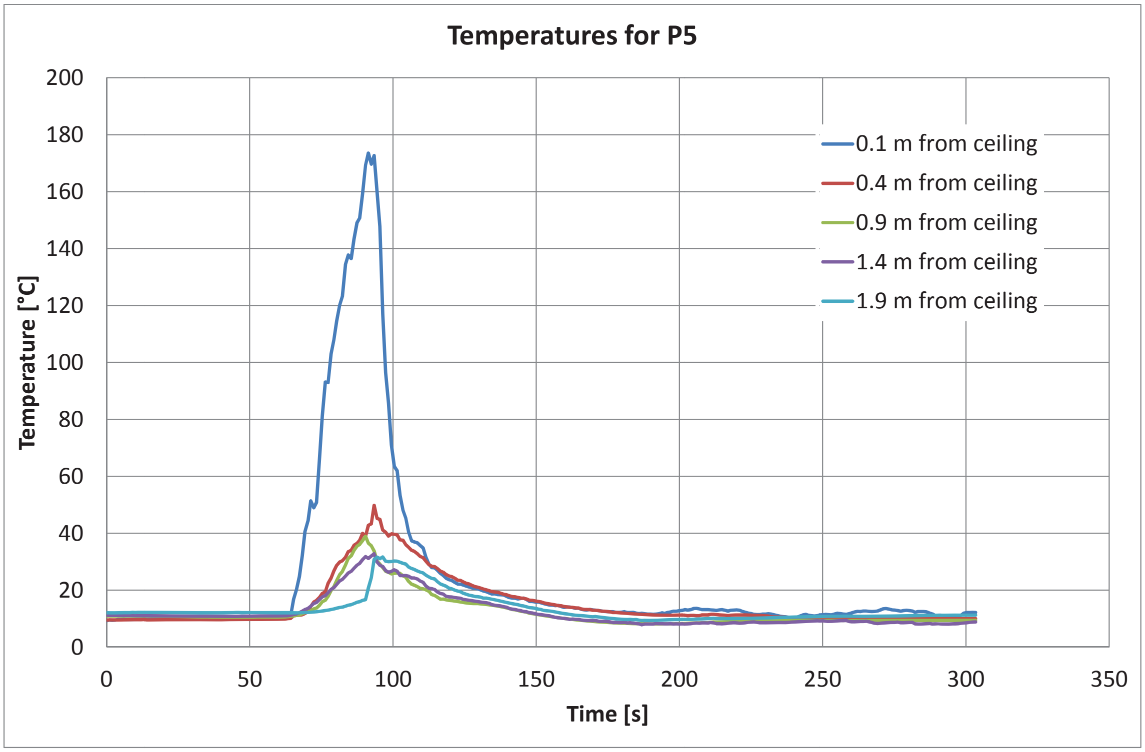

Figure 225. Test 29, Temperatures for P5

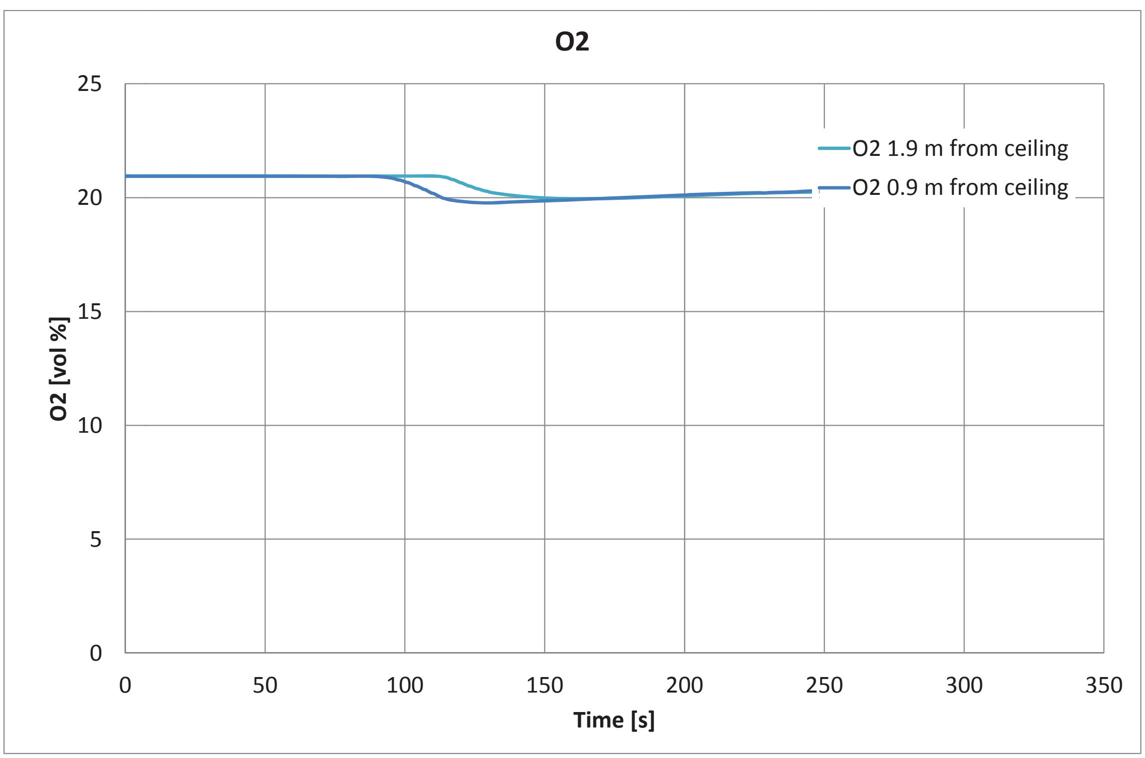

Figure 226. Test 29, O2 level. Not time-adjusted

Test protocol

Test: 30

Date: 2012-02-07

Test engineer: Michael Rahm, Johan Lindström

Type of test	Thin walled torpedo, drencher system 10 mm/min
Pool fire size (Ø in mm)	1170
Position of pool fire	1
Obstruction (% of pool area)	Torpedo, placed 50mm above pool surface
Amount of diesel (L)	5
Height of freeboard (mm)	25
Water mist nozzle	
Bulkhead nozzle	
Drencher nozzle	BETE 460.928
Distance from nozzle to pool area	
Pressure (bar)	10
Water flow (L/min)	
Notes:	
Time (s)	
0	Start measuring program and video camera
60	Ignition
90	Activation of drencher system
	Instant suppression of the fire
122	The fire was extinguished
240	The water flow to the drencher nozzles was stopped

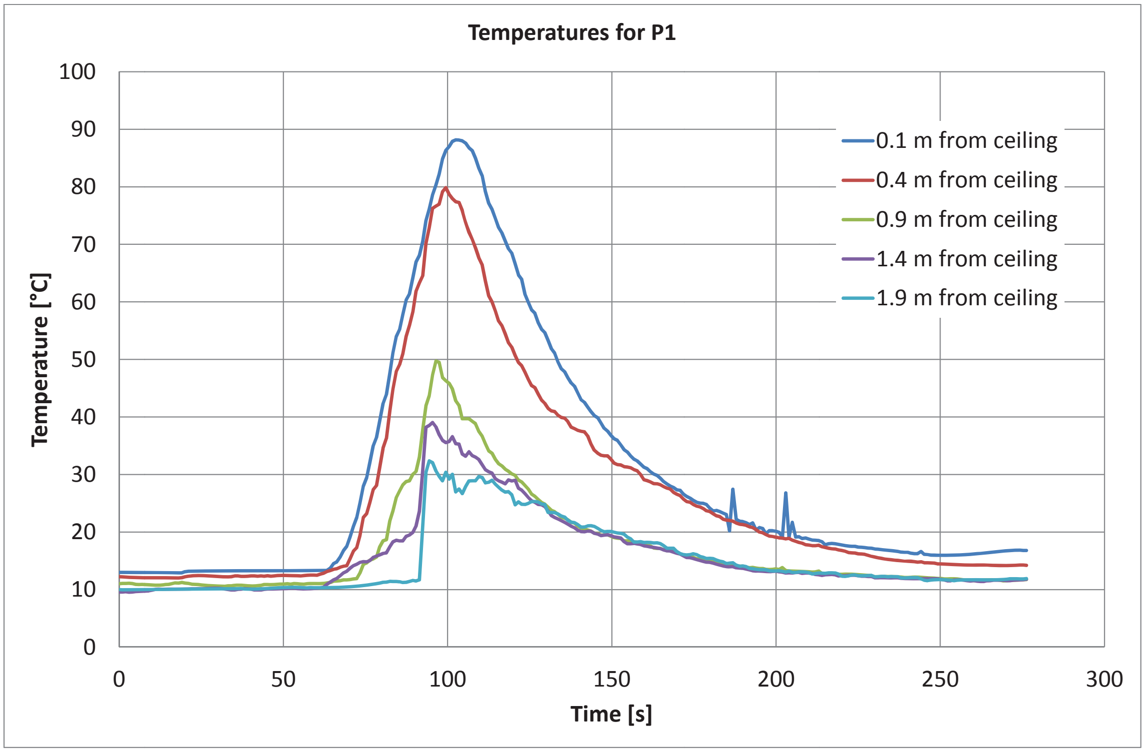

Figure 227. Test 30, Temperatures for P1

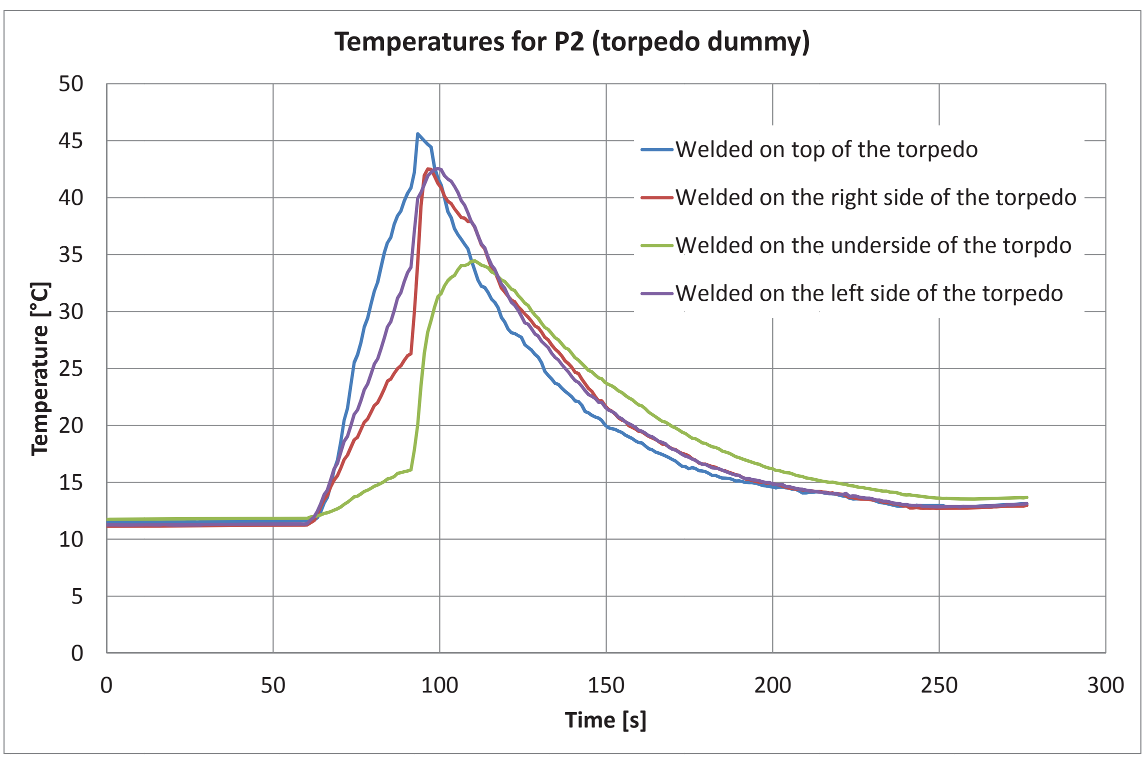

Figure 228. Test 30, Temperatures for P2 (dummy torpedo)

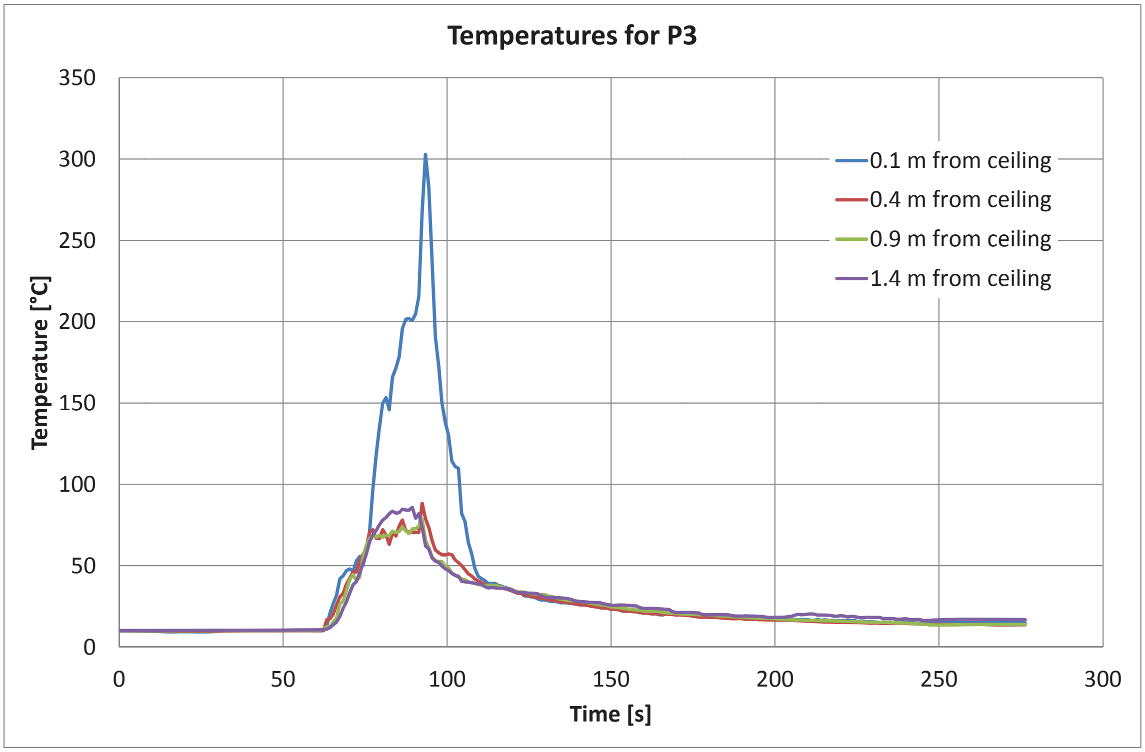

Figure 229. Test 30, Temperatures for P3

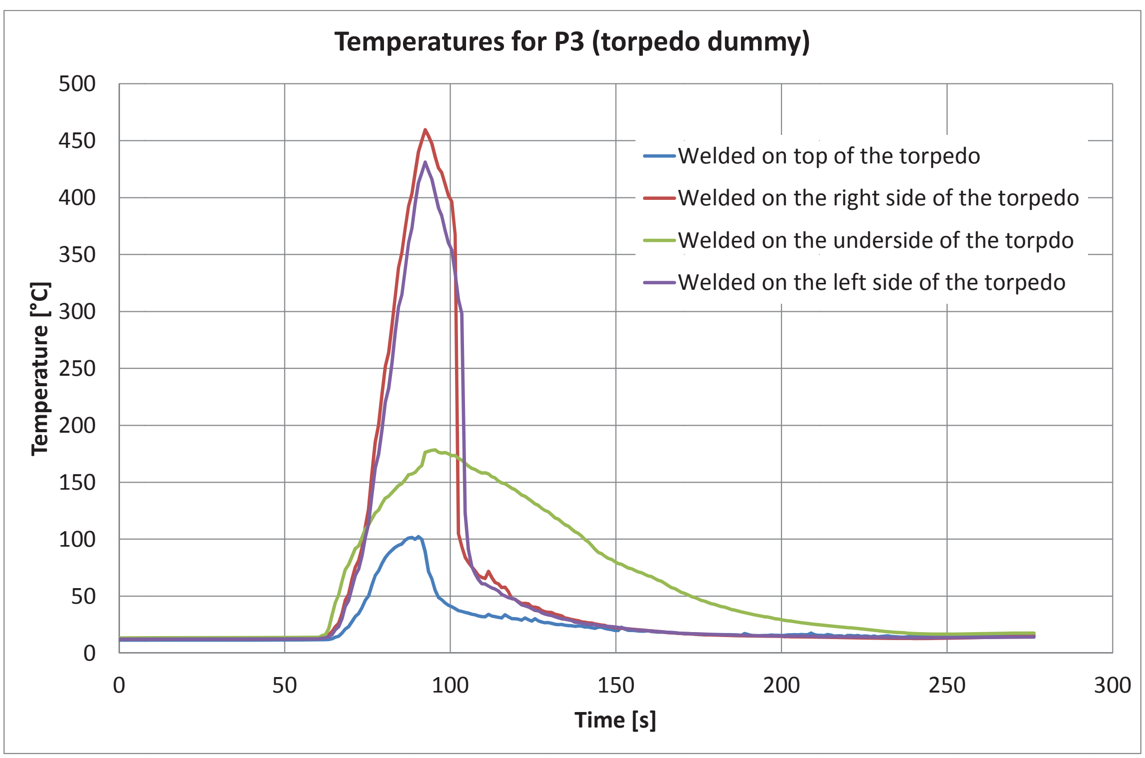

Figure 230. Test 30, Temperatures for P3 (dummy torpedo)

Appendix 1

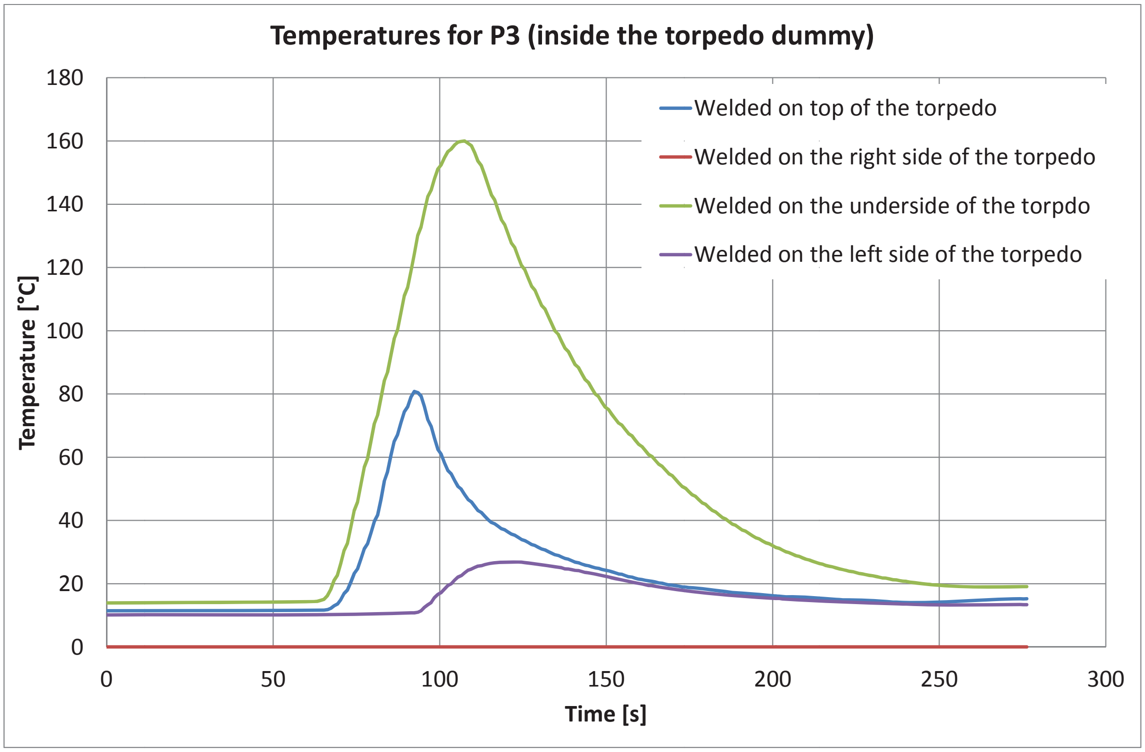

Figure 231. Test 30, Temperatures for P3 (inside the dummy torpedo)

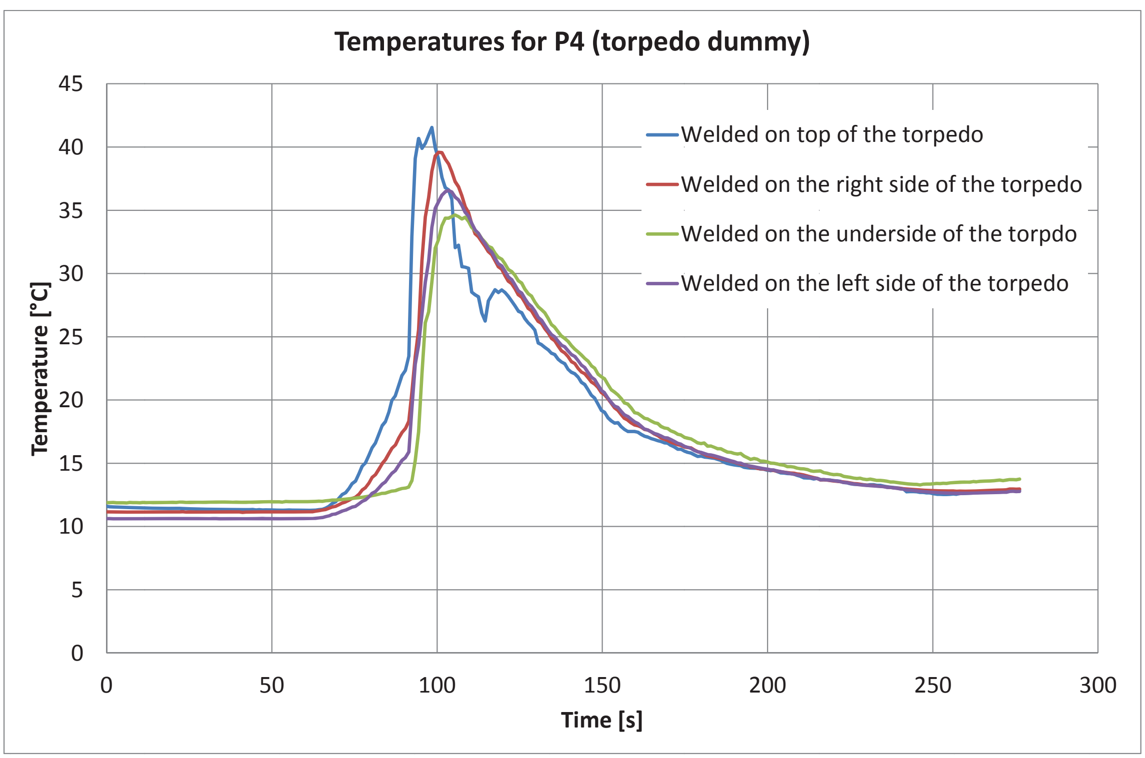

Figure 232. Test 30, Temperatures for P4 (dummy torpedo)

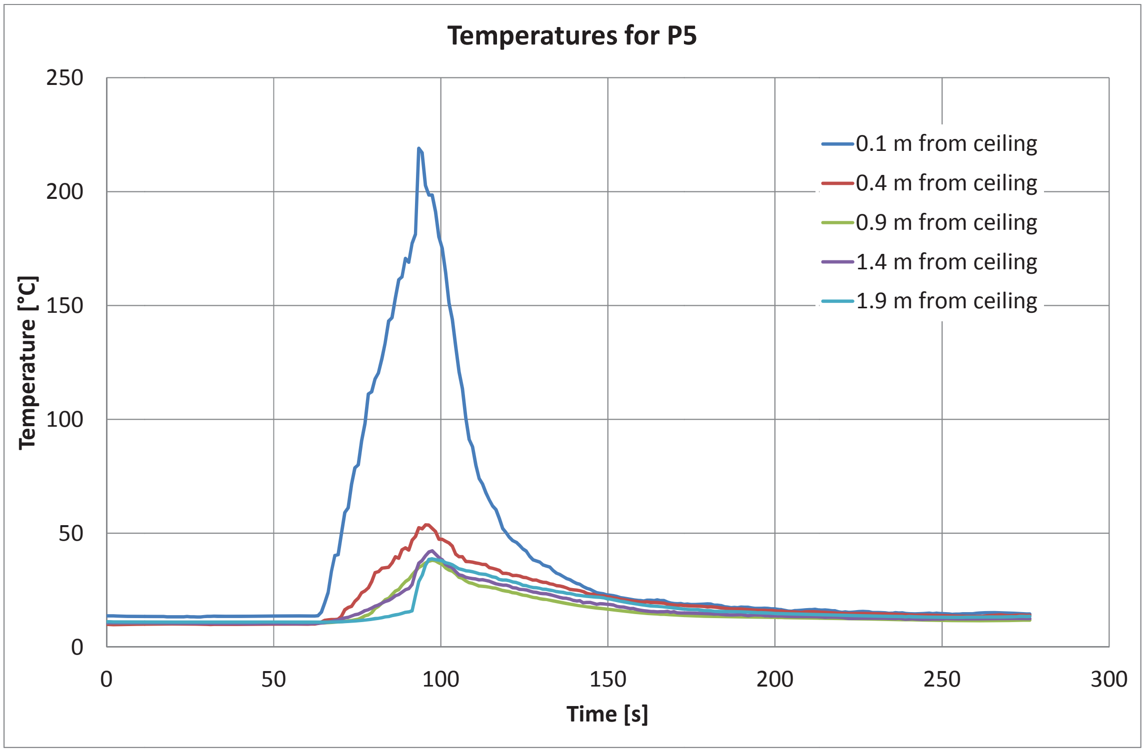

Figure 233. Test 30, Temperatures for P5

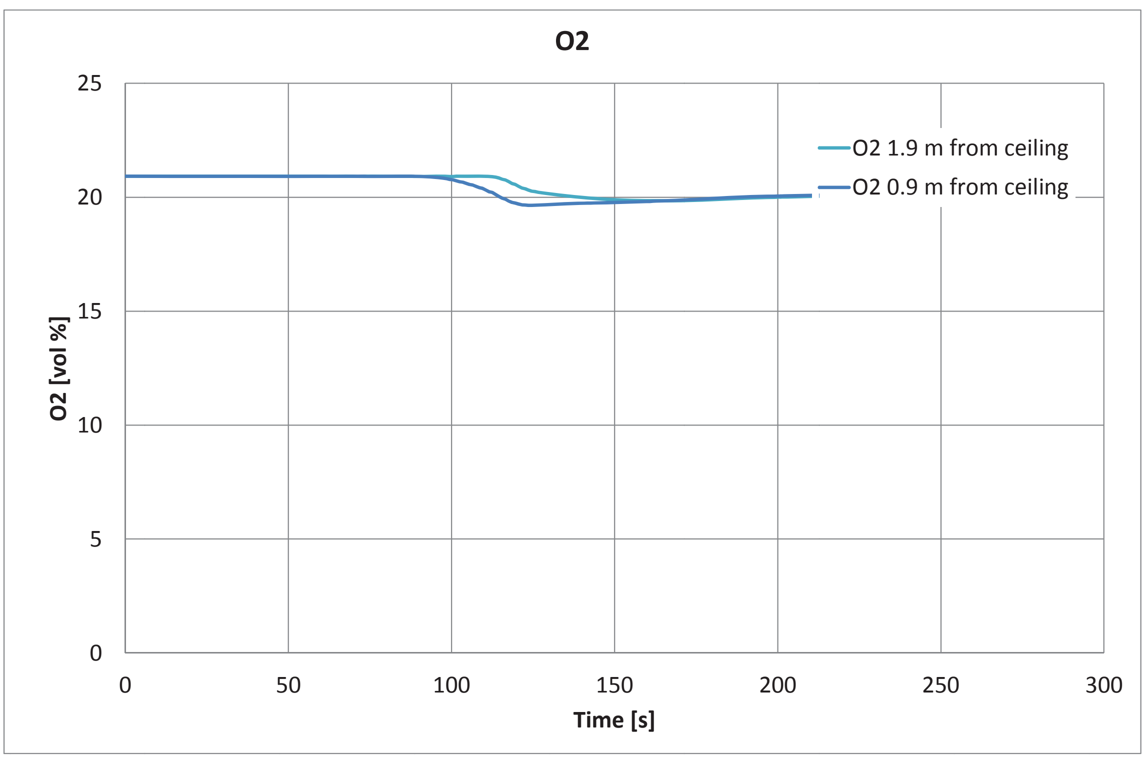

Figure 234. Test 30, O2 level. Not time-adjusted

Test protocol

Test: 31

Date: 2012-02-07

Test engineer: Michael Rahm, Johan Lindström

Type of test	Thin walled torpedo, water mist system
Pool fire size (Ø in mm)	1170
Position of pool fire	2 (250 mm from the edge of the torpedo)
Obstruction (% of pool area)	
Amount of diesel (L)	10
Height of freeboard (mm)	25
Water mist nozzle	BETE TF 8-170
Bulkhead nozzle	
Drencher nozzle	
Distance from nozzle to pool area	
Pressure (bar)	10
Water flow (L/min)	
Notes:	
Time (s)	
0	Start measuring program and video camera
60	Ignition
90	Activation of water mist system
	Instant suppression of the fire
158	The fire was extinguished
250	Stops the water flow to the water mist nozzles

Appendix 1

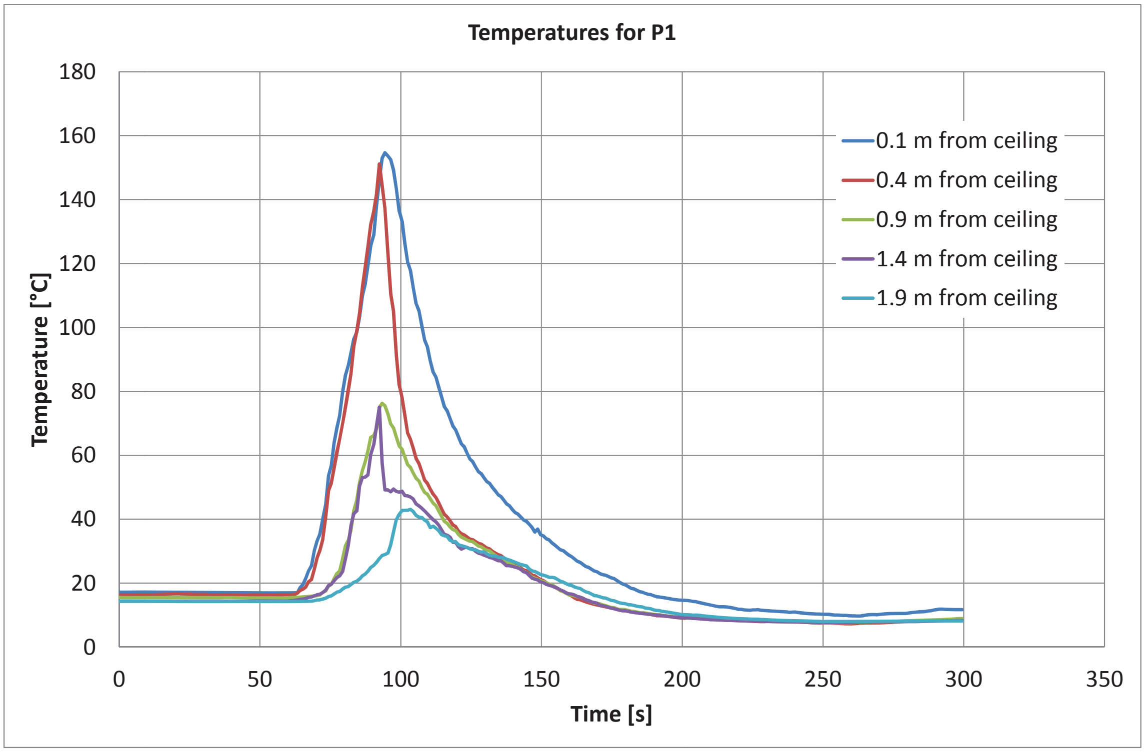

Figure 235. Test 31, Temperatures for P1

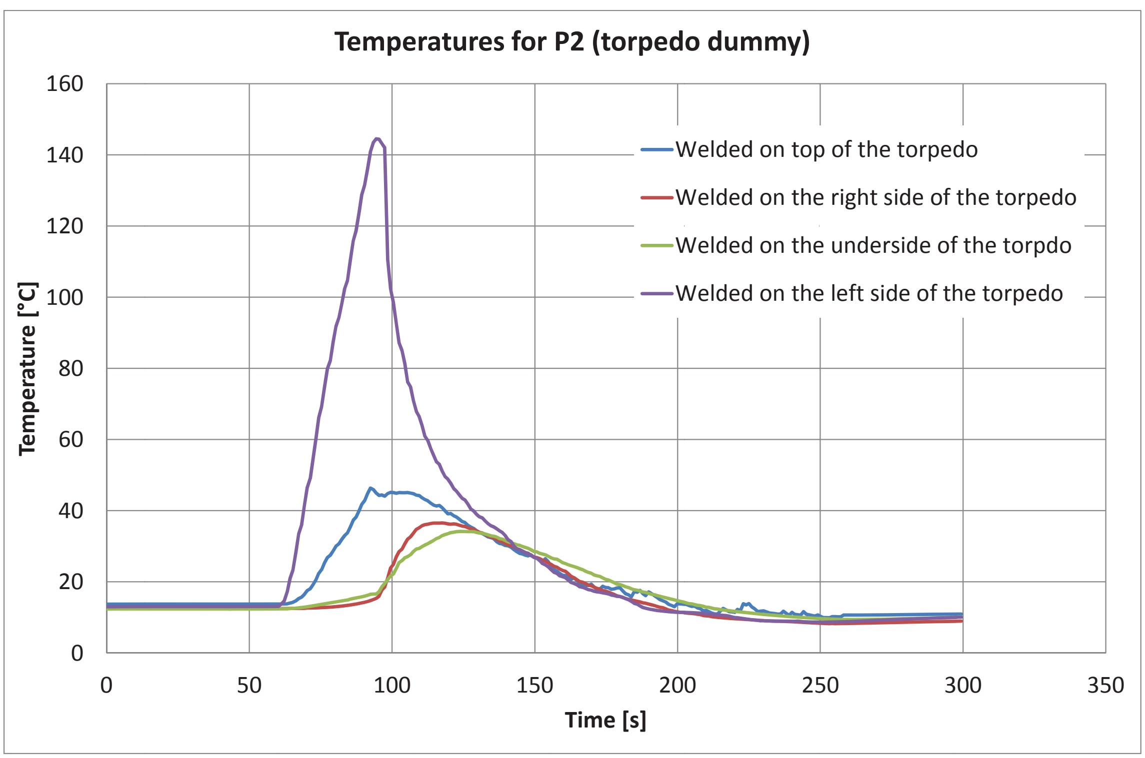

Figure 236. Test 31, Temperatures for P2 (dummy torpedo)

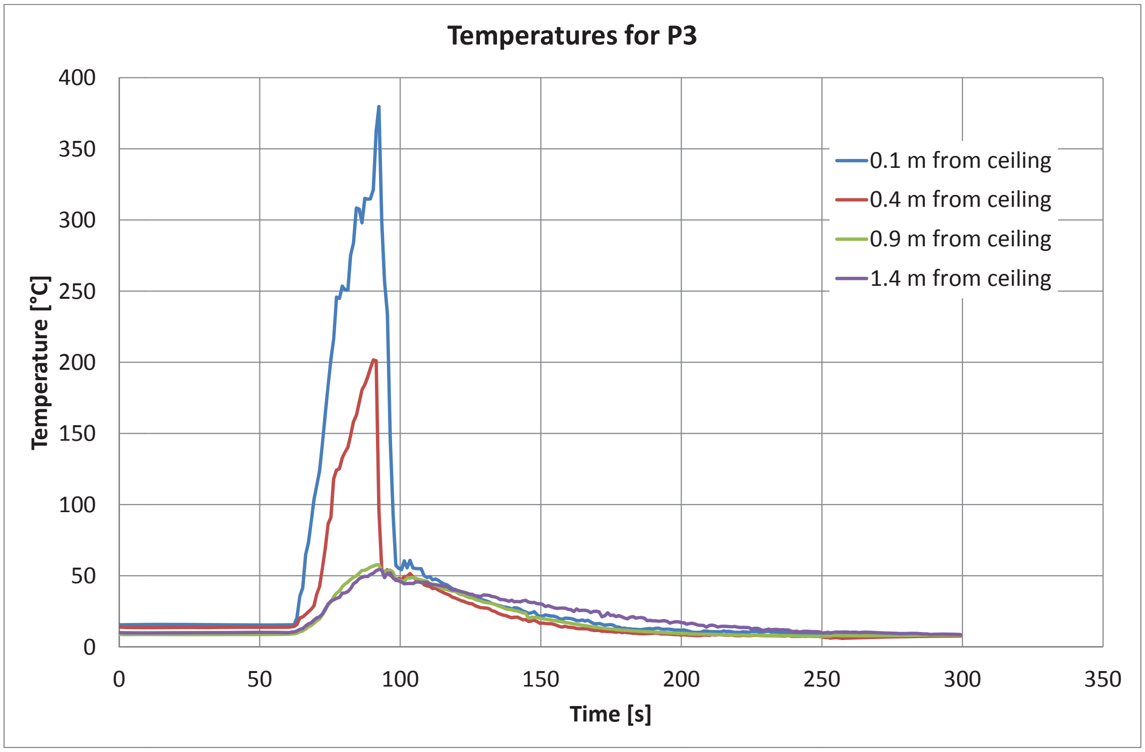

Figure 237. Test 31, Temperatures for P3

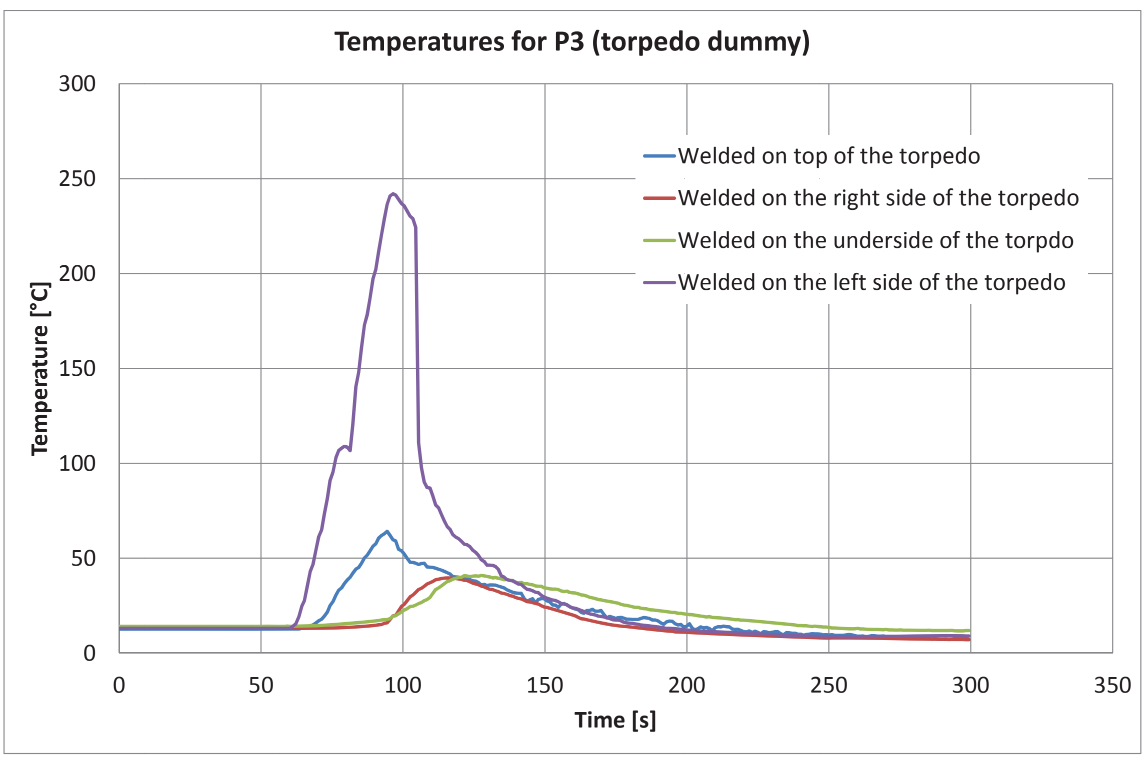

Figure 238. Test 31, Temperatures for P3 (dummy torpedo)

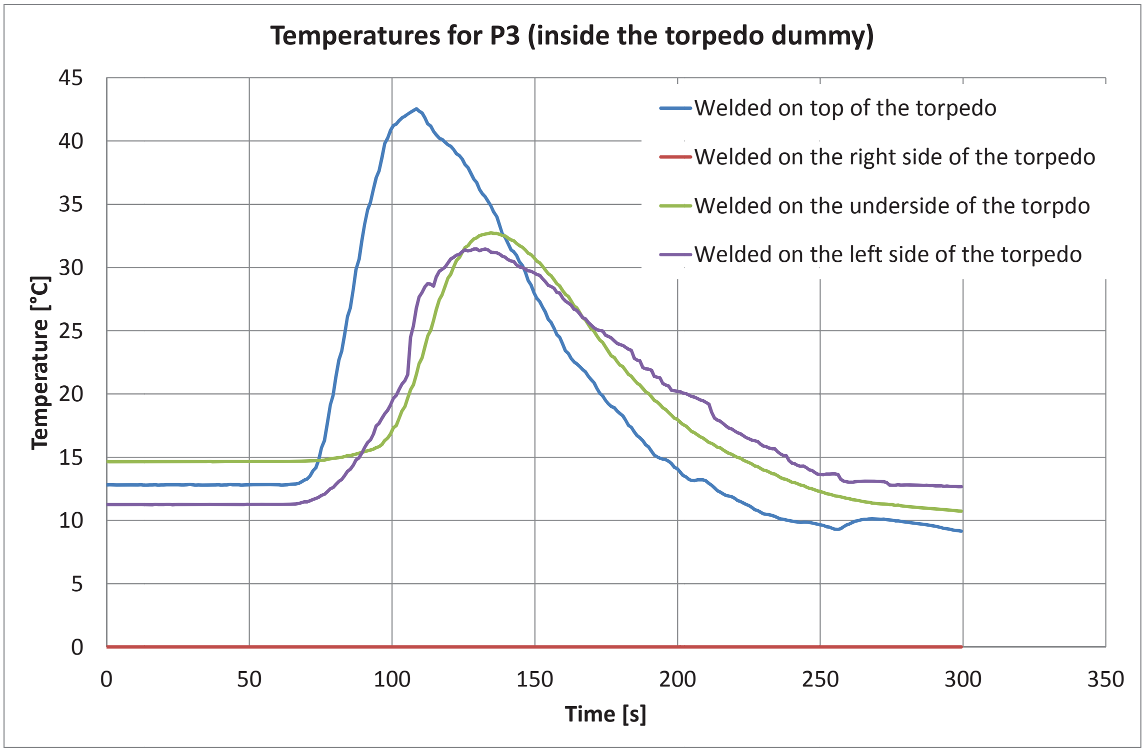

Figure 239. Test 31, Temperatures for P3 (inside the dummy torpedo)

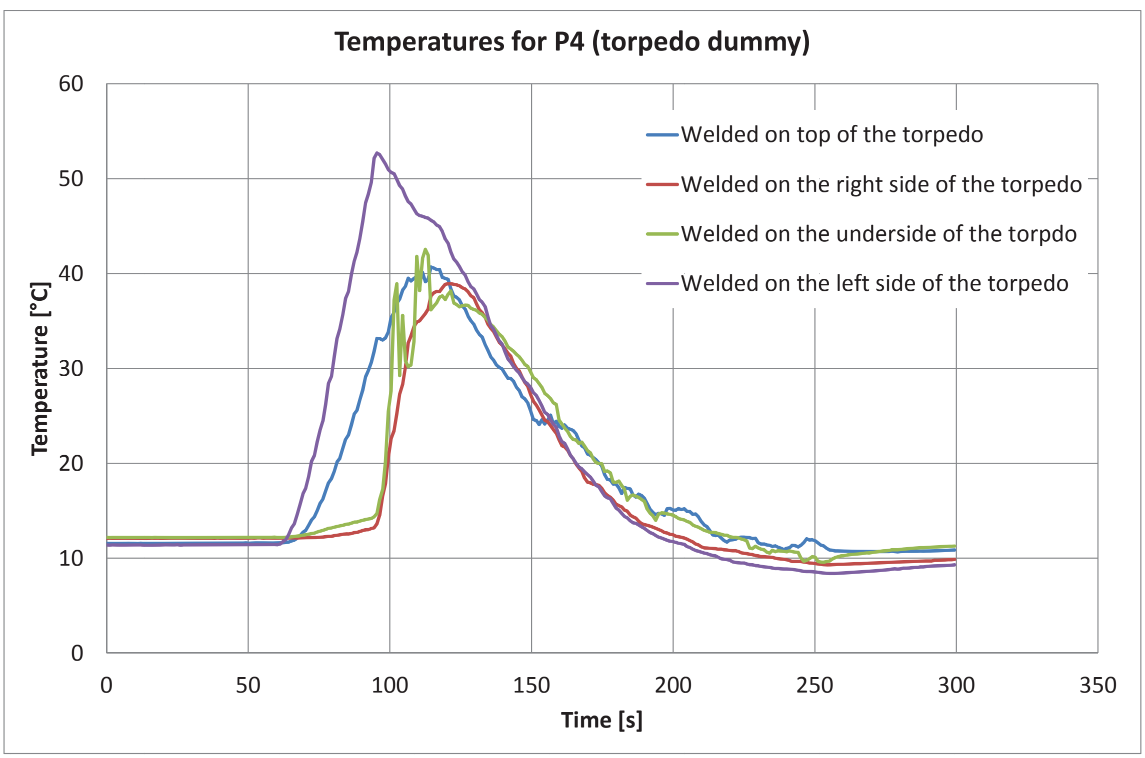

Figure 240. Test 31, Temperatures for P4 (dummy torpedo)

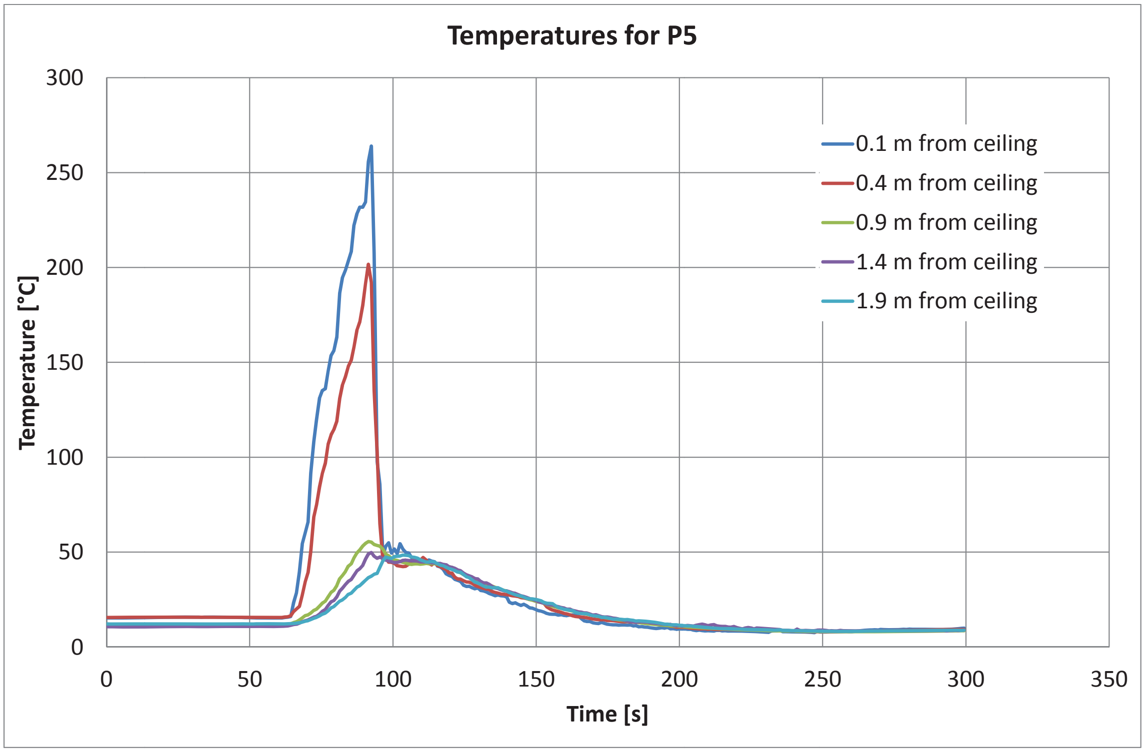

Figure 241. Test 31, Temperatures for P5

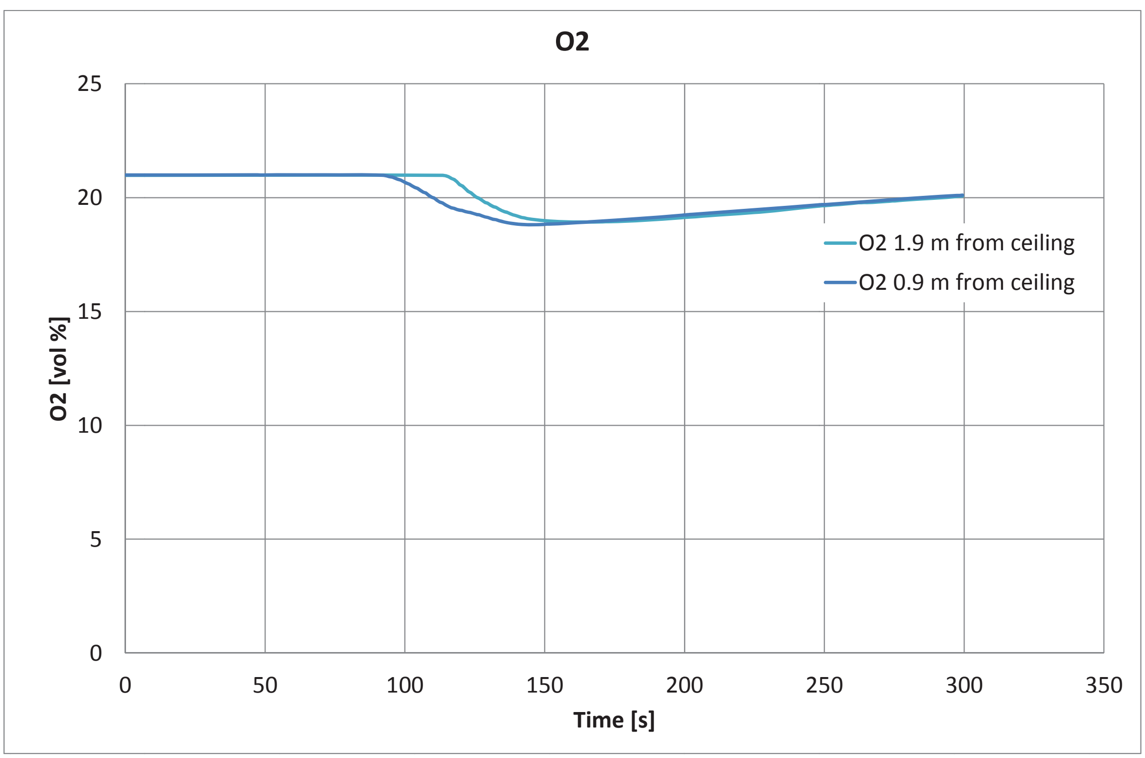

Figure 242. Test 31, O2 level. Not time-adjusted

Test protocol

Test: 32

Date: 2012-02-07

Test engineer: Michael Rahm, Johan Lindström

Type of test	Thin walled torpedo, drencher system 10 mm/min
Pool fire size (Ø in mm)	1170
Position of pool fire	2 (250 mm from the edge of the torpedo)
Obstruction (% of pool area)	
Amount of diesel (L)	5
Height of freeboard (mm)	25
Water mist nozzle	
Bulkhead nozzle	
Drencher nozzle	BETE 460.728
Distance from nozzle to pool area	
Pressure (bar)	10
Water flow (L/min)	52
Notes:	
Time (s)	
0	Start measuring program and video camera
60	Ignition
90	Activation of drencher system
	Instant suppression of the fire
	Continues to burn at the left edge of the pool area
707	The fire was extinguished
724	The water flow to the drencher nozzles was stopped

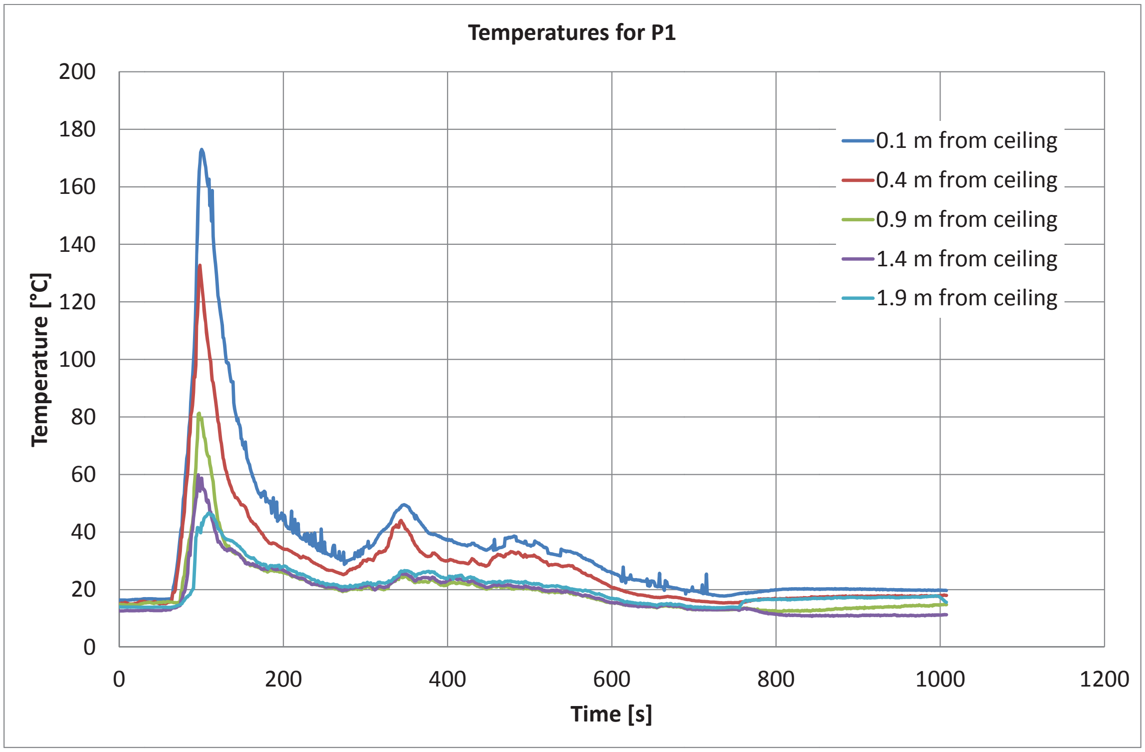

Figure 243. Test 32, Temperatures for P1

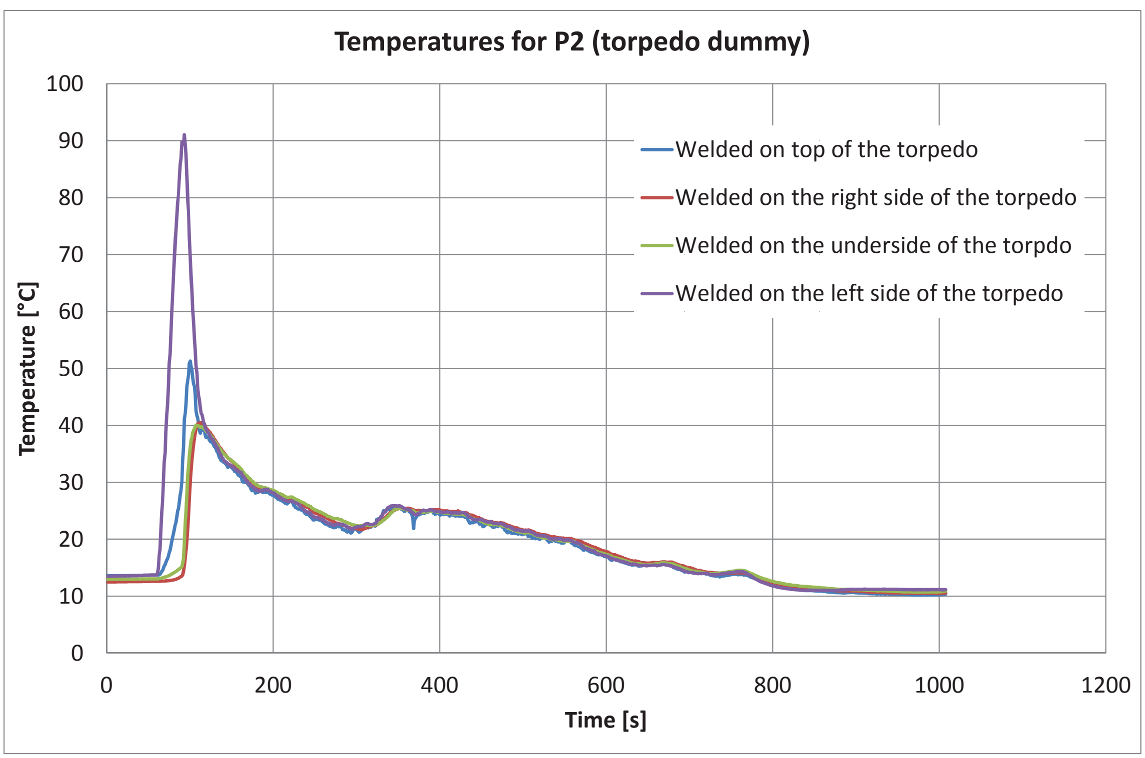

Figure 244. Test 32, Temperatures for P2 (dummy torpedo)

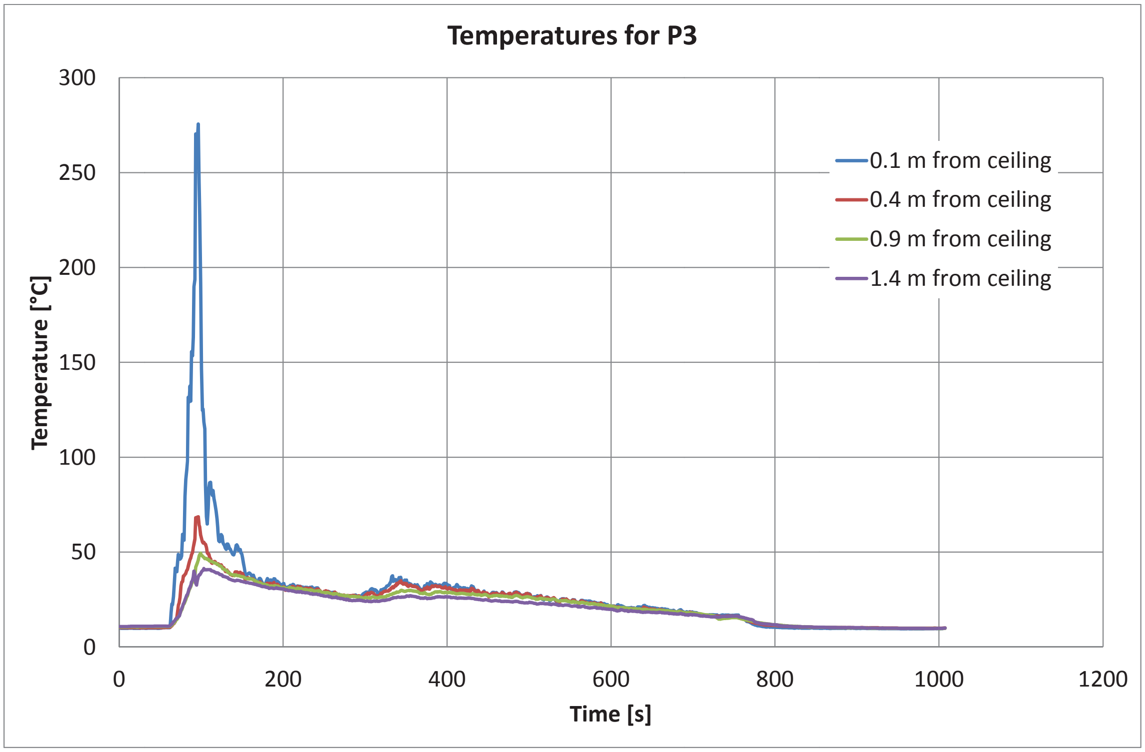

Figure 245. Test 32, Temperatures for P3

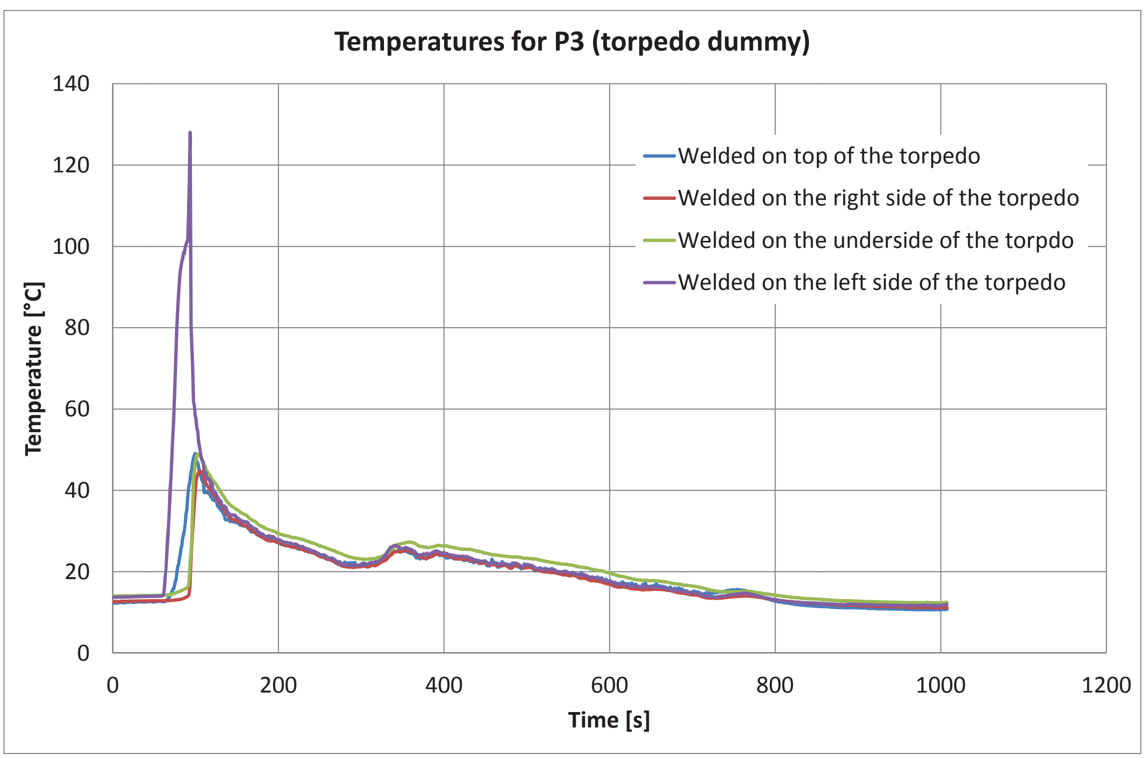

Figure 246. Test 32, Temperatures for P3 (dummy torpedo)

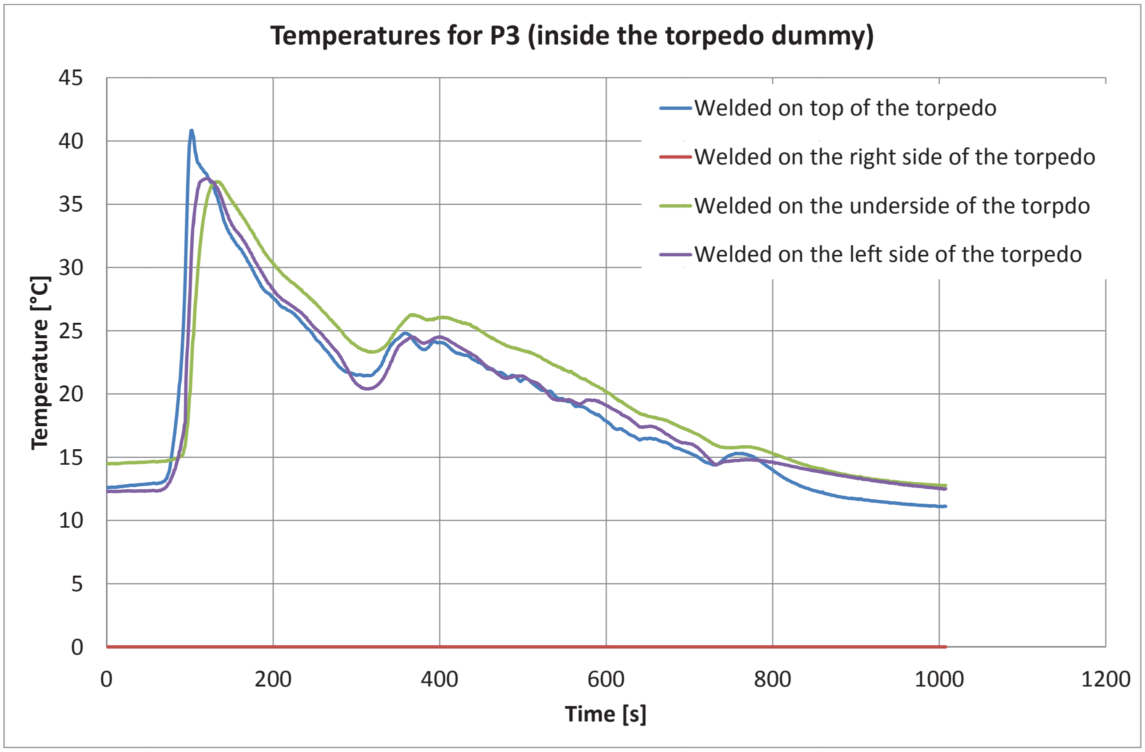

Figure 247. Test 32, Temperatures for P3 (inside the dummy torpedo)

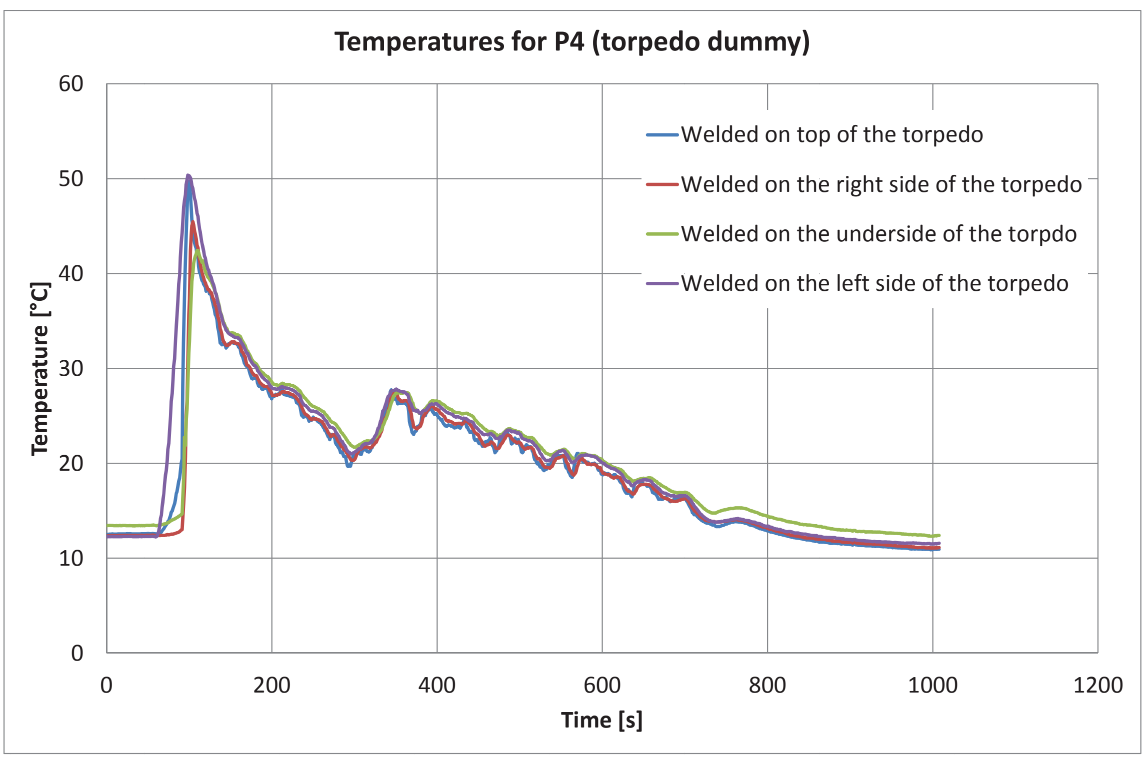

Figure 248. Test 32, Temperatures for P4 (dummy torpedo)

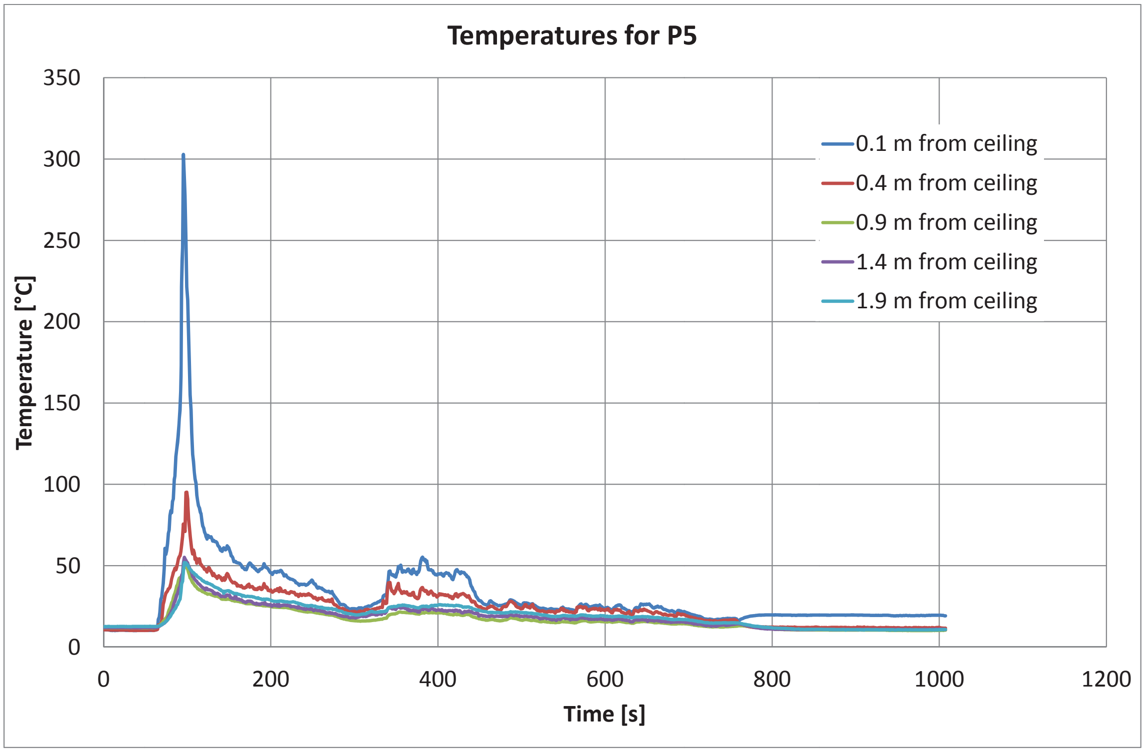

Figure 249. Test 32, Temperatures for P5

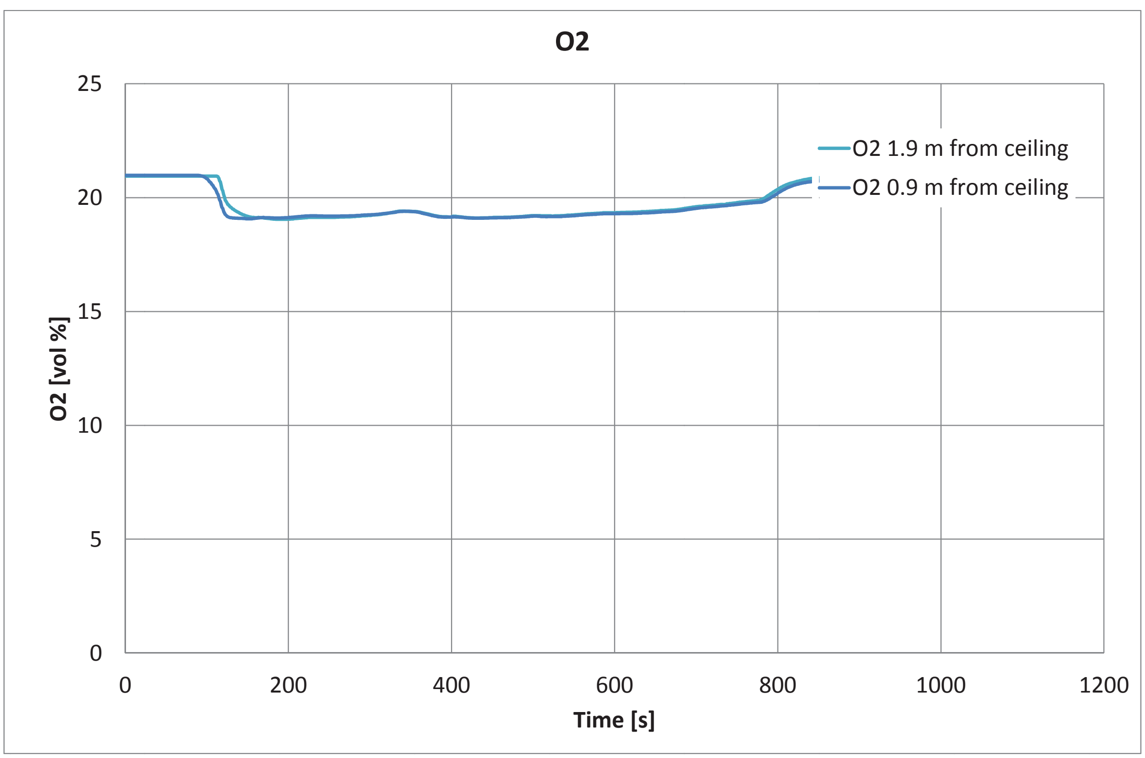

Figure 250. Test 32, O2 level. Not time-adjusted

Test protocol

Test: 33

Date: 2012-02-07

Test engineer: Michael Rahm, Johan Lindström

Type of test	Thin walled torpedo, drencher system 32 mm/min
Pool fire size (Ø in mm)	1170
Position of pool fire	2 (250 mm from the edge of the torpedo)
Obstruction (% of pool area)	
Amount of diesel (L)	10
Height of freeboard (mm)	25
Water mist nozzle	
Bulkhead nozzle	
Drencher nozzle	BETE 460.928
Distance from nozzle to pool area	
Pressure (bar)	10
Water flow (L/min)	52
Notes:	
Time (s)	
0	Start measuring program and video camera
60	Ignition
90	Activation of drencher system
138	The fire was extinguished
185	The water flow to the drencher nozzles was stopped

Appendix 1

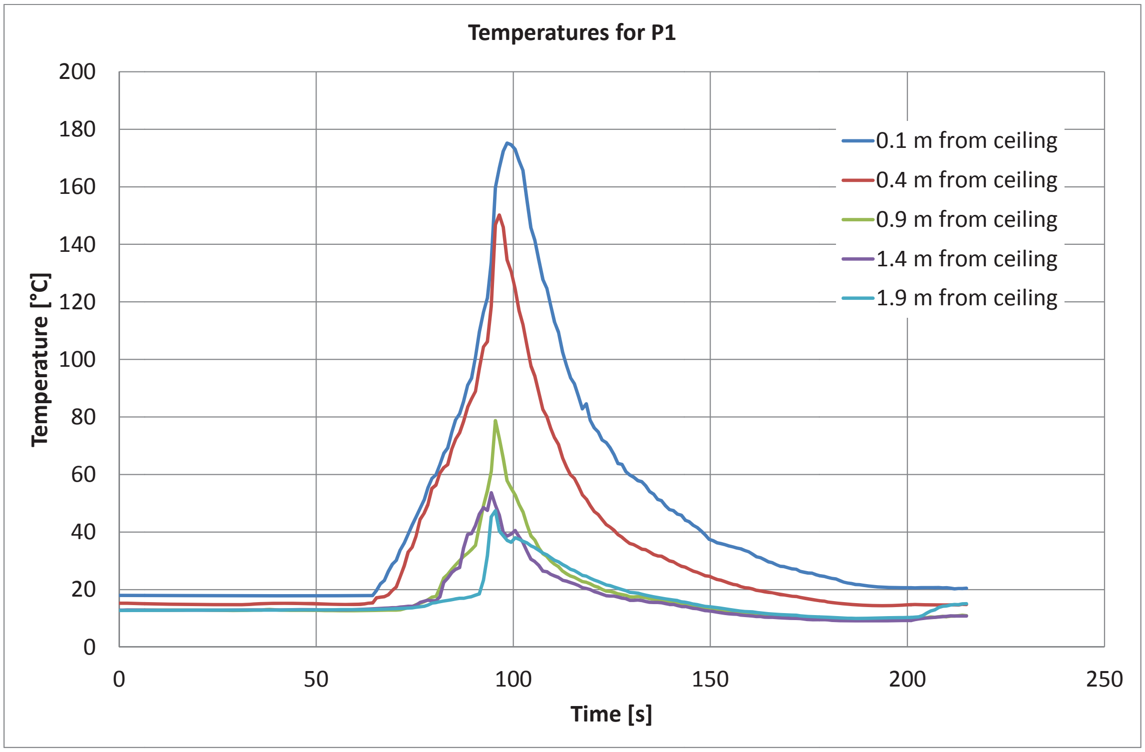

Figure 251. Test 33, Temperatures for P1

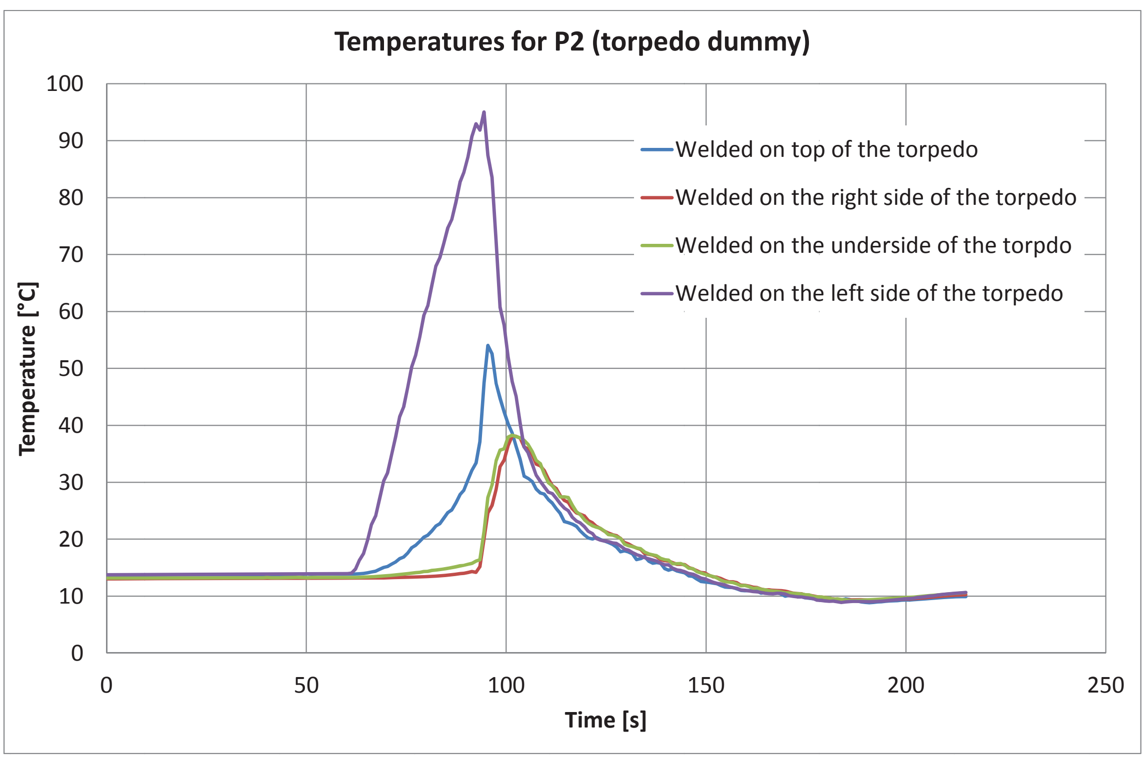

Figure 252. Test 33, Temperatures for P2 (dummy torpedo)

Appendix 1

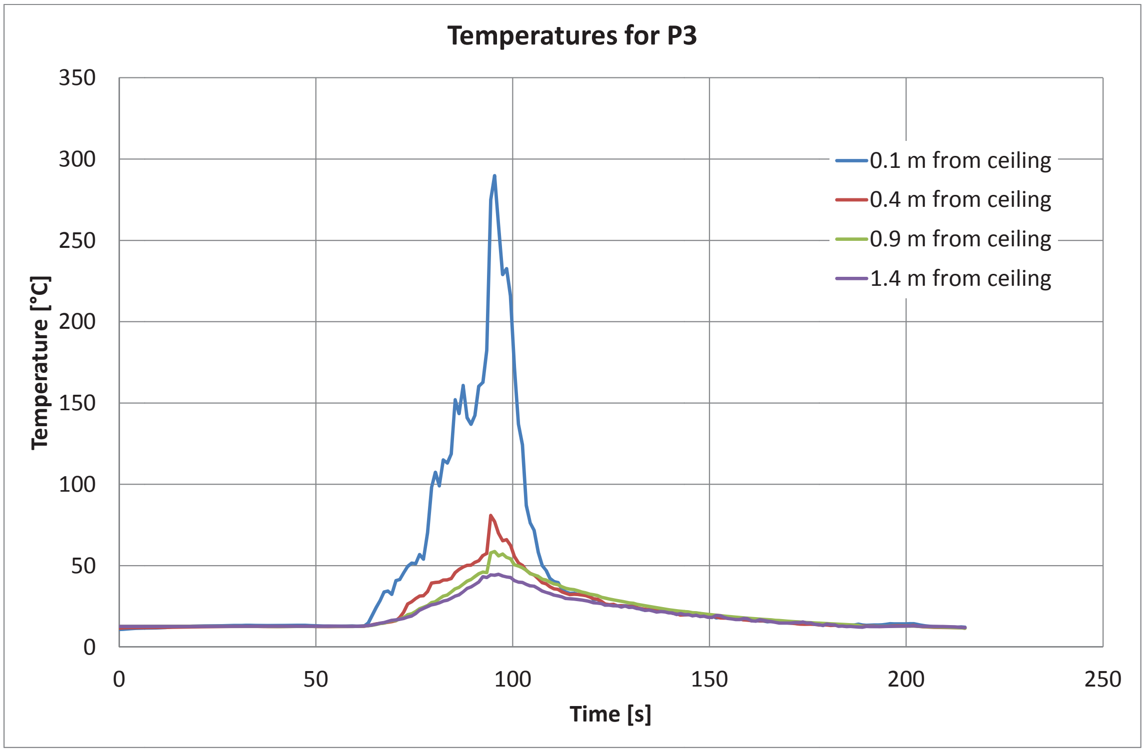

Figure 253. Test 33, Temperatures for P3

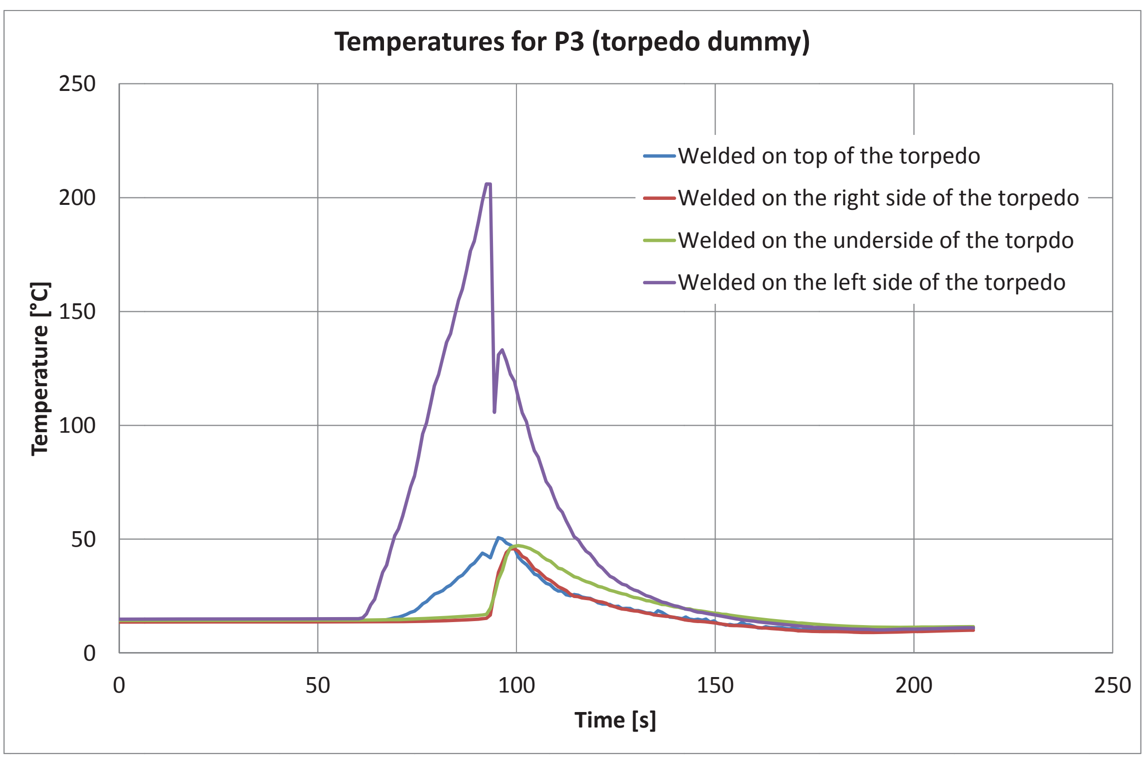

Figure 254. Test 33, Temperatures for P3 (dummy torpedo)

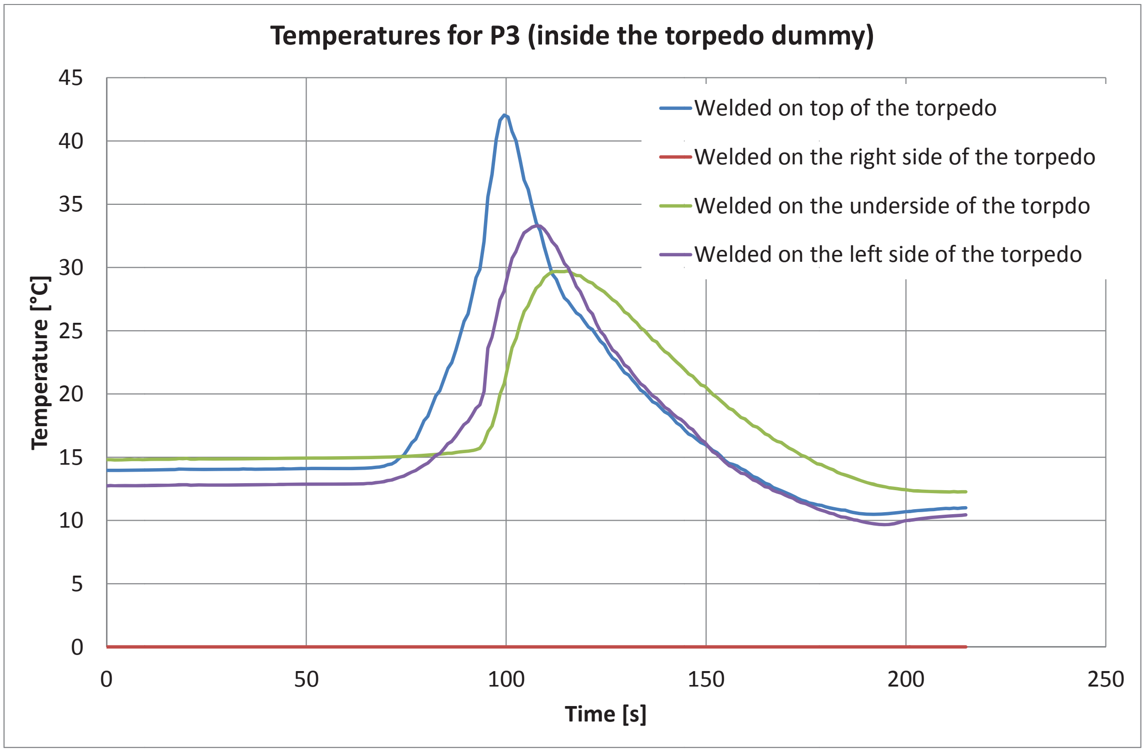

Figure 255. Test 33, Temperatures for P3 (inside the dummy torpedo)

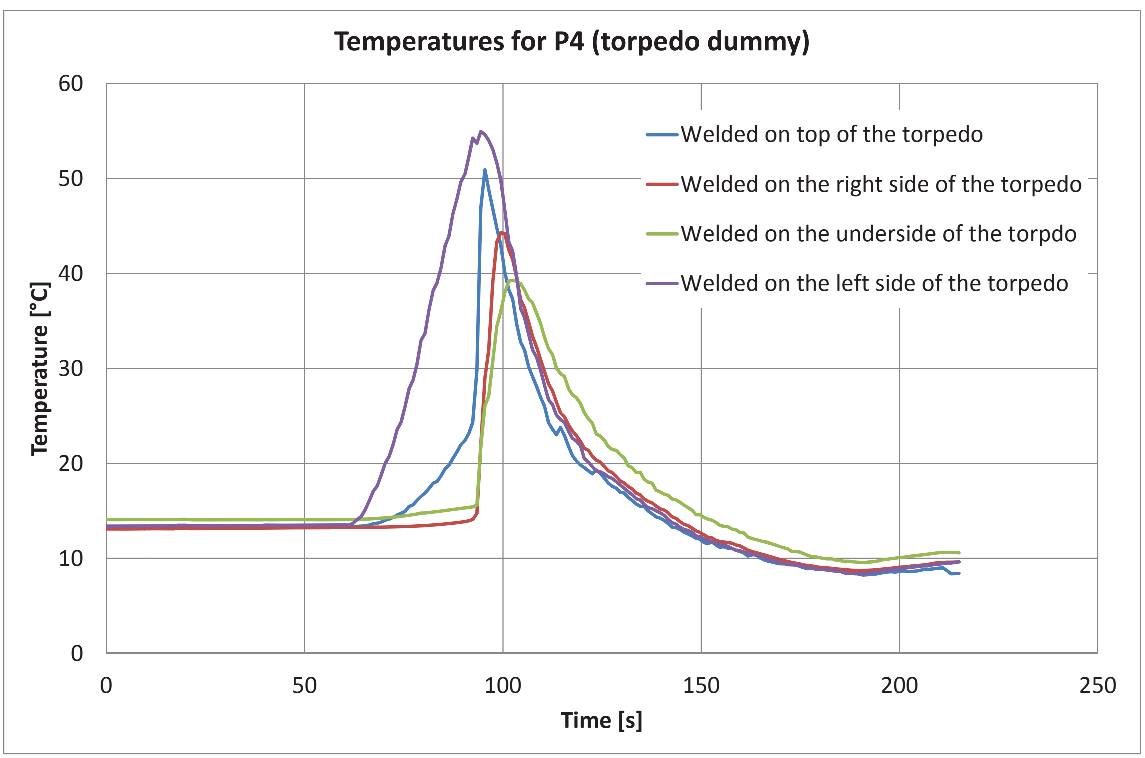

Figure 256. Test 33, Temperatures for P4 (dummy torpedo)

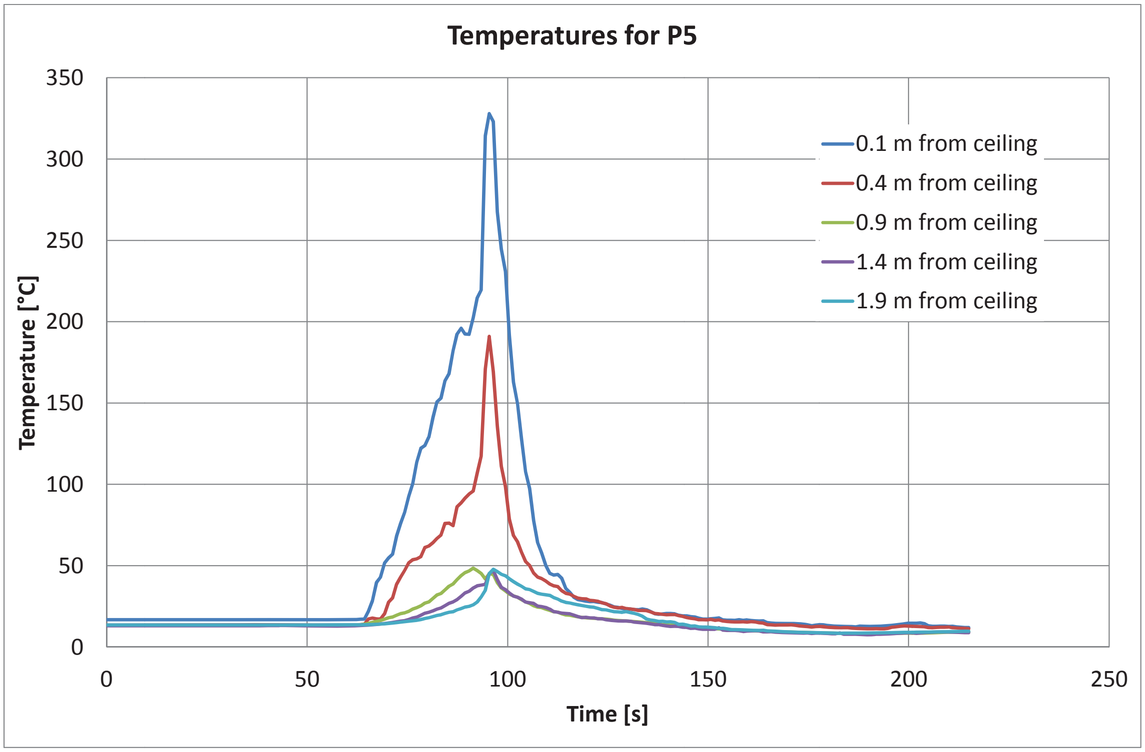

Figure 257. Test 33, Temperatures for P5

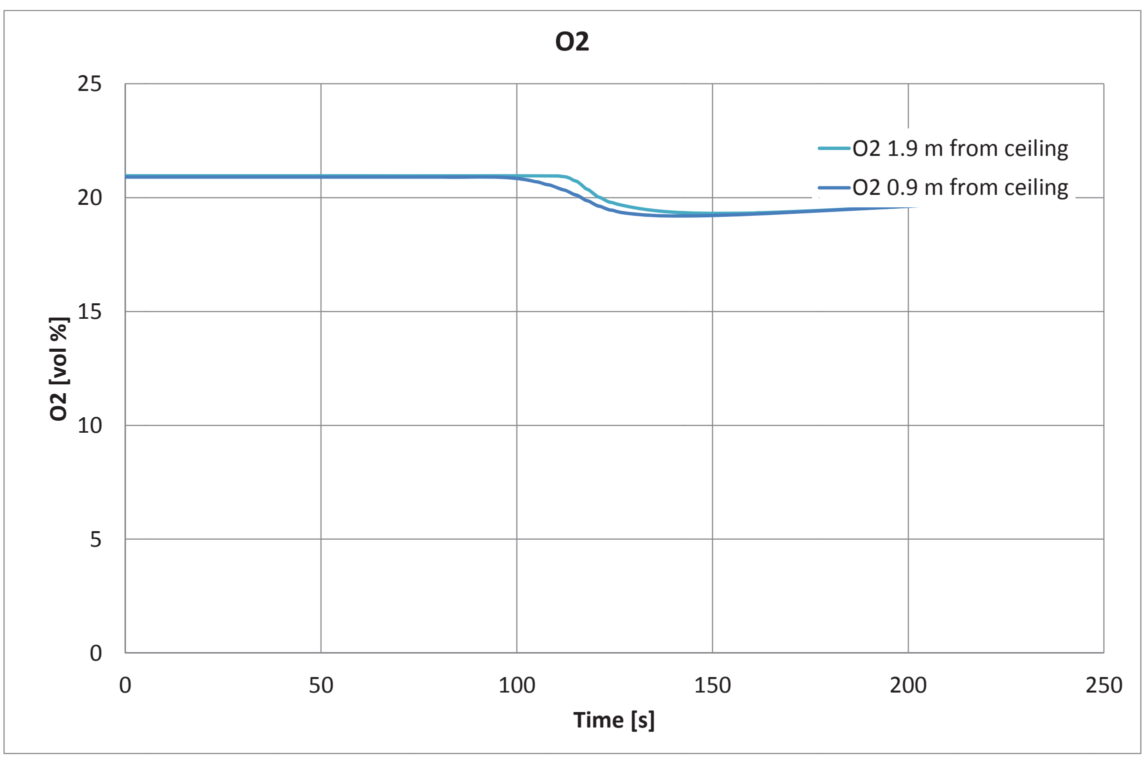

Figure 258. Test 33, O2 level. Not time-adjusted

Appendix 1

Test protocol

Test: 34

Date: 2012-02-07

Test engineer: Michael Rahm, Johan Lindström

Type of test	Thin walled torpedo, free-burn
Pool fire size (Ø in mm)	1170
Position of pool fire	1
Obstruction (% of pool area)	Torpedo, placed 50mm above pool surface
Amount of diesel (L)	5
Height of freeboard (mm)	25
Water mist nozzle	BETE TF 8-170 (used as a backup)
Bulkhead nozzle	
Drencher nozzle	BETE 460.928 (used as a backup)
Distance from nozzle to pool area	
Pressure (bar)	
Water flow (L/min)	
Notes:	
Time (s)	
0	Start measuring program and video camera
60	Ignition
240	Activation of drencher and water mist system

Appendix 1

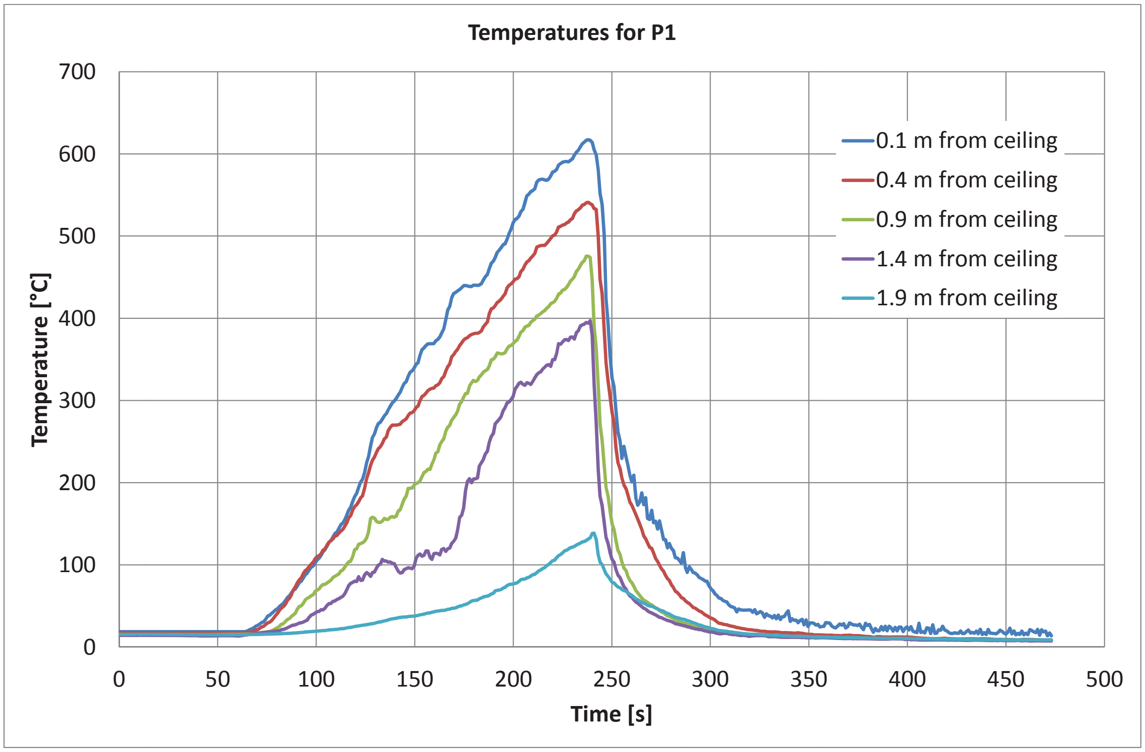

Figure 259. Test 34, Temperatures for P1

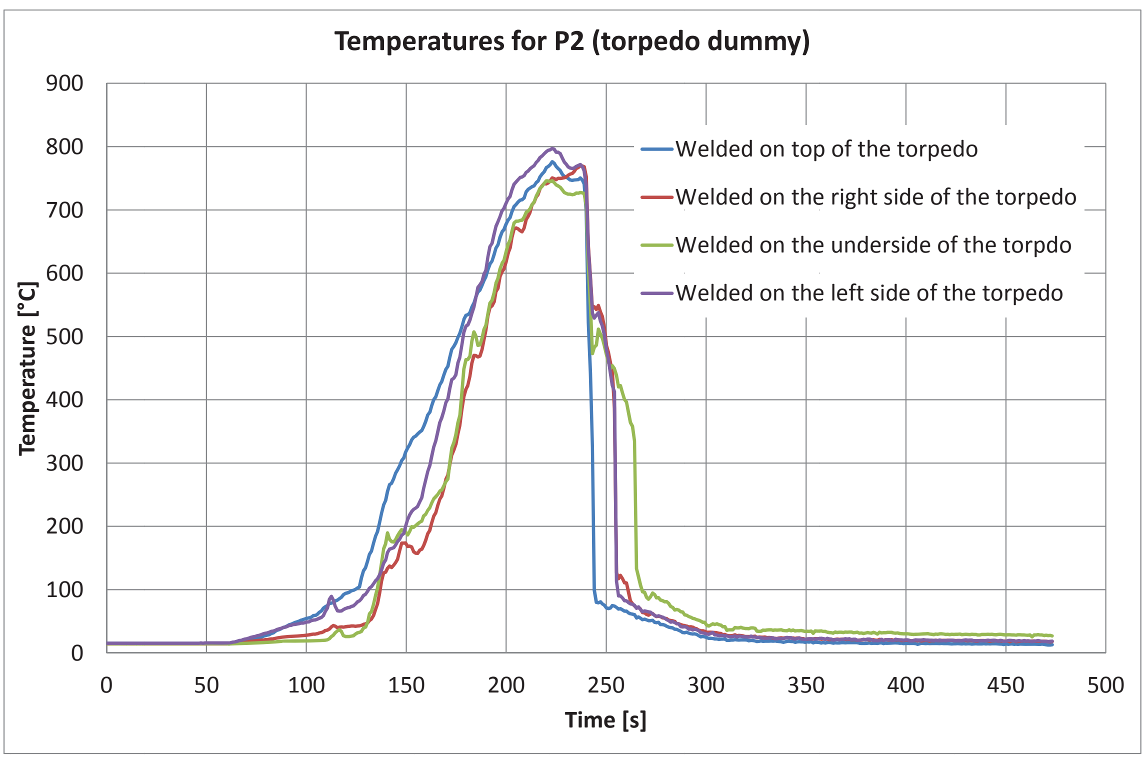

Figure 260. Test 34, Temperatures for P2 (dummy torpedo)

Appendix 1

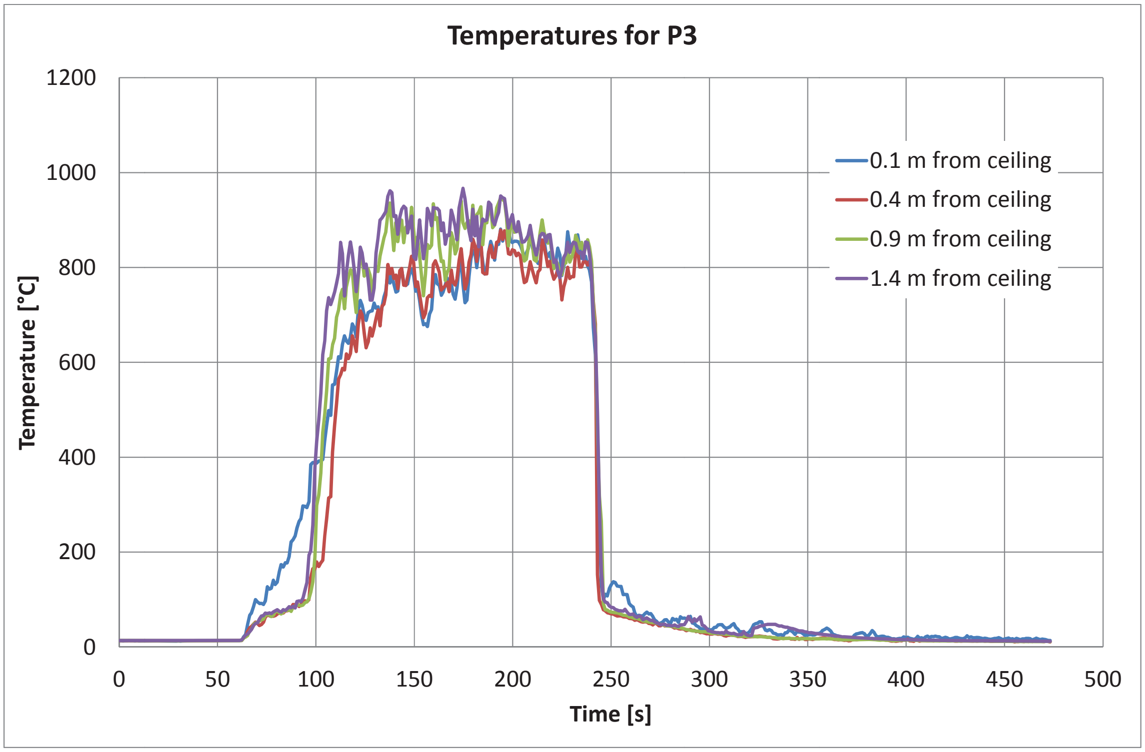

Figure 261. Test 34, Temperatures for P3

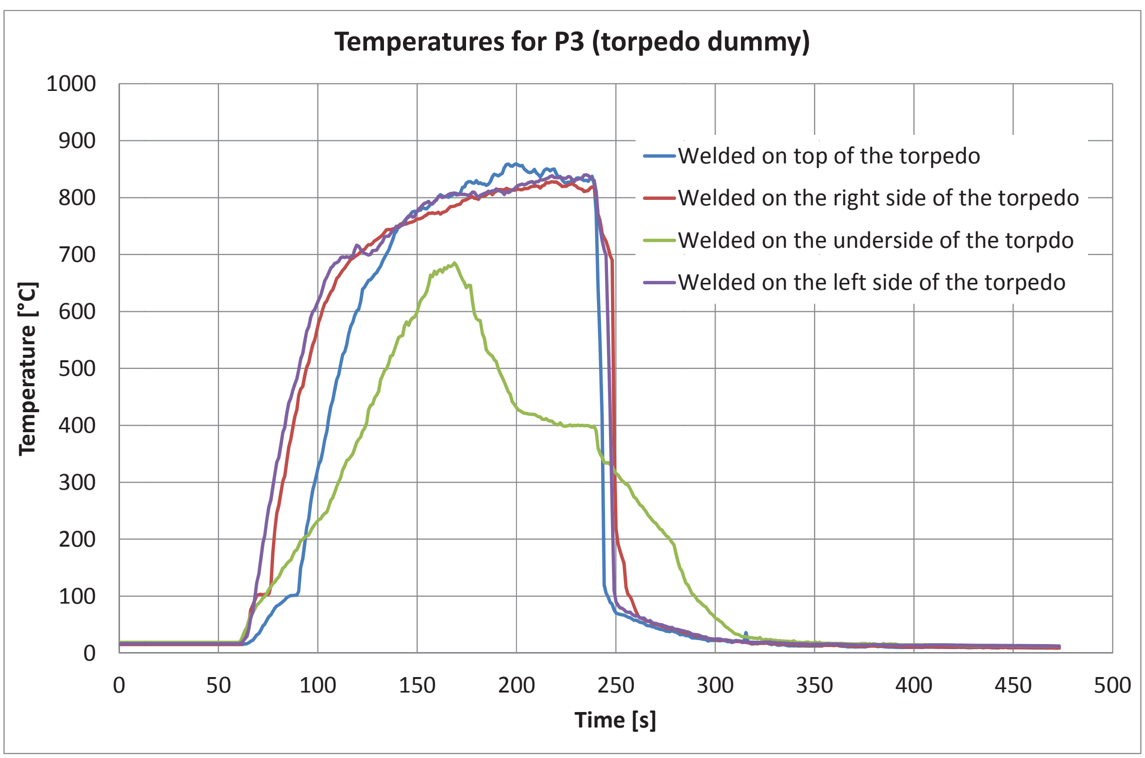

Figure 262. Test 34, Temperatures for P3 (dummy torpedo)

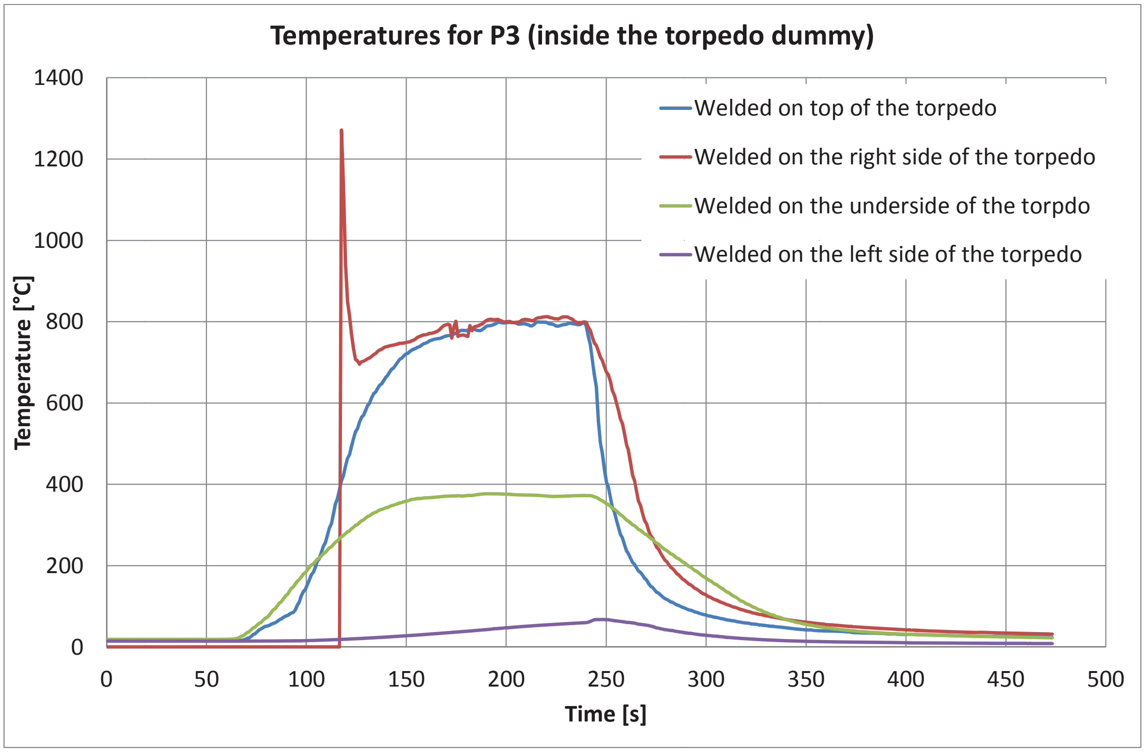

Figure 263. Test 34, Temperatures for P3 (inside the dummy torpedo)

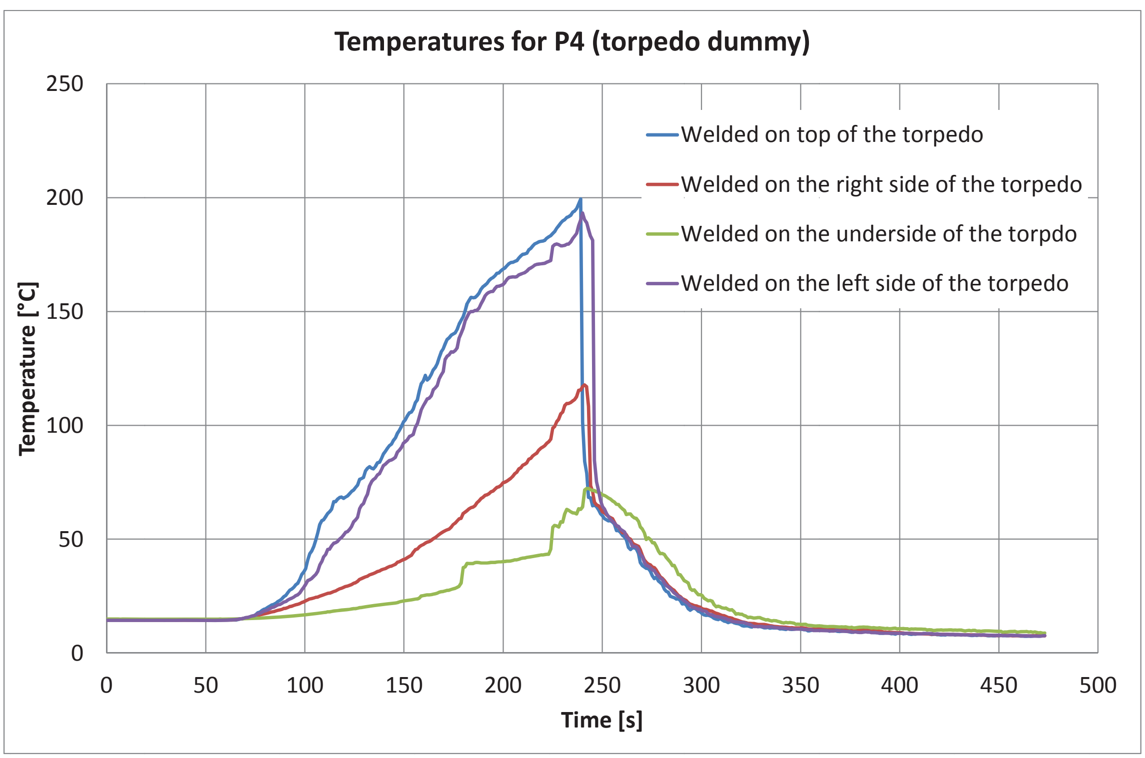

Figure 264. Test 34, Temperatures for P4 (dummy torpedo)

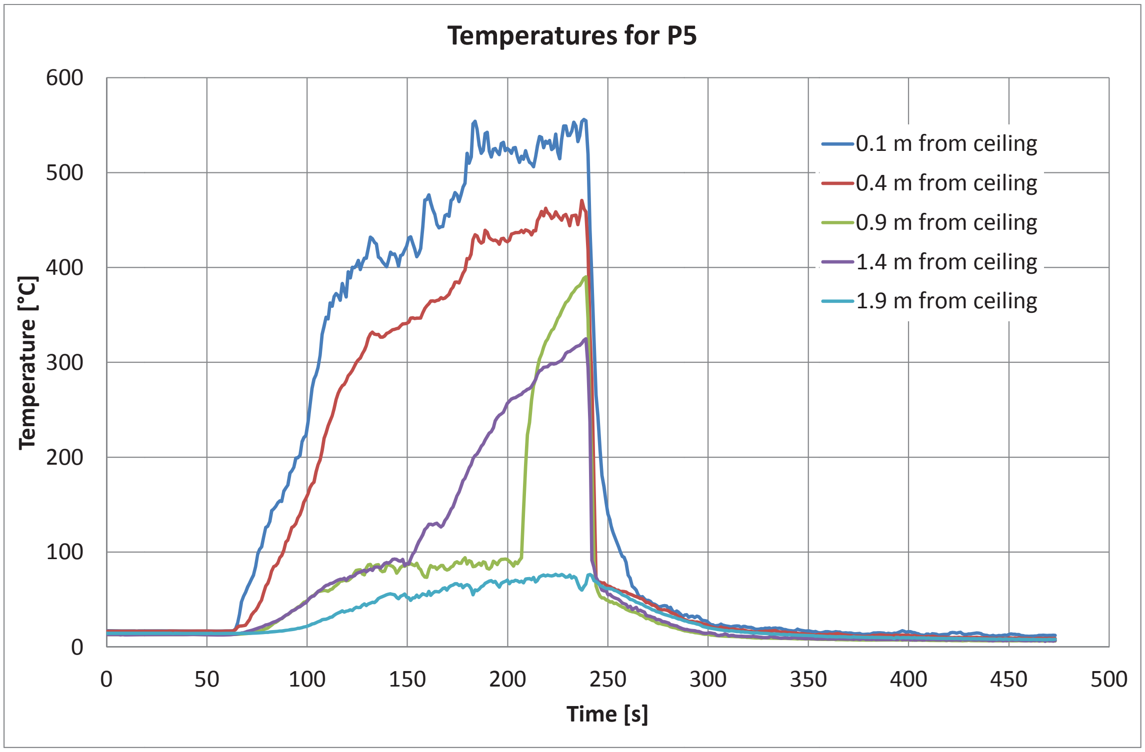

Figure 265. Test 34, Temperatures for P5

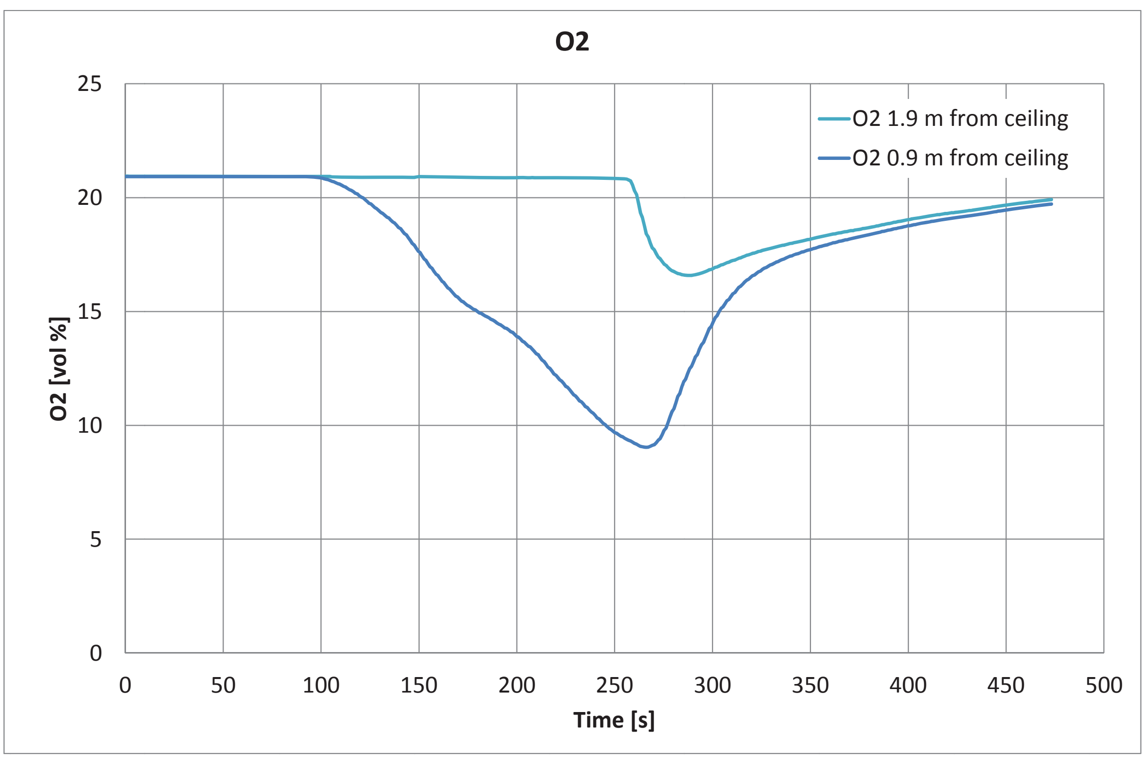

Figure 266. Test 34, O2 level. Not time-adjusted

Test protocol

Test: 35

Date: 2012-02-08

Test engineer: Michael Rahm, Johan Lindström

Type of test	Thin walled torpedo, free-burn
Pool fire size (Ø in mm)	1170
Position of pool fire	2 (250 mm from the edge of the torpedo)
Obstruction (% of pool area)	
Amount of diesel (L)	15
Height of freeboard (mm)	25
Water mist nozzle	BETE TF 8-170 (used as a backup)
Bulkhead nozzle	
Drencher nozzle	BETE 460.928 (used as a backup)
Distance from nozzle to pool area	
Pressure (bar)	
Water flow (L/min)	
Notes:	
Time (s)	
0	Start measuring program and video camera
60	Ignition
237	Flames coming out of the door opening
240	Activation of drencher and water mist system
360	Stops the water flow to the drencher and water mist system

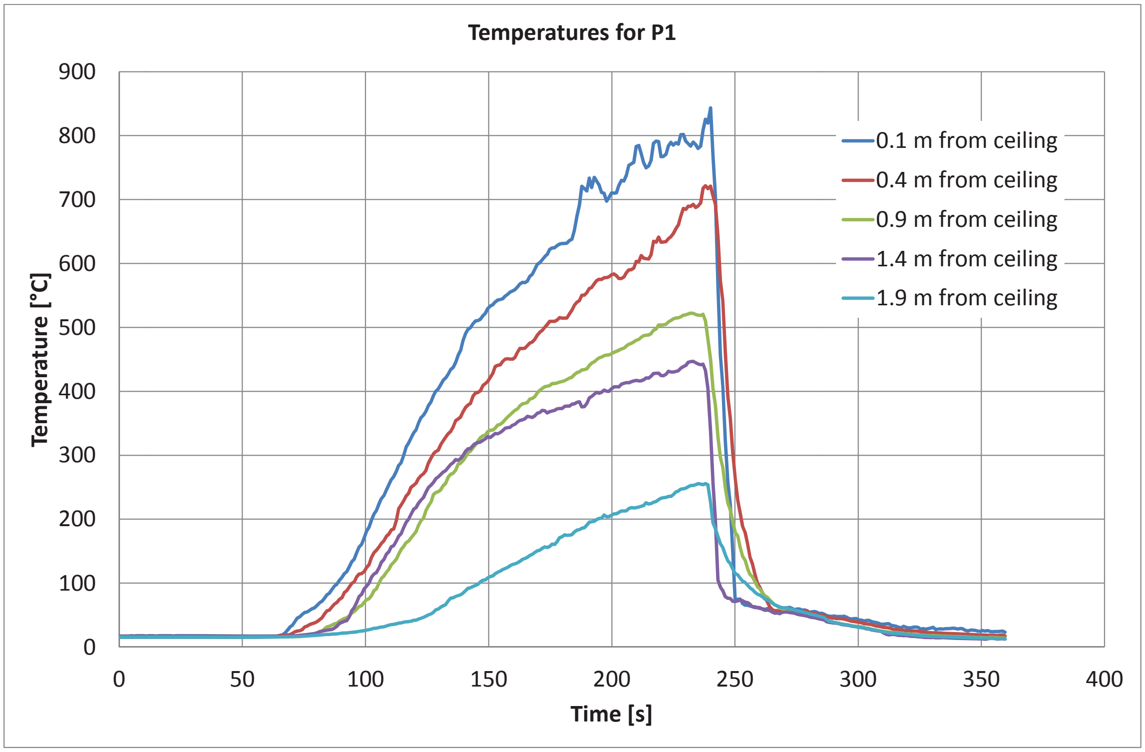

Figure 267. Test 35, Temperatures for P1

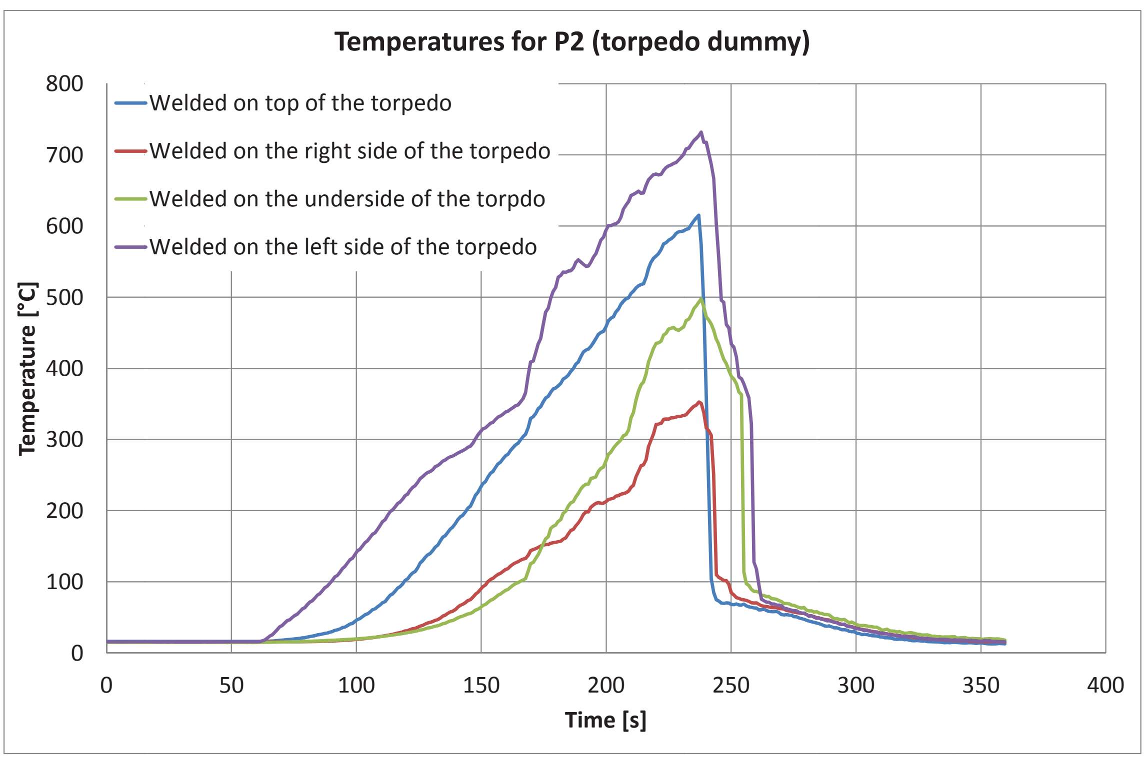

Figure 268. Test 35, Temperatures for P2 (dummy torpedo)

Appendix 1

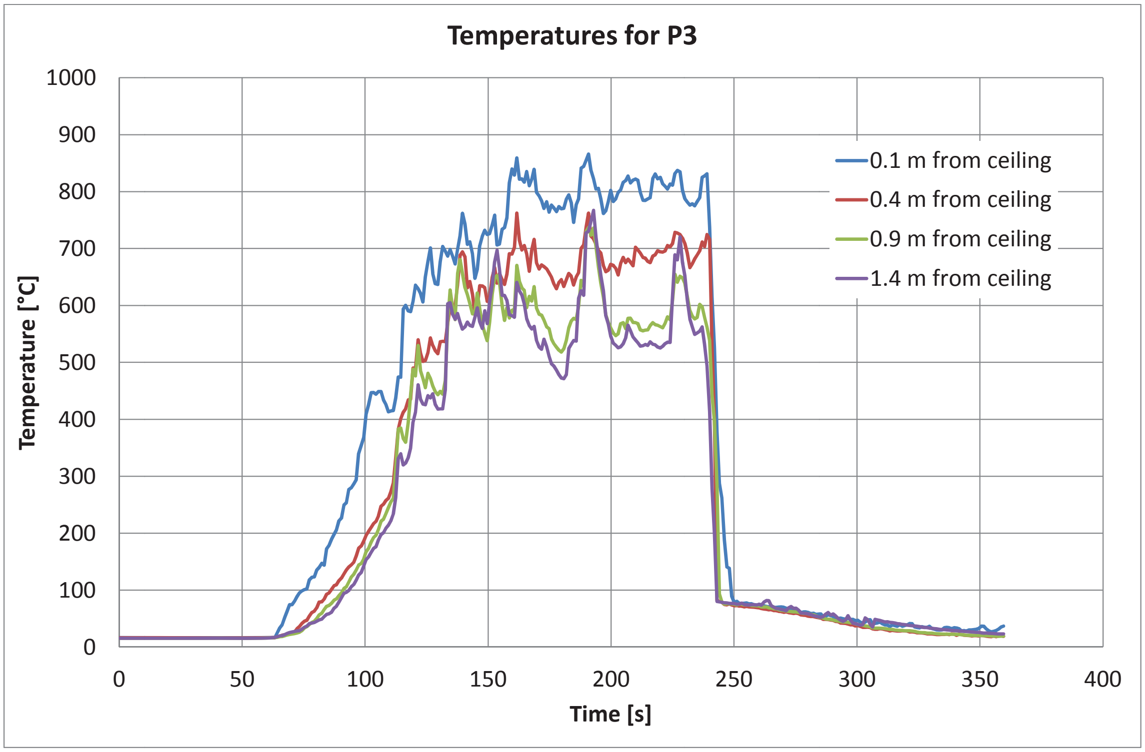

Figure 269. Test 35, Temperatures for P3

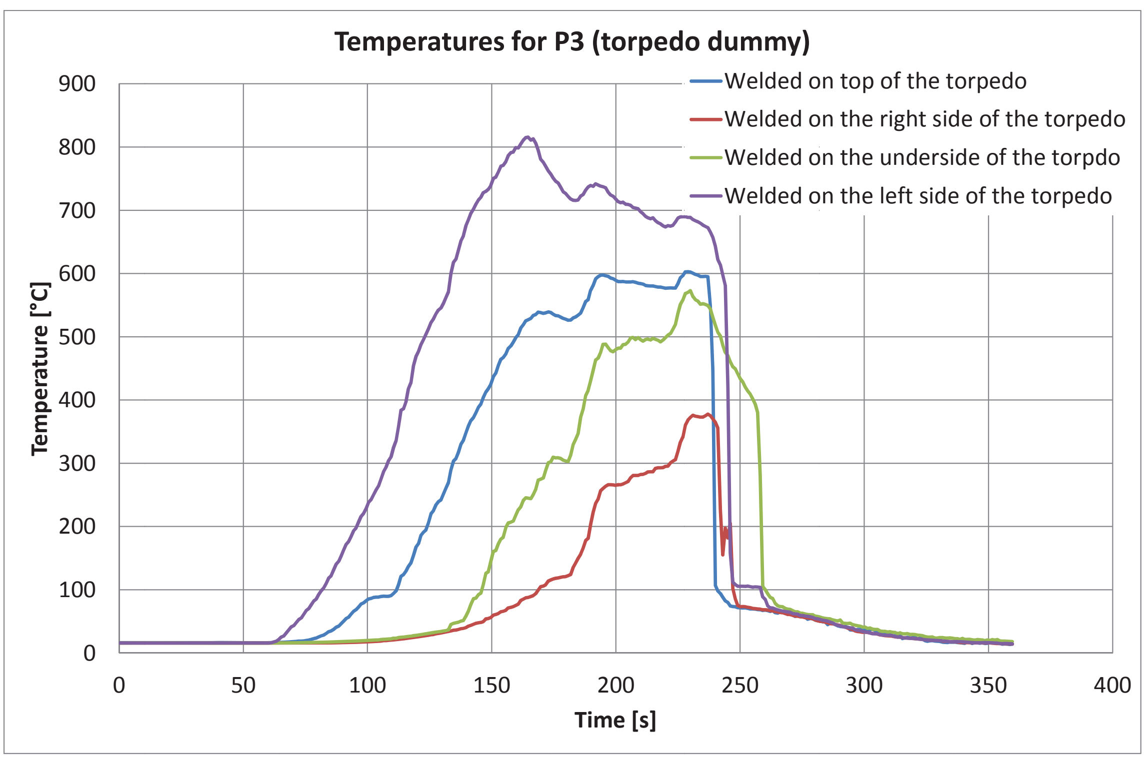

Figure 270. Test 35, Temperatures for P3 (dummy torpedo)

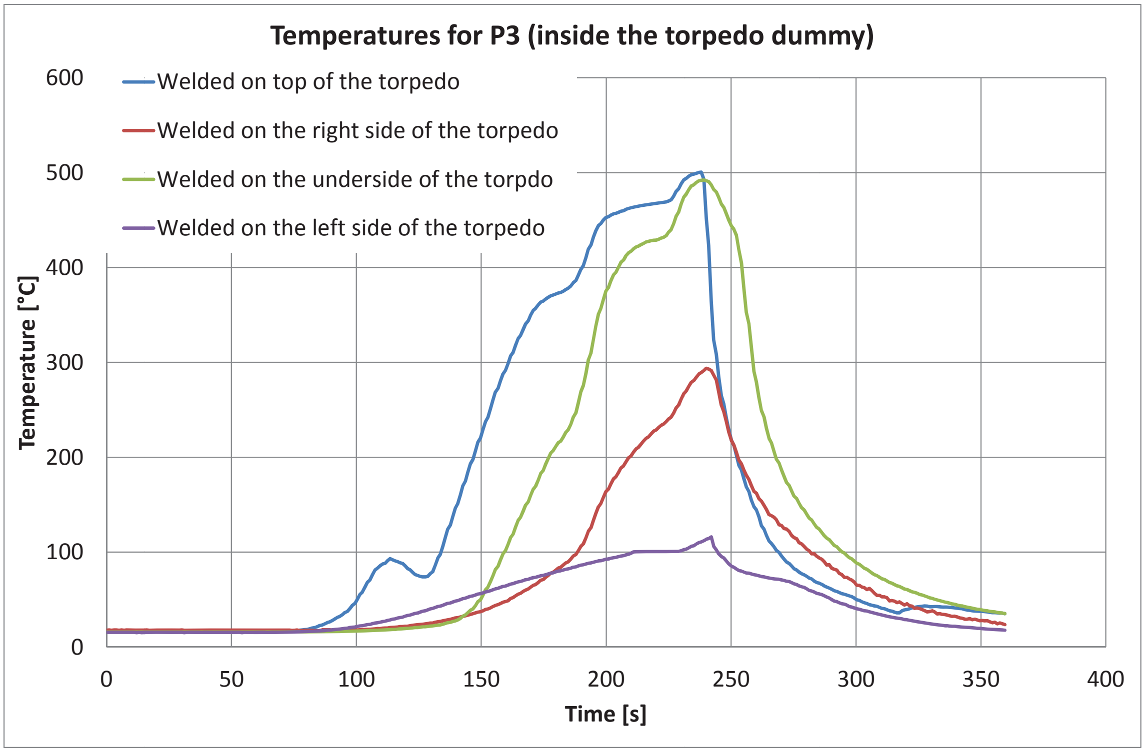

Figure 271. Test 35, Temperatures for P3 (inside the dummy torpedo)

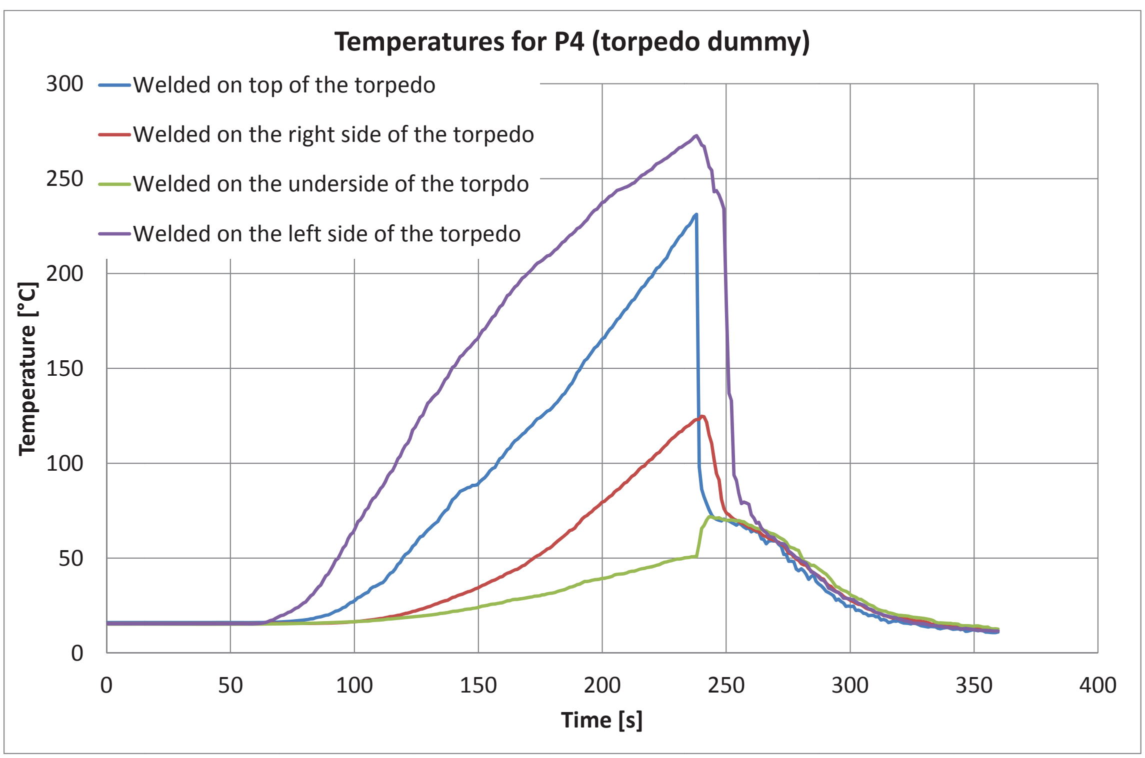

Figure 272. Test 35, Temperatures for P4 (dummy torpedo)

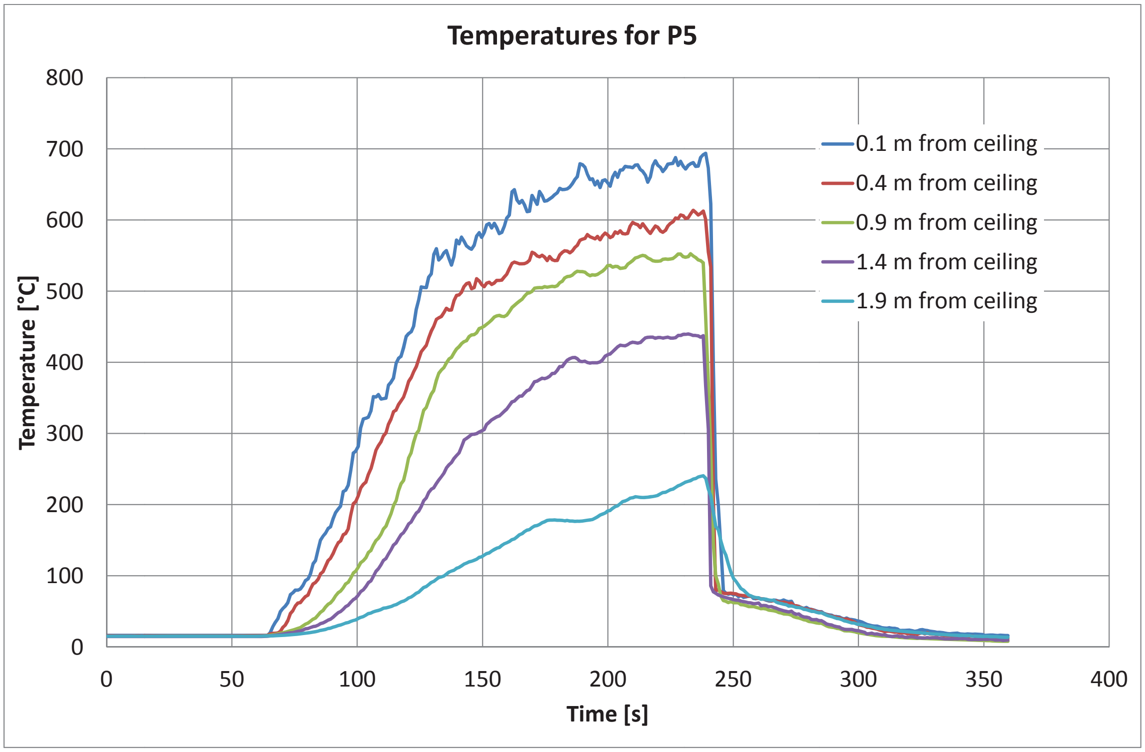

Figure 273. Test 35, Temperatures for P5

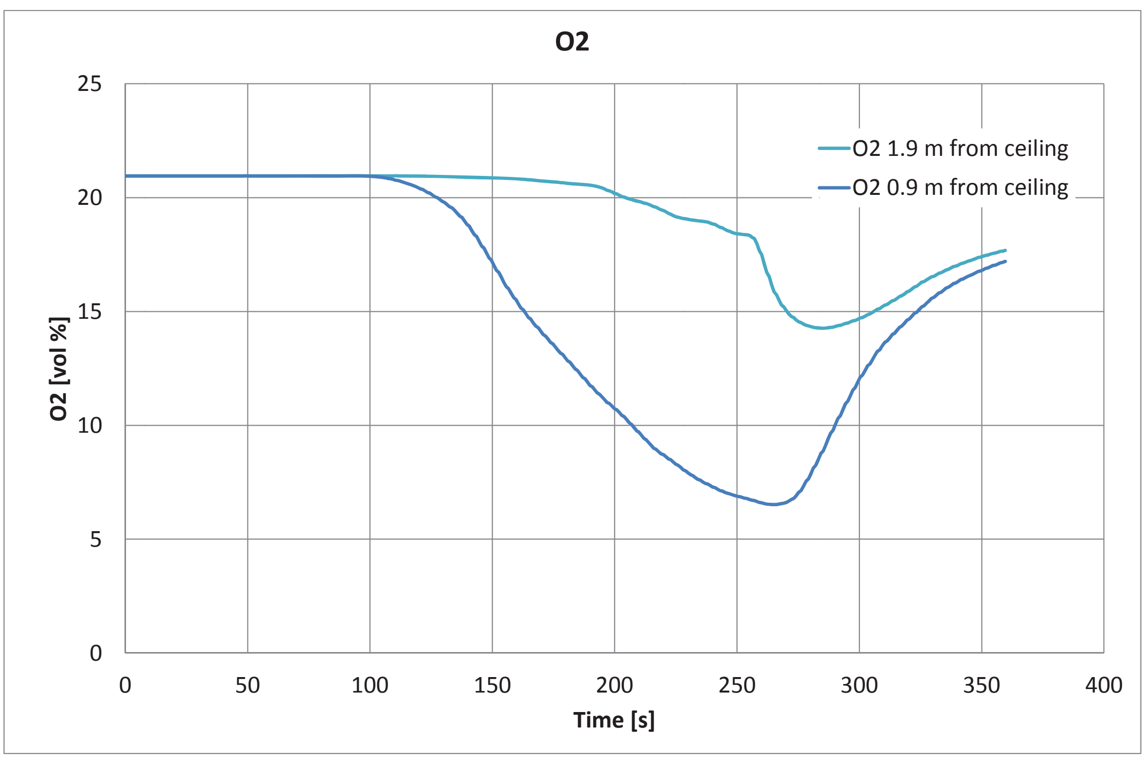

Figure 274. Test 35, O2 level. Not time-adjusted

Test protocol

Test: 36

Date: 2012-02-08

Test engineer: Michael Rahm, Johan Lindström

Type of test	50% water mist system, 10 bar and 30s pre-burn time
Pool fire size (Ø in mm)	1170
Position of pool fire	1
Obstruction (% of pool area)	
Amount of diesel (L)	15
Height of freeboard (mm)	25
Water mist nozzle	BETE TF8-170 (four nozzles)
Bulkhead nozzle	
Drencher nozzle	
Distance from nozzle to pool area	
Pressure (bar)	10
Water flow (L/min)	
Notes:	
Time (s)	
0	Start measuring program and video camera
60	Ignition
90	Activation of water mist system
110	Suppressed fire (almost extinguished)
118	The fire was extinguished
230	The water mist system was stopped

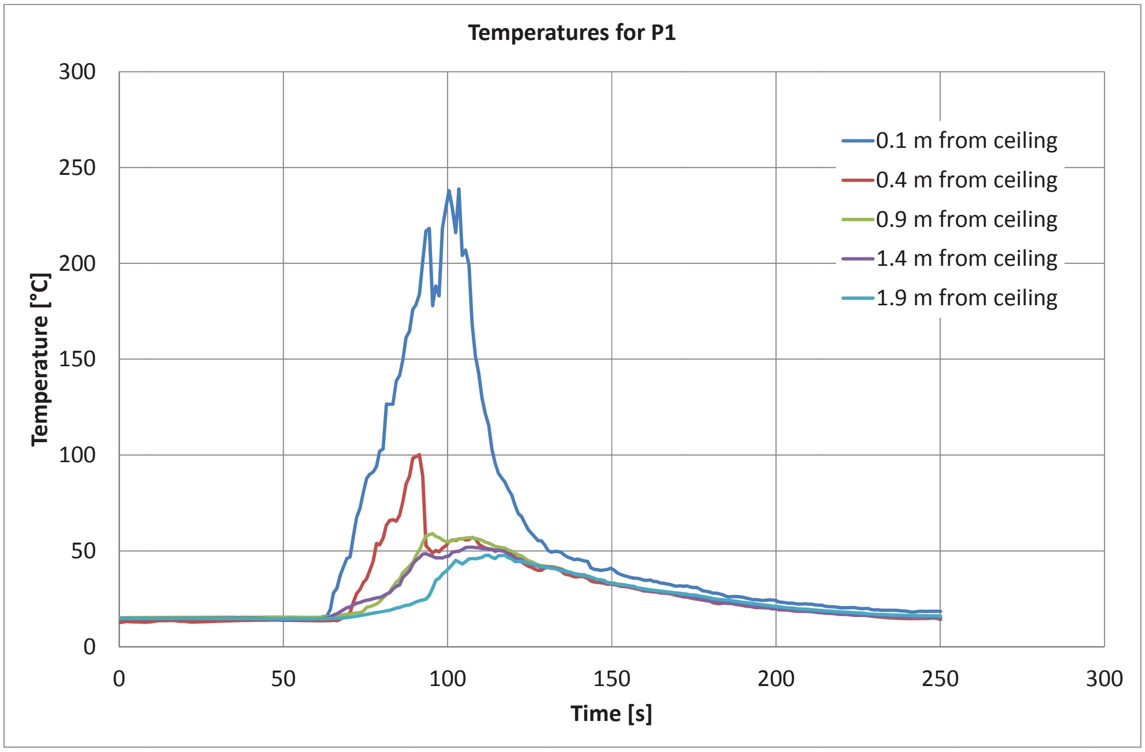

Figure 275. Test 36, Temperatures for P1

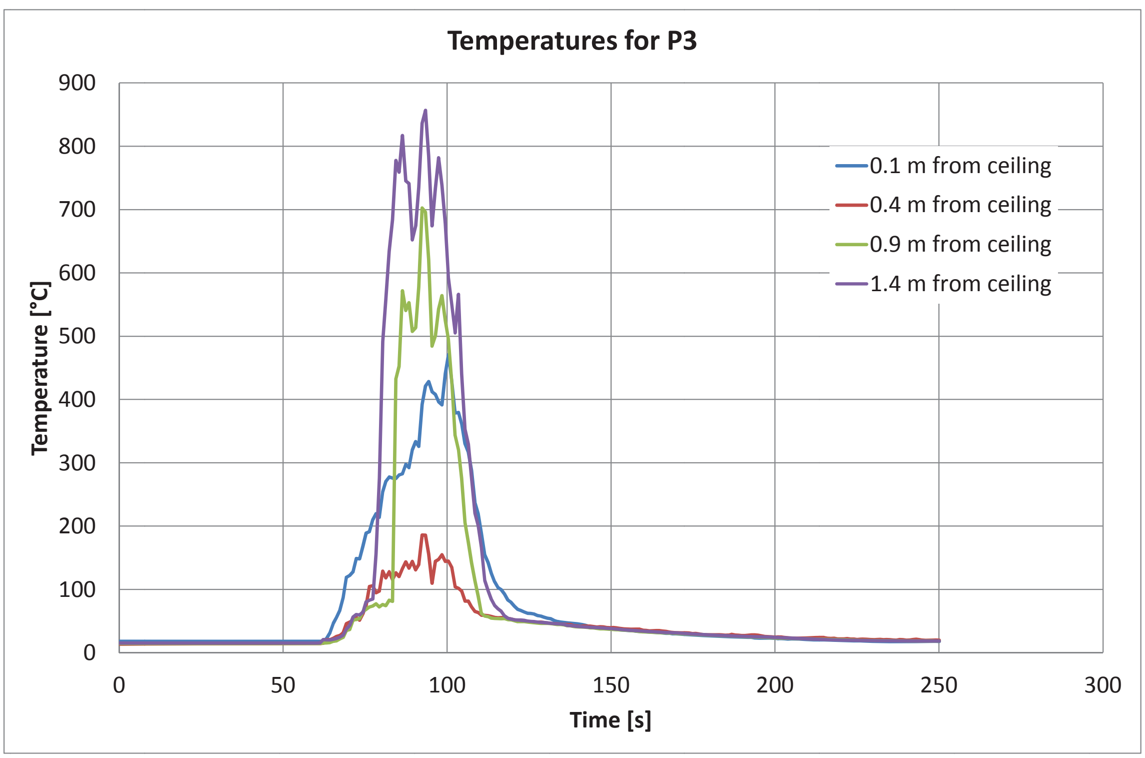

Figure 276. Test 36, Temperatures for P3

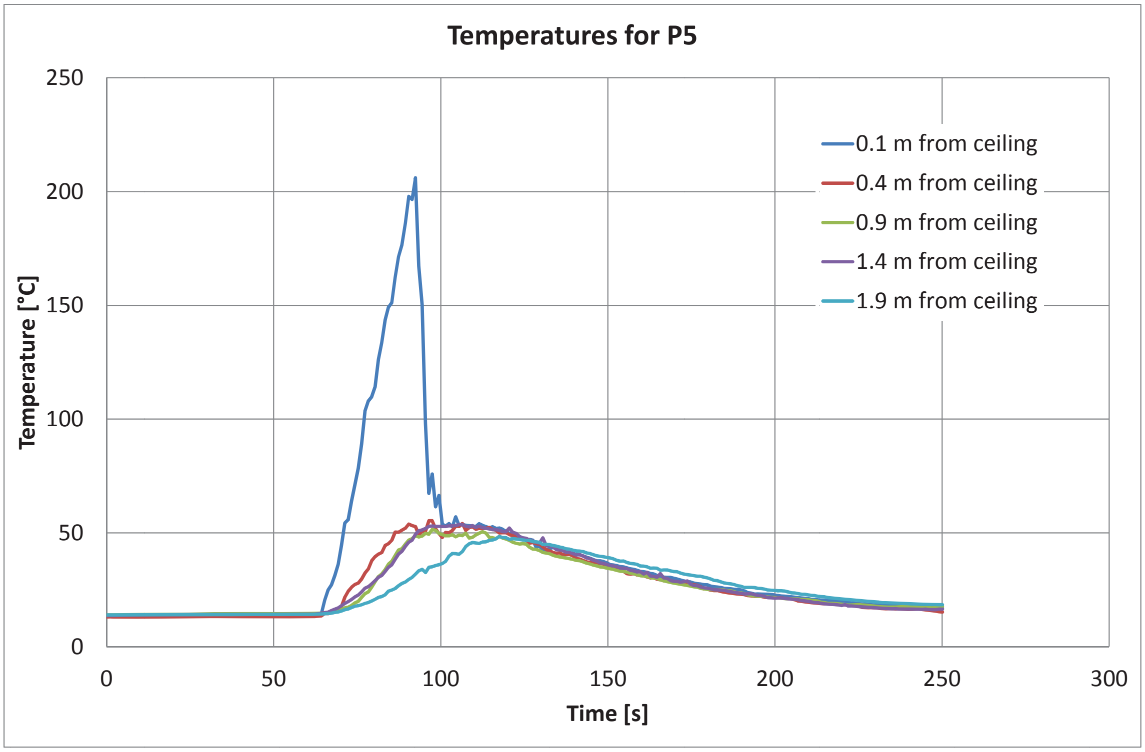

Figure 277. Test 36, Temperatures for P5

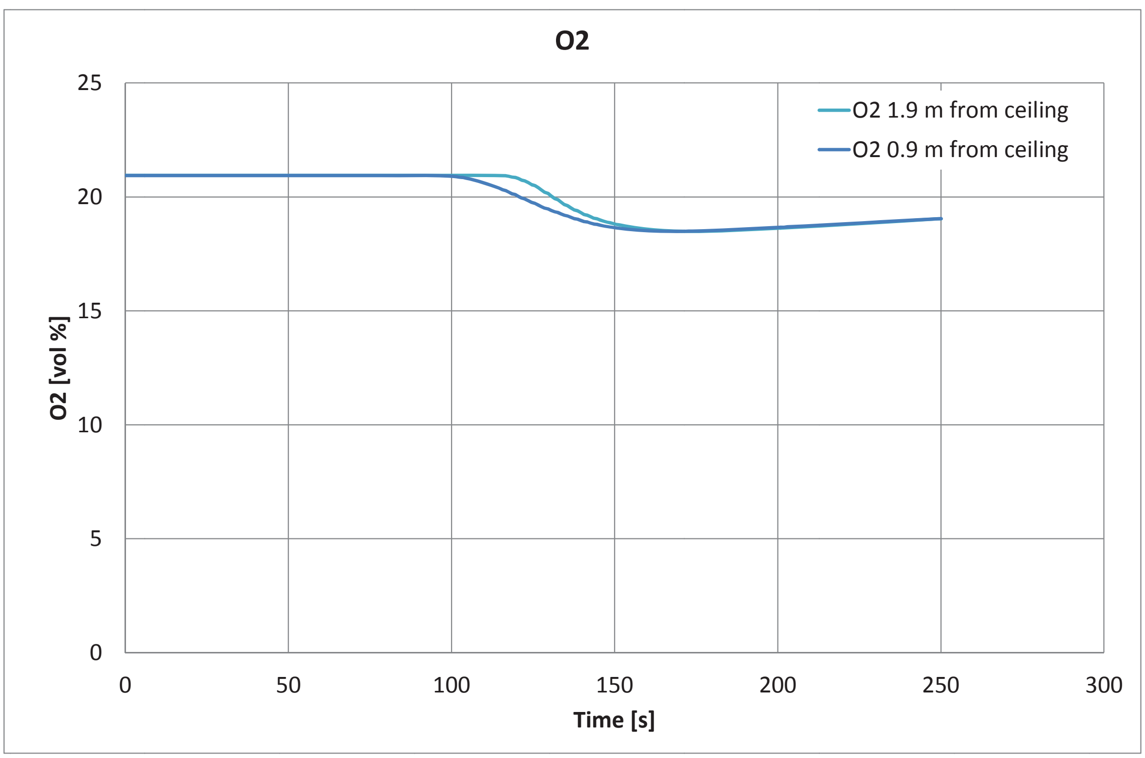

Figure 278. Test 36, O2 level. Not time-adjusted

Test protocol

Test: 37

Date: 2012-02-08

Test engineer: Michael Rahm, Johan Lindström

Type of test	Free-burn
Pool fire size (Ø in mm)	1170
Position of pool fire	1
Obstruction (% of pool area)	
Amount of diesel (L)	15
Height of freeboard (mm)	25
Water mist nozzle	BETE TF 8-170 (used as a backup)
Bulkhead nozzle	
Drencher nozzle	BETE 460.928 (used as a backup)
Distance from nozzle to pool area	
Pressure (bar)	
Water flow (L/min)	
Notes:	
Time (s)	
0	Start measuring program and video camera
60	Ignition
204	Flames coming out of the door opening
235	Activation of drencher and water mist system
245	The fire was extinguished
400	Stops the water flow to the drencher and water mist nozzles

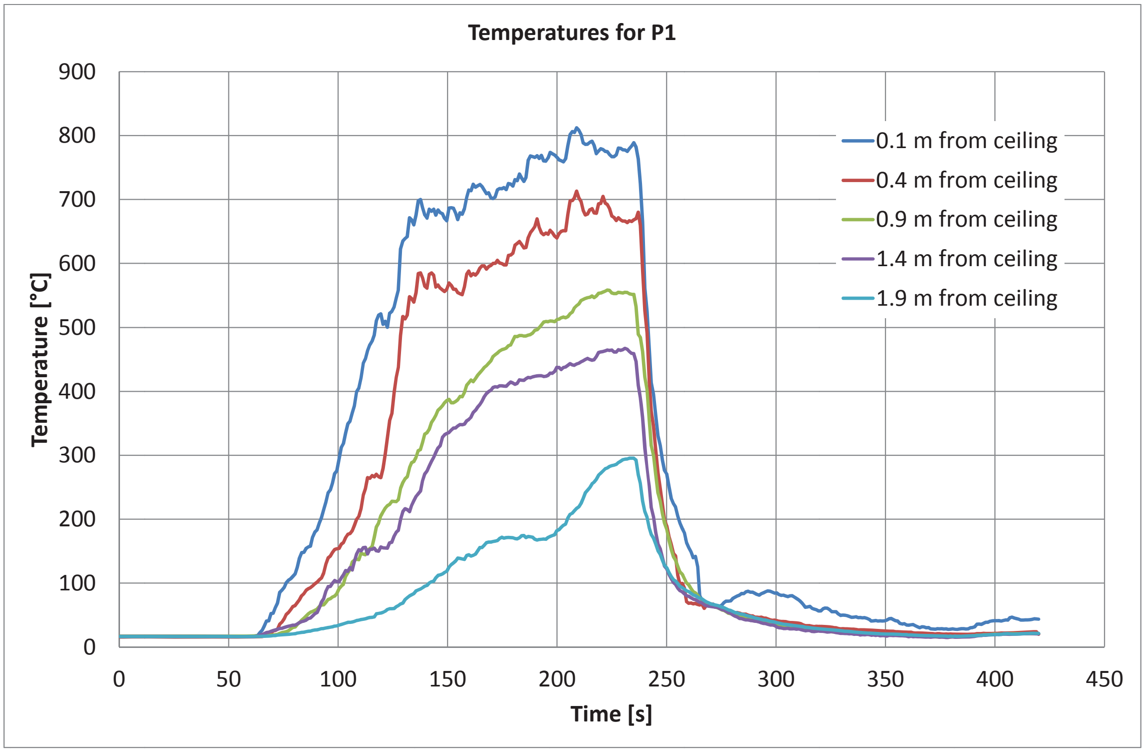

Figure 279. Test 37, Temperatures for P1

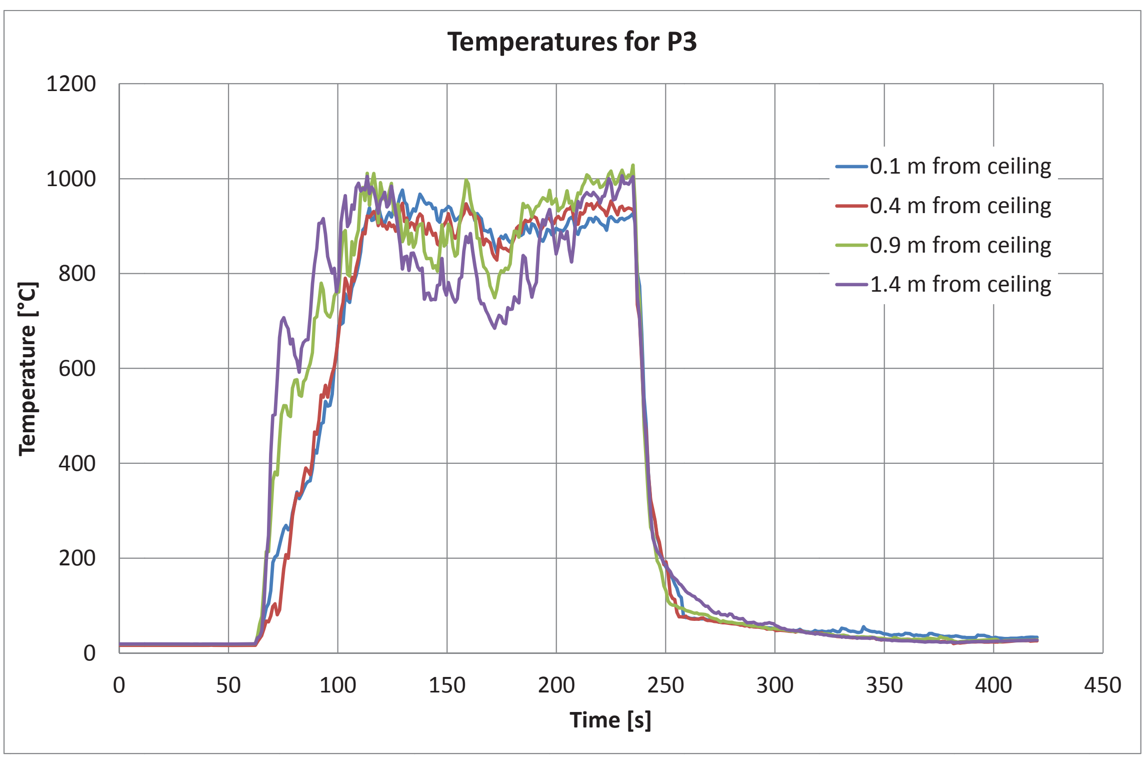

Figure 280. Test 37, Temperatures for P3

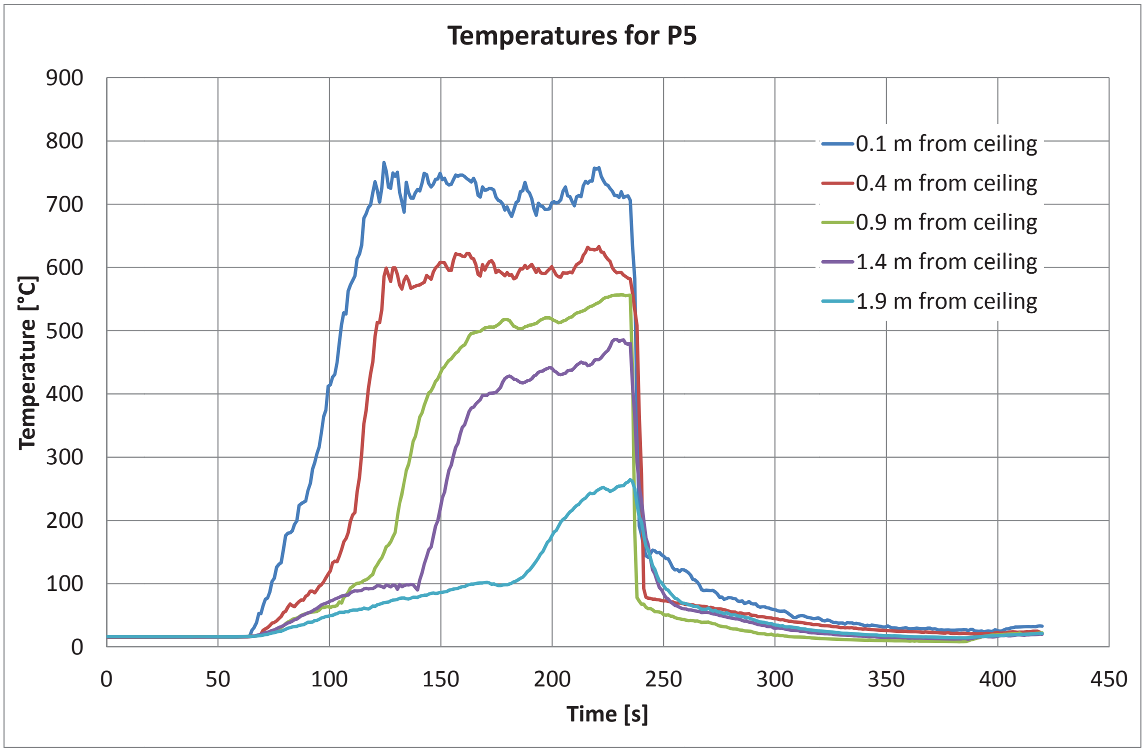

Figure 281. Test 37, Temperatures for P5

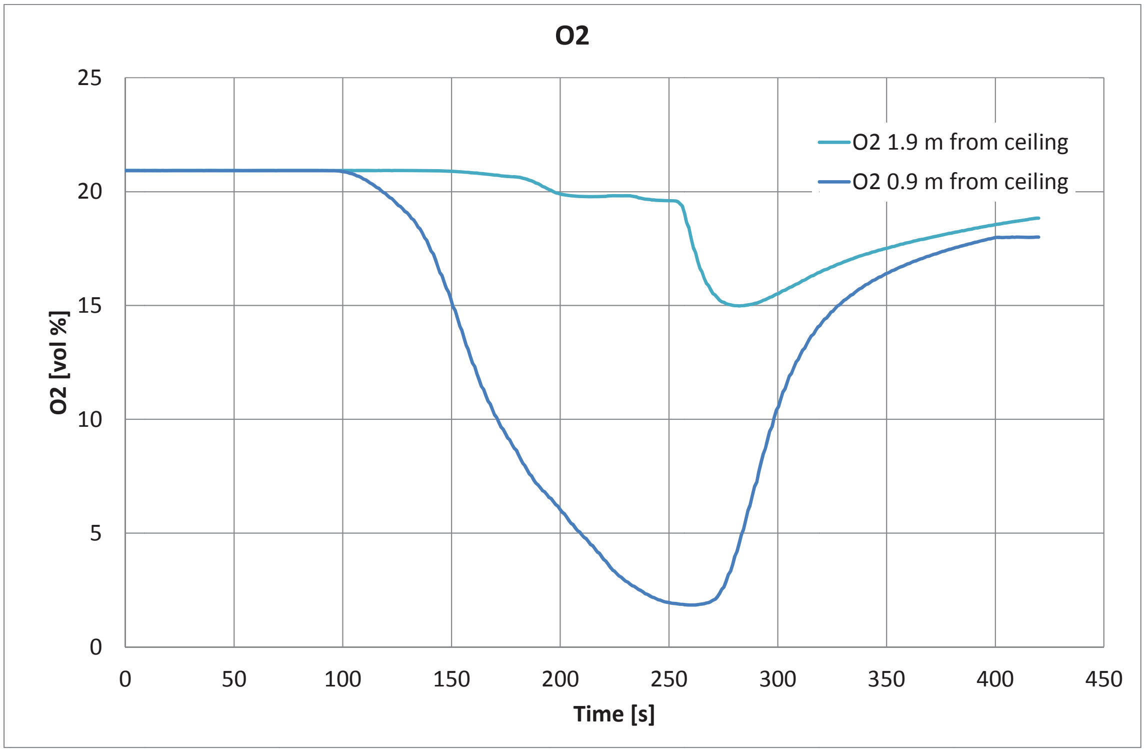

Figure 282. Test 37, O2 level. Not time-adjusted

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Fire protection of weapon storage and water mist redundancy philosophies

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Michael Rahm and Johan Lindstrom

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The FiST-project "New Technologies for Fire Suppression On Board Naval Craft", is a tri-lateral research project under the Canada, the Netherlands, Sweden Cooperative Science and Technology MOU. The focus for the project is active fire fighting on navy ships, with a special emphasis on how firefighting systems might perform in a damaged condition.

The results of a number of full scale fire tests run at SP Technical Research Institute of Sweden, December 2011-February 2012 are reported. The testing had two objectives. The first was to investigate redundancy solutions for fire suppression systems. To this end, the performanceof a low pressure water mist system with reduced capacity and the performance of a redundant extinguishment system attached to a strength bulkhead were investigated. The results of the tests indicated that a low pressure system designed to handle a well-ventilated hydrocarbon fire scenario can suppress the same fire in a less ventilated space with a 50 % reduction in water supply. Further if the system is fed by pumps providing water at lower pressure e.g. the fire main, it still has the capacity to suppress a compartment fire. Testing of the bulkhead mounted system indicated that it could extinguish an obstructed diesel pool fire at water flow rates of 12-14 $L/m^2/min$ provided nozzles that distributed the water spray over the entire test space were used. The second objective was to study the relevance of the weapon storage fire protection water delivery requirements found in Naval Ship Code (NSC) (24 mm/min) or Class DNV (32 mm/min) regulations. For the fire scenario studied, the results indicated that lower water flow rates were successful in keeping the temperature of a dummy torpedo below a 'critical temperature'.

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Fire testing; drencher system; water mist; magazine space

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