Statens vegvesen

FFI-RAPPORT

20/03101

Large scale leakage of liquid hydrogen (LH2)

— tests related to bunkering and maritime use of liquid hydrogen

Jorunn Aaneby
Thor Gjesdal
Øyvind Voie

Large scale leakage of liquid hydrogen (LH_2) – tests related to bunkering and maritime use of liquid hydrogen

Jorunn Aaneby
Thor Gjesdal
Øyvind Voie

Norwegian Defence Research Establishment (FFI) 13 January 2021

Keywords
Drivstoff
Eksplosjoner
Energi
Gassutslipp
Hydrogen
Skip

FFI report
20/03101

Project number
555701

Elektronisk ISBN / Electronic ISBN
978-82-464-3310-3

Approvers
Øyvind A. Voie, *Research Manager*
Janet M. Blatny, *Research Director*

The document is electronically approved and therefore has no handwritten signature.

.

Summary

Hydrogen is a promising energy carrier, which itself does not contribute to greenhouse gas emissions. Liquid hydrogen (LH_2) is an efficient solution for transportation and storage of hydrogen. Especially for large vessels, liquid hydrogen is more practical than compressed hydrogen due to more efficient storage, bunkering, and handling of the fuel. However, to introduce LH_2 as a maritime fuel, more knowledge regarding the behavior of LH_2 is needed. For this purpose, a number of large-scale leakage tests of LH_2 were performed on behalf of the Norwegian Public Roads Administration (NPRA). To simulate spill from a bunkering operation, LH_2 was released in an outdoor test facility. The objectives of the tests were to provide information about:

- formation of a liquid pool caused by leakage of LH_2, and/or condensations and freezing of components in air on the ground
- hydrogen concentration within the gas cloud originating from the leakage
- consequences of ignition of the gas cloud.

To simulate leakage of LH_2 in the technical room connected to the LH_2 tank (Tank Connection Space, TCS), LH_2 was released into a closed room connected to a ventilation mast. The objectives of the closed room and ventilation mast tests were to provide information about:

- concentration of H_2 in TCS due to leakage of LH_2
- flow rate of H_2 out of, and spread of H_2 downwards, from the ventilation mast
- clogging of ventilation mast due to condensation and freezing of components in air
- consequences of explosion in TCS.

Releases of LH_2 resulted in formation of a liquid pool on the ground. The radius of the liquid pool was limited to 0.5 to 1.0 m from the release point. The pool disappeared when the release stopped. The plume of H_2 with flammable concentrations spread along the ground with neutral buoyancy, in a narrow passage from the release point. In the tests with horizontal release orientation, flammable concentrations of H_2 were detected 50 m, but not 100 m, from the release point. No flammable concentrations of H_2 were detected outside a 45° angle, relative to the wind direction. Frozen components from air was observed on the ground around the release point in the tests with a vertically downwards release orientation, but not from the cloud in general. Ignition of the gas cloud caused a combustion blast. No fast deflagration or detonation occurred anywhere or at any time during the tests. Release of LH_2 into the closed room caused build-up of near 100%vol H_2 in the room within 30 seconds. Hydrogen spread from the ventilation mast with a neutral buoyancy. No significant levels of H_2 were measured at ground level. No clogging of the ventilation mast due to condensation and freezing of components in air was observed. The tests where H_2 was ignited at top of the ventilation mast showed that oxygen flowing back through the ventilation mast could cause a low severity explosion in the TCS.

Sammendrag

Hydrogen er en lovende energibærer som i seg selv ikke bidrar til klimagassutslipp. Flytende hydrogen (LH_2) er en effektiv løsning for transport og lagring av hydrogen. Spesielt for store fartøy er flytende hydrogen mer praktisk enn komprimert hydrogen på grunn av enklere lagring, bunkring og håndtering av drivstoffet. For å introdusere LH_2 som et maritimt drivstoff er det behov for mer kunnskap om LH_2s oppførsel. For å innhente mer informasjon, spesielt med tanke på maritim bruk, ble det utført lekkasjetester med store mengder LH_2 på oppdrag fra Statens vegvesen (SVV). LH_2 ble sluppet ut i et testoppsett utendørs for å simulere utslipp fra en bunkring. Formålet med testene var å gi informasjon om:

- dannelse av et væskebasseng forårsaket av lekkasje av LH_2 og/eller utfrysing av komponenter i luft
- hydrogenkonsentrasjon i gass-skyen fra lekkasjen
- konsekvenser i forbindelse med antenning av gasskyen.

For å simulere lekkasje av LH_2 i det tekniske rommet som er koblet til LH_2-tanken (Tank Connection Space, TCS), ble LH_2 sluppet ut i et lukket rom koblet til en ventilasjonsmast. Formålet med testene var å gi informasjon om:

- konsentrasjon av H_2 i TCS som følge av lekkasje av LH_2
- strømningshastighet av H_2 ut av, og spredning av H_2 ned fra, ventilasjonsmasten
- tetting av ventilasjonsmasten grunnet frysing av fuktighet i lufta
- konsekvenser av eksplosjon i TCS.

Utslipp av LH_2 resulterte i dannelse av en væskedam på bakken, men bare i tilfellene der utslippet var rettet vertikalt ned mot bakken. Dammen var begrenset til 0,5 til 1,0 m fra utslippspunktet, og forsvant da utslippet ble stanset. H_2-skyen med brennbare konsentrasjoner spredte seg langs bakken med nøytral oppdrift, i en smal passasje foran utslippspunktet. For testene med horisontal utslippsretning, ble det målt brennbare konsentrasjoner av H_2 i en avstand på 50 m, men ikke 100 m, fra utslippspunktet. Det ble ikke observert brennbare konsentrasjoner av H_2 utenfor en 45° vinkel, relativt til vindretningen. Kondensering og frysing av komponenter i lufta ble observert på bakken rundt utslippspunktet i tilfellene der utslippet var rettet vertikalt ned mot bakken, men ikke fra skyen generelt. Antenning av gasskyen forårsaket en brann. Rask deflagrasjon eller detonasjon skjedde ikke på noe sted eller tidspunkt under testene. Utslipp av LH_2 i lukket rom ga 100 %vol H_2 i rommet løpet av 30 sekunder. Hydrogen spredte seg fra ventilasjonsmasten med en nøytral oppdrift. Ingen signifikante H_2-nivåer ble målt på bakkenivå. Ingen tilstopping av ventilasjonsmasten ble observert. Testene hvor H_2 ble antent på toppen av ventilasjonsmasten viste at oksygen som strømmer tilbake gjennom ventilasjonsmasten kan forårsake en eksplosjon med lav alvorlighetsgrad i TCS.

Contents

Preface

In 2016, the Norwegian Government decided that the Norwegian Public Roads Administration (NPRA) should introduce hydrogen as a fuel in the maritime sector by announcing a developing contract for a hydrogen-electric ferry on a connection in Norway. To contribute to a safe introduction and further use of hydrogen as an energy carrier in the maritime sector, the NPRA included funds for tests related to hydrogen in their budget for the development contract related to maritime use of hydrogen.

The NPRA initiated this test project when the tendering process for the development contract for a hydrogen-electric ferry was started in 2017. During the tendering process, ferry operators and their design teams gave input to the NPRA regarding safety issues related to the use of hydrogen as a maritime fuel, which could be objectives of the tests. In addition, the NPRA requested the Norwegian Directorate for Civil Protection (DSB) and the Norwegian Maritime Authority to identify areas with limited knowledge in their work with hydrogen, which could be a subject for the tests. The tests in this test project are based on general safety issues related to the use of liquid hydrogen in the maritime sector and are not related to any specific ferry concept or design.

The Norwegian Defence Research Establishment (FFI) has been responsible for the procurement and follow up of the tests. DNV GL, Spadeadam Research and Testing, located in the United Kingdom has conducted the tests and written two test reports. The decisions regarding the tests have been made by the NPRA, in collaboration with FFI, the Norwegian Maritime Authority and DSB, with DNV GL as advisor. A reference group with members from research institutes, universities and private companies has contributed with their knowledge in the planning of the specifications, details and implementations of the tests, and interpretation of the results. In addition to the authors of this report, Helge Weydahl and Tor Erik Kristensen at FFI have also contributed in the planning of the tests and interpretation of the test results.

The project was funded by NPRA.

The two reports prepared by DNV GL are “Data report: Outdoor leakage studies” (Medina et al., 2020a) and “Data report: Closed room and ventilation mast studies” (Medina et al. 2020b). The reports include details about the experimental programme, experimental arrangement and experimental procedure, in addition to introduction, results, discussion and summary. The appendices in the reports include details about the experimental arrangement, instrumentation and results. The outdoor leakage report also includes predictions and analysis of outflow conditions, liquid spread and dispersion, and PHAST predictions.

This report, prepared by FFI, includes:

1) Introduction, which describes the background and objectives of the tests.

2) Outdoor leakage studies and 3) Closed room and ventilation mast studies, which describe the experimental setup, measurements, test conditions and results, for the outdoor leakage tests, and closed room and ventilation mast tests, respectively. These two chapters are based on the results given in Appendix A and B in this report. The results are also given in the result appendices (Appendix C) of the DNV GL reports (Medina et al., 2020a, Medina et al., 2020b).

4) Discussion, where each of the test objectives given in the introduction is discussed based on the results from the tests.

5) Conclusions, which summarize the main findings from the tests.

All the results from these tests are freely available. The results include spreadsheets with data from all the tests, in addition to photos and videos from the tests.

Kjeller, 9 December 2020
Jorunn Aaneby
Thor Gjesdal
Øyvind Voie

1 Introduction

1.1 Background

Hydrogen is considered as a promising energy carrier, as hydrogen itself does not contribute to greenhouse gas emissions. However, it should be noted that the greenness of hydrogen might vary with the production method. Liquid hydrogen (LH_2) is considered an efficient solution for transportation and storage of hydrogen. Especially when it comes to large vessels, liquid hydrogen is more practical than compressed hydrogen due to more efficient storage, bunkering, and handling of the fuel. The expected behavior of LH_2 releases suggests that a higher safety standard may be required when designing hydrogen-fueled vessels compared to existing liquefied natural gas (LNG) vessels. Hydrogen has a wide flammable range of 4–75 vol% (in air) and a very low ignition energy of 0.019 mJ. The issue of hydrogen safety is associated with leakage, since this might induce damage (fire/explosion) on humans and infrastructure. In addition, the low temperature of LH2 of -259 °C means it can liquefy and solidify components of air. A practical consequence of this is that LH_2 can clog lines with air (Verforndern and Dienhart, 2007). The question of whether LH_2 can cause clogging of ventilation masts, piping or other components on vessels is a potential safety concern. The effect of cryogenic spills on other substrates is yet another issue. The knowledge of the behavior of hydrogen from LH_2 spills, that is available today, originates from experiments. Most of the tests of liquid hydrogen that have been performed so far have been on a laboratory scale. Only a few large-scale LH_2 spill tests have been conducted. These tests have provided data for the establishment, calibration and improvement of numerical models that are used as a basis for risk assessment, thus they have been of great value for the introduction of LH_2 as a fuel. However, in order to reduce the uncertainty with the models, more large-scale tests are warranted.

The three large-scale tests that have been performed are those by NASA (Chirivella and Witofski, 1986), BAM (Federal Institute for Materials Research and Testing, Germany) (Marinescu-Pasoi and Sturm, 1994) and HSL (Health and Safety Laboratory, UK) (Hooker et al., 2011). The release rates in the tests of BAM and HSL were low (respectfully 300–360 L/min, and ~60 L/min), whereas the release rates in the NASA tests were high (~5.7 m^3 released in 38 s). To be relevant for the planned marine use of LH_2, the previous tests lack several conditions. E.g., the release rates during a bunkering operation will differ from those tested in the past. A release rate close to 700 L/min might be realistic for a bunkering operation (NCE, 2020). The buildings present in the BAM test are interesting since they may represent obstacles in the bunkering area on a quay. For the marine use of LH_2, releases in closed room are of relevance. Especially with respect to the tank connection space (TCS), or cold box, which contains valves, equipment and entry points to the LH_2 tank. Although tests of release of hydrogen in confined spaces have been performed (e.g. Shebeko et al., 1988; GEXCON, 2003), no large scale studies have been conducted regarding leakage of LH_2 in closed rooms/confined spaces.

1.2 Objectives

The objective of the current tests was to contribute to the understanding of the behavior of LH_2 for introduction of LH_2 as a maritime fuel, thereby facilitating safe hydrogen use for the next generation of hydrogen-electric ships. The tests included a set of releases of LH_2 at a rate and duration that differed from the past experimental tests, and were deemed to be realistic for accidental spills in a marine setting.

The suggested tests were intended to provide data that could be applied directly to maritime operations, but also to be used to validate and update existing empirical, phenomenological and computational fluid dynamic (CFD) models for prediction of the hazards from maritime use of hydrogen.

The tests were divided in two parts; 1) outdoor leakage studies and 2) closed room and ventilation mast studies.

1.2.1 Outdoor leakage studies

The outdoor leakage studies were intended to simulate spill of LH_2 from a bunkering operation. Spill related to bunkering of LH_2 was the basis for developing the scopes of the outdoor leakage tests. A bunkering operation is illustrated in Figure 1.1. For a maritime case, it is realistic to assume that a leakage can occur at the ship's side, with bunkering directly from an LH_2 truck, which can store around 3.5 tonnes of LH_2. The outdoor leakage tests were designed with realistic dimensions of bunkering hose, leakage rates, leakage profile, and duration, as well as leakage point (assumed slightly above ground). Release rates up to 50 kg/min, equivalent to ~705 L/min, were tested in the current study, and represents a release rate that could occur during bunkering operations. Two containers were used as a barrier to simulate the ship`s side. In addition, a barrel and other obstacles were placed on the test pad. Obstacles might contribute to a more severe explosion in the case of a release since the hydrogen gas can concentrate around the obstacles due to turbulence and enhance the combustion of hydrogen (e.g. Xiaoa and Oran, 2020).

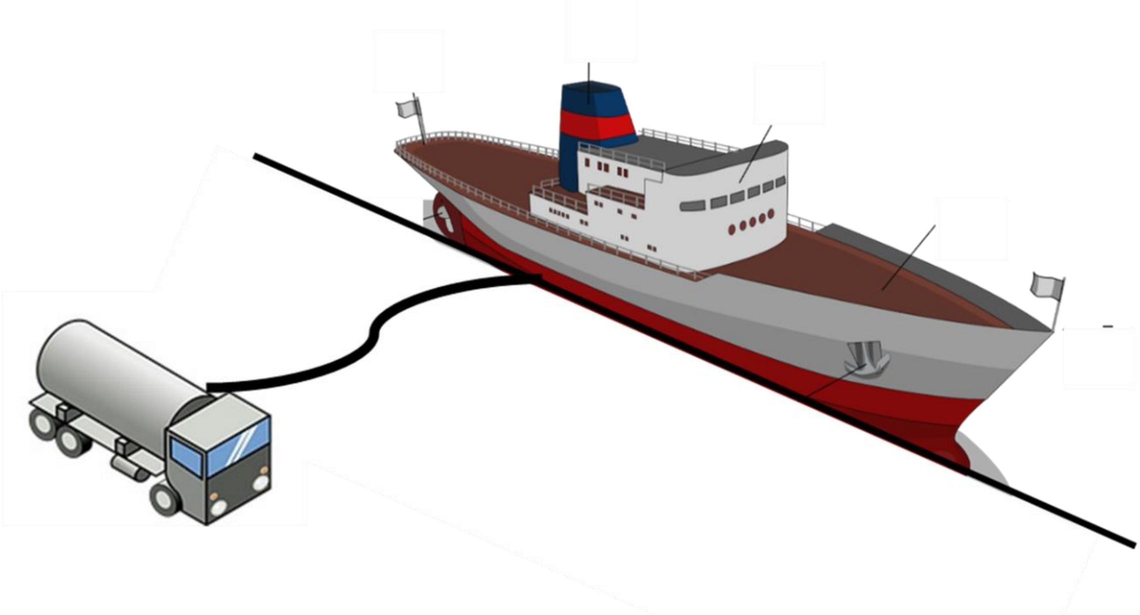


Figure 1.1 Illustration of a truck to ship bunkering (FFI). This was the starting point for the development of a test case for leakage of LH_2 outdoors.

The objectives of the outdoor leakage studies were to provide information about:

- Formation, including propagation and duration, of a liquid pool caused by leakage of LH_2, and whether the liquid pool ceased to grow due to equilibrium between leakage and vaporization.
- Hydrogen concentration within the gas cloud, including propagation and duration of the hydrogen concentration, caused by leakage of LH_2.
- Condensation and freezing of components in air caused by leakage of LH_2.
- Burning/deflagration/detonation of the gas cloud with H_2 when ignited, and energy/pressure from any blast.

1.2.2 Closed room and ventilation mast studies

The closed room and ventilation mast studies were intended to simulate spill in tank connection space (TCS) connected to a ventilation mast. Leakage of LH_2 in an enclosed space is of special interest as thee documentation available on this is limited. The principle sketch as shown in Figure 1.2 was the starting point for developing the test case for leakage of LH_2 in closed room. The TCS are enclosed spaces that most likely will be present regardless of whether the LH_2 is stored in tanks above or below the deck level. They are normally filled with tubes, pipelines, valves and processing equipment etc., which will represent obstacles that can affect the local hydrogen concentration hydrogen and the propagation of a deflagration detonation transition (ddt) (e.g. Xiaoa and Oran, 2020). Hence, the simulant TCS used in the tests contained structures to mimic these lines and tubes.

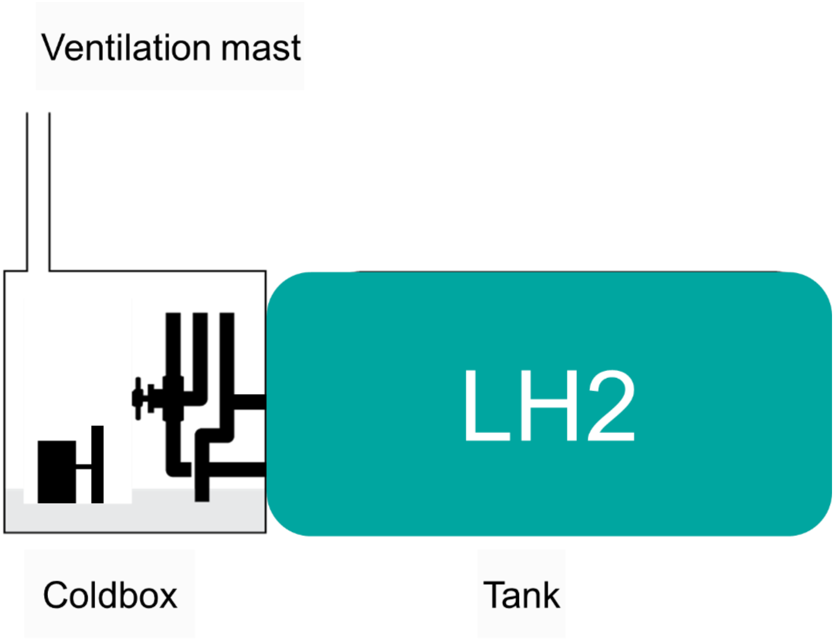


Figure 1.2 Illustration of a tank connection space (TCS) (also called coldbox) connected to a ventilation mast (FFI). A leakage in this area was the starting point for the development of a test case in closed rooms.

The objectives of the closed-room and ventilation mast tests were to provide information about:

- Concentration of H_2 in TCS due to leakage of LH_2.
- Pressure build-up in TCS due to evaporation of LH_2.
- Unwanted inflow of oxygen into TCS due to negative pressure.
- Flow rate of H_2 out of ventilation mast.
- Spread of cold H_2, especially downwards, from the ventilation mast.
- Clogging of ventilation mast due to solidification of moisture in the atmosphere.
- Explosion pressure resulting from ignition after leakage of LH_2 in TCS.

2 Outdoor leakage studies

This chapter gives an overview of the accomplishment and results from the outdoor leakage tests. The outdoor leakage tests were conducted between December 11th and 13th, 2019, at the DNV GL Spadeadam Research and Testing Centre in Cumbria, UK. Totally 7 leakage tests were performed outdoor.

A detailed description of the test facility and measurement instrumentation for the outdoor leakage tests is given in “Chapter 4 Experimental arrangement”, and “Appendix A Experimental arrangement” and “Appendix B Instrumentation” in the DNV GL Outdoor leakage studies report (Medina et al., 2020a). A brief description of the test setup and measurements is given in Chapter 2.1. An overview of the outdoor leakage tests is given in Chapter 2.2. The test conditions and results for each of the outdoor leakage tests is described in Chapter 2.3. The results, which Chapter 2.3 is based on, are given in “Appendix A Results outdoor leakage tests” of this report. The results (mainly graphs) are also given in “Appendix C Results” of the DNV GL Outdoor leakage studies report (Medina et al., 2020a).

2.1 Experimental setup and measurements

The experimental setup for the outdoor leakage tests is shown in Figure 2.1. Obstacles in form of two containers on top of each other, a plastic drum and an instrument box were placed on the test pad. The blue arrangement above the release point, and grey array extending from the release point, were used for attaching the instrumentation and recording equipment. The orange cones were placed on the test pad to be able to estimate the prevalence of the emission and extent of any pool.

Figure 2.1 Test site with obstacles. The obstacles were two containers on top of each other, simulating a shipside, a plastic drum and an instrument box.

The liquid hydrogen was released in the middle of the test setup, at the white insulated pipe in the middle of Figure 2.1. Most of the outdoor leakage tests were conducted with a vertical downward release orientation. A close-up photo of the release point with a vertical downward release orientation is shown in Figure 2.2. A photo of the release point in a horizontal orientation is shown in Figure 2.3.

Figure 2.2 Vertical downwards release orientation.

Figure 2.3   Horizontal release orientation.

Ambient conditions were recorded in each test. The measurements included wind speed and direction, ambient temperature and humidity. The wind speed and direction were measured with two sensors installed in a mast near the test pad, one sensor (“high”) 10 meters above the ground and one sensor (“low”) 5 meter above the ground. Only the average result for the “high” sensor is included in this report.

In each test, pad temperature, field temperature and gas concentration, were recorded. The pad and field temperatures were measured with thermocouples. The gas (oxygen) concentration was measured with oxygen sensors and the results were translated to hydrogen concentration based on oxygen depletion. The pad temperature can provide information about formation of a liquid pool of LH_2 on the surface. The hydrogen concentration in the field is interesting to consider with regards to the flammable limit of H_2. The field temperature can also provide information about the spread of hydrogen in the field. Details about the instrumentation and measurements of pad temperature, field temperature and gas concentration is given chapter 4.2.3 and 4.2.4 in the DNV GL Outdoor leakage studies report (Medina et al., 2020a).

The pad temperature was measured on the surface of the concrete pad at distances of 0.2, 0.5, 1.0, 5.0 and 10.0 m from the release point. In addition, the temperature was measured 20 mm and 30 mm below the surface of the concrete at distances of 0.2 and 0.5 m from the release point. Totally 48 thermocouples (TT_01-TT_48) were placed on or in the concrete test pad. The locations of the pad temperature measurements are shown in Figure 2.4. The thermocouples on and in the concrete pad were kept in the same positions throughout all the outdoor leakage tests.

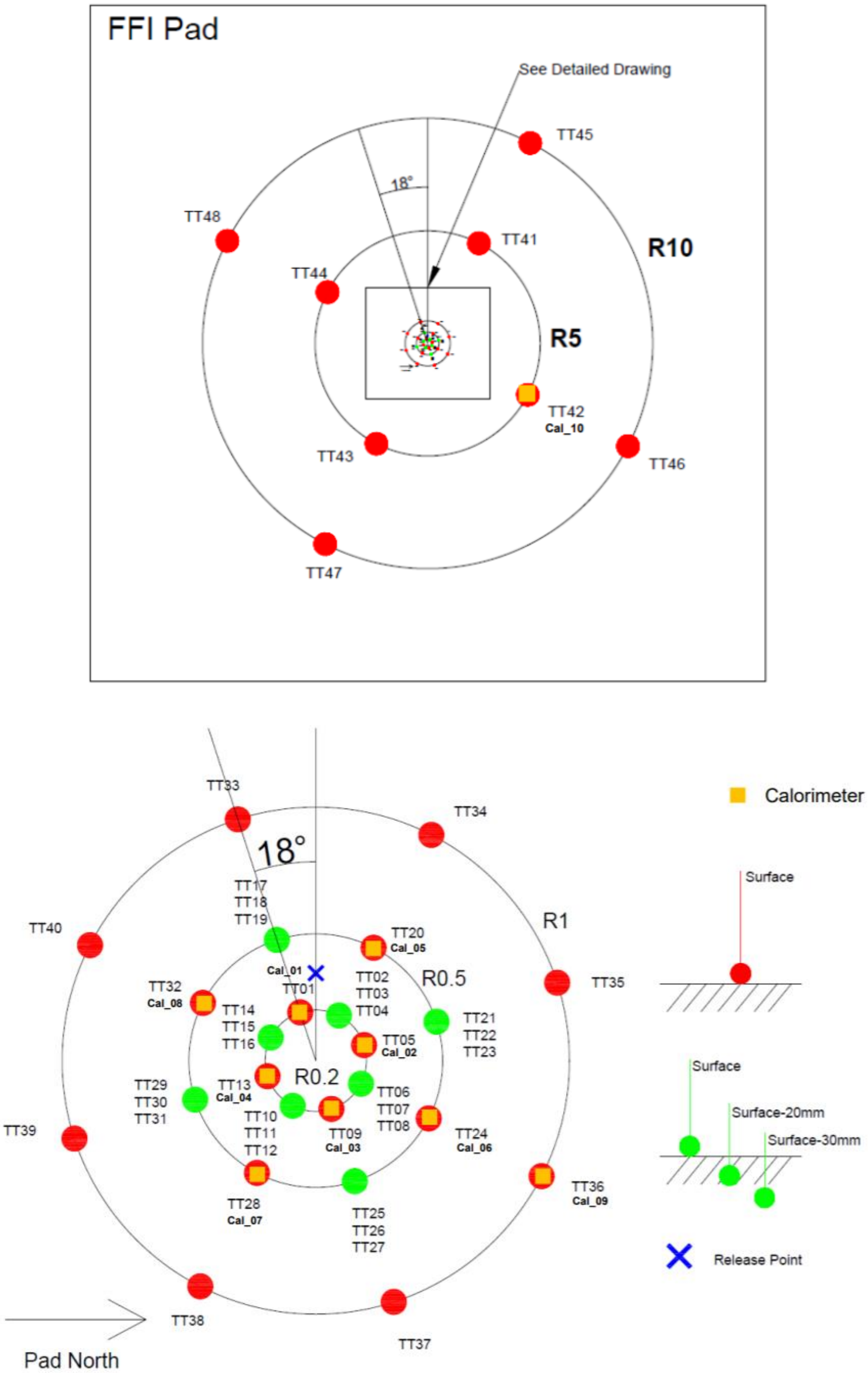


Figure 2.4 *Placement of thermocouples to measure pad temperature and calorimeters to measure heat flux (ignited tests only). The top image shows the full test pad. The bottom image shows the details around the release point. The red dots indicate the locations of the surface measurements; the green dots indicate the locations of the measurements below the concrete surface. The blue cross indicate the release point of LH_2.*

The field temperature and gas concentration were measured at distances of 30, 50 and 100 m from the release point, at heights of 0.1, 1.0 and 1.8 m above the ground. The field temperature was also measured at ground level (0 m). Totally 40 thermocouples (TT_49-TT_88) were used for field temperature measurements. Totally 30 oxygen sensors (OC_01-OC_30) were used for gas measurements. The initial locations of the field temperature and gas concentration measurements are shown in Figure 2.5. The stands were moved in some of the tests due to altered wind conditions. The altered setup is described for the second test in Chapter 2.3.2.

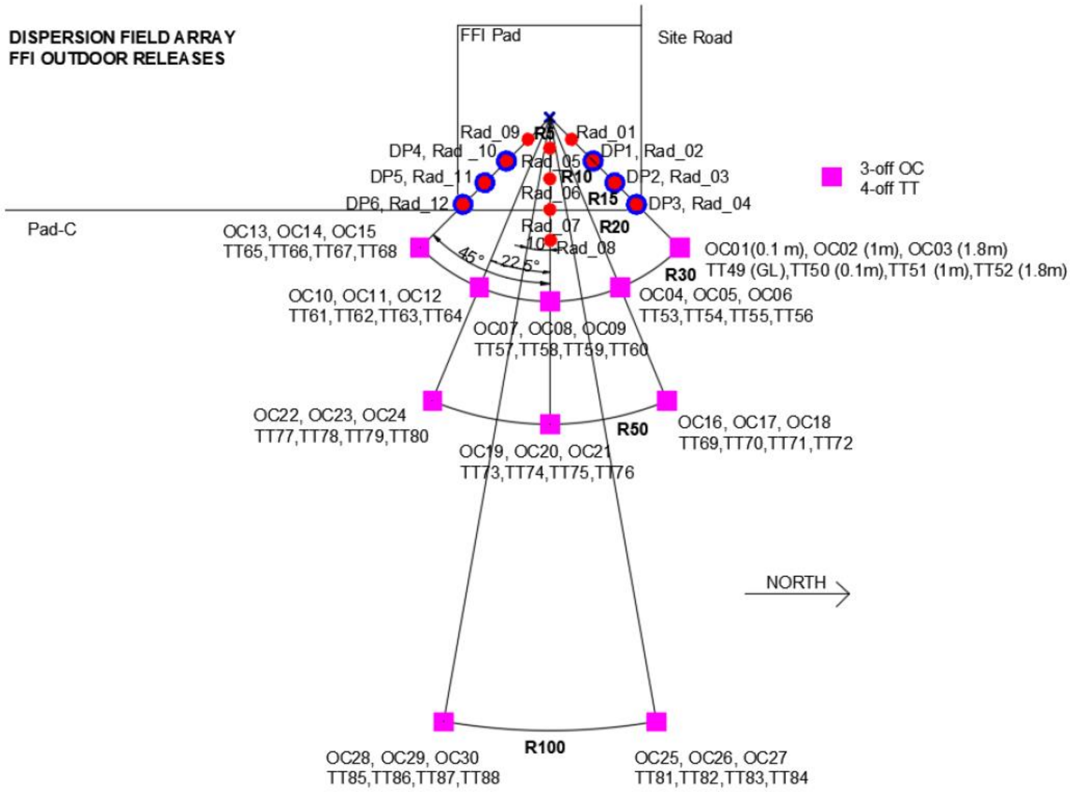


Figure 2.5 Initial instrument locations for measurements of field temperature, gas concentration, thermal radiation and field overpressure. Pink squares indicate oxygen sensors and thermocouples for field temperature measurements. Red dots indicate radiometers. Blue circles indicate pressure sensors. The blue cross indicate the release point of LH_2.

The release of LH_2 was ignited in two of the tests. In the ignited tests, radiometers to measure thermal radiation, calorimeters to measure heat flux, and pressure sensors to measure field overpressure were applied in addition to the measurements described above. Thermal radiation was measured with 12 radiometers (Rad_01-Rad_12) at distances of 5, 10, 15 and 20 m from the release point, all 1.2 m height from ground level. Heat flux was measured with 10 calorimeter blocks (FLUX_CB1-FLUX_CB10/Cal_01-Cal_10)) at distances of 0.2, 0.5, 1 and 5 m from the release point, all 0.1 m height from ground level. Details about the instrumentation and measurements of thermal radiation, heat flux and dynamic pressure are given chapter 4.2.5 in the DNV GL Outdoor leakage studies report (Medina et al, 2020a).

The locations of the calorimeter blocks are shown together with the pad thermocouples in Figure 2.4. The initial locations of the radiometers and pressure sensors are shown together with the field thermocouples and oxygen sensors in Figure 2.5. Some of the radiometers and pressure sensors were moved for the second ignited test. The altered setup is described for the second ignited test in Chapter 2.3.6.

2.2 Overview outdoor leakage tests

A total of 7 outdoor leakage tests were conducted between Dec 11th and 13th, 2019. Some of the test parameters varied throughout the tests. These included the release orientation of LH_2, which was either vertical downwards on the concrete or horizontal; the LH_2-tanker pressure; the outflow rate of LH_2 from the tanker; whether the gas cloud was ignited or not; and the run time of the test (duration of the release). An overview of the outdoor leakage tests and the test parameters is given in Table 2.1.

Table 2.1 Overview outdoor leakage tests.

Test	Date and time	Release orientation	Tanker pressure (barg)	Nozzle size	Outflow rate (kg/min)	Ignition	Run time (min)
1	12/11/19, 5.11 pm	Vertical downwards	2	1”	13.5	No	13
2	12/12/19, 2.57 pm	Vertical downwards	6	1”	28.2	No	8
3	12/13/19. 11.05 am	Vertical downwards	10	1”	43.8	No	15
4	12/13/19, 12.37 pm	Horizontal	10	1”	49.7	No	6
5	12/13/19, 2.37 pm	Vertical downwards	10	1”	42.9	Yes	6
6	12/13/19, 8.11 pm	Horizontal	10	1”	49.9	Yes	3
7	12/13/19, 9.30 pm	Vertical downwards	0.8	1”	9.7	No	8

Chapter 2.3.1 to 2.3.7 give a brief description of the test conditions and results from each of the outdoor leakage tests. The main findings regarding pad temperature, field temperature and field gas concentration for each test are given. For the two ignited tests, the main findings regarding thermal radiation and heat flux, are also given. The results for field overpressure have not been reviewed in this report. The full results are given in “Appendix A Results outdoor leakage tests”

of this report. The results (mainly graphs) are also given in “Appendix C Results” of the DNV GL Outdoor leakage studies report (Medina et al., 2020a).

2.3 Test conditions and results

2.3.1 Test 1 – Release without increasing tanker pressure

The first test was conducted on Dec 11th, 2019. The test had a run time of 13 minutes. The outflow rate was 13.5 kg/min (0.228 kg/s) and the release orientation was vertical downwards on the concrete. The first test was conducted without increasing the pressure in the LH_2-tanker. The tanker pressure was 2 barg. The weather conditions for Test 1 are given in Table 2.2.

Table 2.2 Weather conditions Test 1.

Weather conditions	
Wind speed	3.2 ± 0.8 m/s
Wind direction	WSW (246 ± 14 deg)
Ambient temperature	1 °C
Weather	Overcast, rain prior to test

The lowest pad temperatures measured on the concrete surface 0.2, 0.5 and 1 m distance from the release point in Test 1 ranged from -242 to -170 °C. The pad temperature measurements indicated that liquid hydrogen was observed on the ground 0.5 m from the release point.

The field temperatures measured in Test 1 ranged from -2.9 to +1.6 °C, with averages for the different measuring points ranging from +0.5 to +1.5 °C. The lowest temperatures (-2.9 °C) were measured at sensor TT_56 and TT_60, both 30 m from the release point, 1.8 m height. Generally, no very cold temperatures were measured in the field in Test 1, which reflects the relatively low release rate of LH_2.

The highest maximum H_2 concentration in Test 1 was 1.8%vol, measured at sensor OC_05, 30 m from the release point, 1 m height and in line with the wind direction from the release point. The highest H_2 concentration measured in Test 1 was below the flammable limit of H_2 (4%vol) in air. The highest average H_2 concentration in Test 1 was 0.4%vol, measured at sensor OC_03 and OC_06, both 30 m from the release point, 1.8 m height and in line with the wind direction from the release point. The H_2 concentrations decreased with the distance from the release point. The highest maximum H_2 concentration measured 50 and 100 m from the release point was 0.6 and 0.5%vol, respectively.

The outflow rate of LH_2 in Test 1 was 13.5 kg/min, which is lower than the outflow rate of 50 kg/min, which can be expected in a bunkering situation. It was decided to increase the outflow rate in Test 2.

Photos of the test site after completion of Test 1 are shown in Figure 2.6.

Figure 2.6 Photos of the test site after completion of Test 1.

2.3.2 Test 2 – Higher release rate and opposite wind direction

The second test was conducted on Dec 12th, 2019. The test had a run time of 8 minutes. The outflow rate was 28.2 kg/min (0.473 kg/s), which was about twice as high as in Test 1. The pressure in the LH_2-tanker was increased to 6 barg prior to the release to achieve the higher outflow rate. The release orientation was vertical downwards on the concrete, which was the same as for Test 1. The weather conditions for Test 2 are given in Table 2.3.

Table 2.3 Weather conditions Test 2.

Weather conditions	
Wind speed	4.1 ± 0.8 m/s
Wind direction	E (82 ± 10 deg)
Ambient temperature	1.5 °C
Weather	Overcast, rain prior to test

The wind direction in Test 2 was from the east, as opposed to Test 1 where the wind direction was from the west (WSW). Some of the field instrumentation stands was re-positioned in Test 2 to allow for measurements in the opposite wind direction. The oxygen sensors OC_16-OC_24 and thermocouples TT_69-TT_80 were moved from the positions 100 m from the release point (locations shown in Figure 2.5) to positions in the opposite direction, 30 m from the release point. The oxygen sensors OC_25-OC_27 and thermocouples TT_81-TT_87 were moved from the positions 100 m from the release point (locations shown in Figure 2.5) to positions in front of the ISO container. The locations of the field temperature and hydrogen concentration measurements for Test 2 are shown in Figure 2.7. The placement of the field instrumentation in front of the ISO container is shown in Figure 2.8.

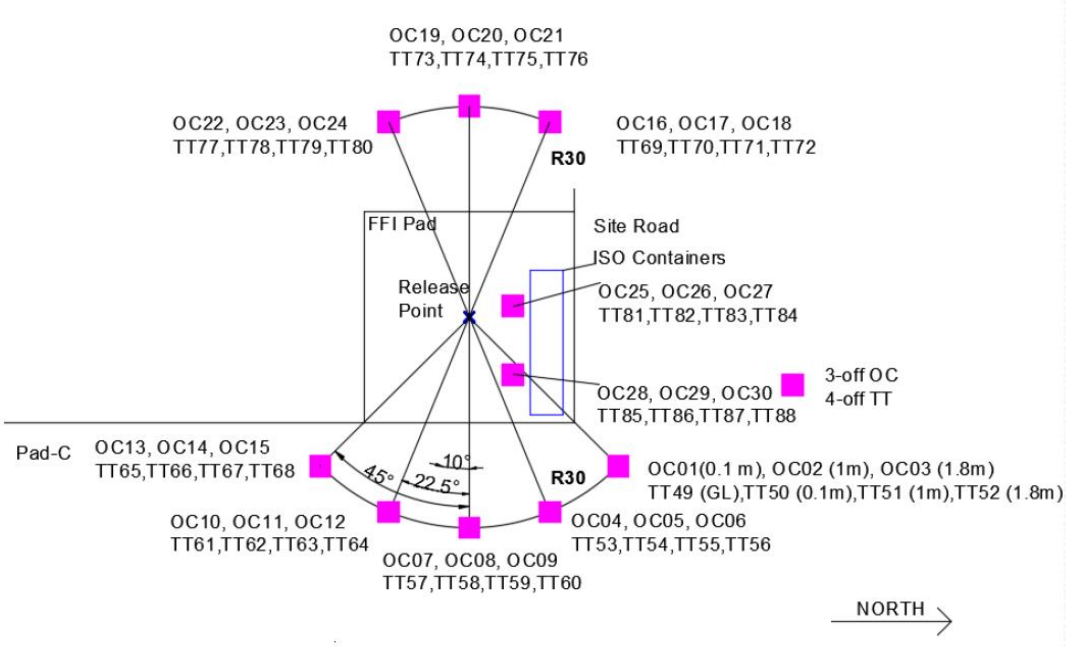


Figure 2.7 Locations of field temperature thermocouples and oxygen sensors to measure H_2 concentration in Test 2, which was conducted with wind from the east.

Figure 2.8 Placement of field temperature and oxygen sensors in front of the ISO container.

The lowest pad temperatures measured on the concrete surface 0.2, 0.5 and 1.0 m from the release point in Test 2 ranged from -237 to -139 °C. The pad temperature measurements indicated that liquid hydrogen was observed on the ground 0.5 m from the release point. The average pad temperatures 1 m from the release point was slightly lower in Test 2 than in Test 1, which could indicate that the liquid hydrogen reached further in Test 2.

The field temperatures in Test 2 ranged from -7.6 to +2.1 °C, with averages ranging from -1.8 to +2.0 °C. The lowest temperature (-7.6 °C) was measured at sensor TT_72, 30 m from the release point, in opposite direction of the release orientation, but in line with the wind direction.

The highest maximum H_2 concentration in Test 2 was 4.2%vol, measured at sensor OC_20, 30 m from the release point, 1 m height and in line with the wind direction from the release point. The highest average H_2 concentration in Test 2 was 2.0%vol, measured at the same location as the highest maximum H_2 concentration, but 1.8 m height. The oxygen sensors in the original instrument positions measured no hydrogen (max 0.1%vol). This was as expected as the wind, and thus the spread of LH_2, occurred in the opposite direction from where these sensors were placed. Also, no hydrogen (max 0.1%vol) was measured in front of the ISO container, which was located 9 to 11 m from the release point. The measurements of H_2 in Test 2 showed that the spread of H_2 it is highly dependent on the wind direction.

Photos of the test site after completion of Test 2 are shown in Figure 2.9.

Figure 2.9 Photos of the test site after completion of Test 2.

2.3.3 Test 3 – Higher outflow rate

The third test was conducted on Dec 13th, 2019. The test had a run time of 15 minutes. The outflow rate was 43.8 kg/min (0.730 kg/s), which was about three times higher than Test 1 and 50% higher than Test 2. The pressure in the LH_2-tanker was increased to 10 barg prior to the release to achieve the higher outflow rate. The release orientation was vertical downwards on the concrete, which was the same as for Test 1 and 2. The weather conditions for Test 3 are given in Table 2.4.

Table 2.4 Weather conditions Test 3.

Weather conditions	
Wind speed	5.8 ± 1.8 m/s
Wind direction	W (259 ± 11 deg)
Ambient temperature	2.9 °C
Weather	Overcast, rain prior to test

The wind direction in Test 3 was from the west, similar to Test 1. The field instrumentation, which was moved for Test 2, was moved back to the original positions for Test 3 (Figure 2.5).

The lowest temperatures measured on the concrete surface 0.2, 0.5 and 1 m distance from the release point in Test 3 ranged from -91 to -237 °C. The pad temperature measurements indicated that liquid hydrogen was observed 0.5 m from the release point. The temperatures measured 1 m from the release point in Test 3 and Test 2 were similar, even if the outflow rate was higher in Test 3. However, no pad temperature measurements were done between 1 and 5 m distance from the release point. The liquid hydrogen may have reached further in Test 3 even if this was not seen directly from the temperature measurements.

The field temperatures measured in Test 3 ranged from -8.0 to +3.1 °C, with averages ranging from -1.4 to +3.0 °C. The lowest temperature (-8.0 °C) was measured at sensor TT_60, 30 m from the release point, 1.8 m height, and in line with the wind direction from the release point.

The highest maximum H_2 concentration in Test 3 was 6.3%vol, measured at sensor OC_07, 30 m from the release point, 0.1 m height and in line with the wind direction from the release point. The highest H_2 concentration was above the flammable limit of H_2 in air. The highest average H_2 concentration measured in Test 3 was 2.7%vol, measured at the same location as the highest maximum H_2 concentration, but 1 m height. The H_2 concentrations measured in Test 3 decreased with the distance from the release point, as was also found for Test 1 (no measurements at different distances from the release point were done in Test 2). The highest maximum H_2 concentration measured 50 and 100 m from the release point in Test 3 was 3.3 and 1.4%vol, respectively, thus below the 4%vol flammable limit of H_2 in air.

The outflow rate of LH_2 in Test 3 was 43.8 kg/min, which is slightly lower than the outflow rate of 50 kg/min, which can be expected in a bunkering situation. However, the pressure in the LH_2-tanker was increased to 10 barg, which was the maximum limit for the tanker.

Photos of the test site after completion of Test 3 are shown in Figure 2.10.

Figure 2.10 Photos from the test site after completion of Test 3.

2.3.4 Test 4 – Horizontal release

The fourth test was conducted on Dec 13th, 2019. The test had a run time of 6 minutes. The outflow rate was 49.7 kg/min (0.828 kg/s), which was slightly higher than in Test 3. As for Test 3, the pressure in the LH_2-tanker was increased to 10 barg prior to the release to achieve the higher outflow rate. The weather conditions for Test 4 are given in Table 2.5.

Table 2.5 Weather conditions Test 4.

Test conditions	
Wind speed	6.7 ± 1.6 m/s
Wind direction	W (264 ± 10 deg)
Ambient temperature	3.3 °C
Weather	Mainly cloudy, rain prior to test

In Test 4, the release orientation was changed to horizontal, along the wind axis, which differed from the prior tests. The horizontal release position is shown in Figure 2.3. Test 4 was intended to be a repetition of Test 3, with horizontal instead of vertical downward release position, and with a slightly higher outflow rate.

The wind direction in Test 4 was from the west, similar to Test 1 and Test 3. The field instrumentation was kept in the original positions as shown in Figure 2.5.

The pad temperature measurements in Test 4 indicated no presence of liquid hydrogen on the ground. This was in contrast to the observations in Test 1, 2 and 3, and is likely to be related to the horizontal rather than vertical downward release orientation in Test 4. The lowest temperature measured on the concrete pad in Test 4 was -42.4 °C, measured at sensor TT_02, 0.2 m from the release point, at the surface (0 m).

The field temperatures measured in Test 4 ranged from -26.8 to +3.9 °C, with averages ranging from -9.6 to +3.7 °C . The lowest temperatures were measured at the sensors closest to the release position (30 m), in line with and in 22.5° angle, in both directions relative to the release/wind direction. The temperatures measured 50 and 100 m from the release point, and 30 m and 45° angle relative to the release/wind direction were similar to the ambient temperature, indicating that LH_2 had not reached these areas. The exception was the sensors placed 50 m in straight line from the release point (TT_73-TT_76), which showed lower than ambient temperatures (-0.1 to -10.9 °C). The lowest temperature (-10.9 °C, TT_76) was measured at the highest point of the sensor, 1.8 m, which indicated that the LH_2 had raised when it reached this distance.

The highest maximum H_2 concentrations in Test 4 were 11.8 to 17.2%vol, measured at sensors OC_07, OC_08 and OC_09, located at the same position, but different heights, 30 m from the release point, and in line with the wind direction from the release point. The highest maximum H_2 concentration (17.2%vol) was measured at the sensor closest to the ground (0.1 m). The maximum H_2 concentrations measured in 22.5° angle in each direction relative to the release/wind direction ranged from 6.4 to 11.5%vol, whereas the H_2 concentrations measured in 45° angle ranged from 0.9 to 3.4%vol. The results indicate that the H_2 spread in a narrow passage from the release point and that flammable concentrations of H_2 only were found in the middle of this passage. The maximum H_2 concentration measured 50 and 100 m from the release point in Test 4 was 6.5 and 1.1%vol, respectively. The highest average H_2 concentrations in Test 4 were 6.1 to 8.4%vol, measured at the same sensors as the highest maximum H_2 concentrations.

Both the maximum and average H_2 concentrations in Test 4 were higher than those measured in the prior tests, including Test 3, which had a similar outflow rate as Test 4. The results indicate that a horizontal release of LH_2 results in a greater spread of H_2 than in case of a vertical downwards release. No liquid pool of liquid hydrogen was observed on the ground in Test 4. The results indicate that a horizontal release of liquid hydrogen is less likely to cause formation of a liquid pool than a vertical release.

The outflow rate in Test 4 was 49.7 kg/min, which is similar to the outflow rate of 50 kg/min, which can be expected in a bunkering situation. The pressure of LH_2-tanker was increased to 10 barg prior to the release. This was the same as for Test 3, where a slightly lower outflow rate as achieved.

2.3.5 Test 5 – First ignited test, vertical downward release

The fifth test was conducted on Dec 13th, 2019. The test had a run time of 6 minutes. The outflow rate was 42.9 kg/min (0.715 kg/s), which was similar to Test 3, slightly lower than Test 4. As for Test 3 and 4, the pressure in the LH_2-tanker in Test 5 was increased to 10 barg prior to the release to achieve the higher outflow rate. The release orientation was re-positioned to be vertical downwards on the concrete. Test 5 was similar to Test 3, but with ignition. The weather conditions for Test 5 are given in Table 2.6.

Table 2.6 Weather conditions Test 5.

Weather conditions	
Wind speed	5.2 ± 1.9 m/s
Wind direction	W (257 ± 12 deg)
Ambient temperature	3.7 °C
Weather	Mainly cloudy, rain prior to test

The wind direction in Test 5 was from the west, similar to Test 1, 3 and 4. The field instrumentation was kept in the original positions as shown in Figure 2.5. In addition to the instrumentation in Test 1-Test 4, radiometers to measure thermal radiation, calorimeters to measure heat flux, and pressure sensors to measure field overpressure were included in Test 5. The locations of the radiometers and pressure sensors are also shown in Figure 2.5.

In Test 5, first a release without ignition was conducted for 2 minutes. When the ignition sources were activated, the system experienced voltage interferences, which caused the valves to close. The release had to be re-established and a release without ignition was conducted for another 2 minutes before the release was ignited by fireworks placed 18 m from the release point. The release was continued for another 1 minute after ignition. Results for pad temperatures, field temperatures and H_2 concentrations in Test 5 are based on the readings during the second release, before ignition was initiated. Results for thermal radiation and heat flux are based on the readings after ignition and until the release was stopped. The results for field overpressure are not reviewed in this report. We refer to Figure 121 in Appendix C.05 in the DNV GL Outdoor leakage studies report (Medina et. al, 2020a) for this information.

The lowest temperature measured on the concrete pad in Test 5 was -232.6 °C, at sensor TT_13, 0.2 m from the release point, on the surface (0 m), in the same direction, but not in straight line, as the release orientation. The pad temperature measurements in Test 5 prior to the ignition indicated that liquid hydrogen was observed on the surface at 0.2 and 0.5 m from the release point.

The field temperatures measured in Test 5 ranged from -8.5 to +4.1 °C, with averages ranging from -2.1 to +4.0 °C. The lowest temperatures were measured at the sensors closest to the release point (30 m), in line with and in 22.5° angle, in both directions relative to the release/wind direction. The temperatures measured 50 and 100 m from the release point, and 30 m and 45° angle relative to the release/wind direction were similar to the ambient temperature, indicating that LH_2 had not reached these areas. The exception was the sensors 50 m in straight line from the release point (TT_73-TT_76), which showed slightly lower temperatures (-0.4 to +2.0 °C) than the ambient temperature. The trend was similar to the observations in Test 4, although the temperatures were lower in Test 4, which could be explained by the horizontal rather than vertical downward release orientation in Test 4. In Test 5, the lowest temperatures were generally measured at the sensors placed at the highest positions (1.0 and 1.8 m), indicating that the H_2 had raised from the ground. This was the case for the measuring points both 30 and 50 m from the release point. The results differed from the observations in Test 4, where this mainly was observed at the sensors 50 m from the release point.

The highest maximum H_2 concentrations in Test 5 were 6.2 to 7.7%vol, measured at sensors OC_10, OC_11 and OC_12, all located at the same position, but different heights, 30 m from the release point, in 22.5° angle relative to the release/wind direction. The slightly different wind directions in Test 4 and Test 5 could possibly explain the different locations for measurement of the maximum H_2 concentrations in these tests. As opposed to Test 4, the highest maximum H_2 concentrations (7.5 and 7.7%vol) in Test 5 were measured at the sensors furthest from the ground (1.0 and 1.8 m). The hydrogen concentrations measured at the different heights did not differ much from each other, this was the case both for Test 4 and Test 5. The highest average H_2 concentrations in Test 5 were 2.8 to 3.6%vol, measured at sensors OC_07, OC_08 and OC_09, all at the same position, but different heights, 30 m from the release point in straight line with the release orientation. The highest average H_2 concentrations were measured at different sensors than the highest maximum H_2 concentrations.

The highest maximum thermal radiation measured during the fire in Test 5 was 109.6 kW/m^2, measured at Rad_02, 10 m from the release point. The radiometer 5 m from the release point, in the same direction as Rad_02, did not work, and the thermal radiation may have been higher at this point. The second highest thermal radiations were measured at the radiometers in straight line with the release orientation (Rad_05 and Rad_06), with maximum values of 61.1 and 97.5 kW/m^2.

The highest maximum heat flux measured during the fire in Test 5 was 301.6 kW/m^2, measured at FLUX_CB7/Cal_7, 0.5 m from the release point. Generally, the highest heat fluxes were measured 0.5 m from the release point. The heat flux measured at the points closer (0.2 m) and further (1 and 5 m) from the release point were lower.

Photos of the jet fire resulting from ignition of the LH_2-release in Test 5 are shown in Figure 2.11. Photos of the test site after completion of the test are shown in Figure 2.12.

Figure 2.11 Photos from Test 5 taken during the jet fire resulting from igniton of the LH_2 release.

Figure 2.12 Photo from the test site after completion of Test 5. A burning drum can be seen.

2.3.6 Test 6 – Second ignited test, horizontal release

The sixth test was conducted on Dec 13th, 2019. The test had a run time of 3 minutes. The outflow rate was 49.9 kg/min (0.833 kg/s), which was similar to Test 4. As for Test 3, 4 and 5, the pressure in the LH_2-tanker was increased to 10 barg prior to the release to achieve the higher outflow rate. The release orientation was changed to horizontal release, as for Test 4. Test 6 was similar to Test 4, but with ignition. The weather conditions for Test 6 are given in Table 2.7.

Table 2.7 Weather conditions Test 6.

Weather conditions	
Wind speed	2.7 ± 0.9 m/s
Wind direction	WSW (245 ± 15 deg)
Ambient temperature	3.8 °C
Weather	Mainly cloudy, rain prior to test

The wind direction in Test 5 was from the west, similar to Test 1, 3, 4 and 5. The oxygen sensors and thermocouples were kept in the original positions as shown in Figure 2.5. Some of the radiometers to measure thermal radiation and pressure sensors to measure field overpressure were moved to other positions in Test 6. The locations of the radiometers and pressure sensors in Test 6 are shown in Figure 2.13.

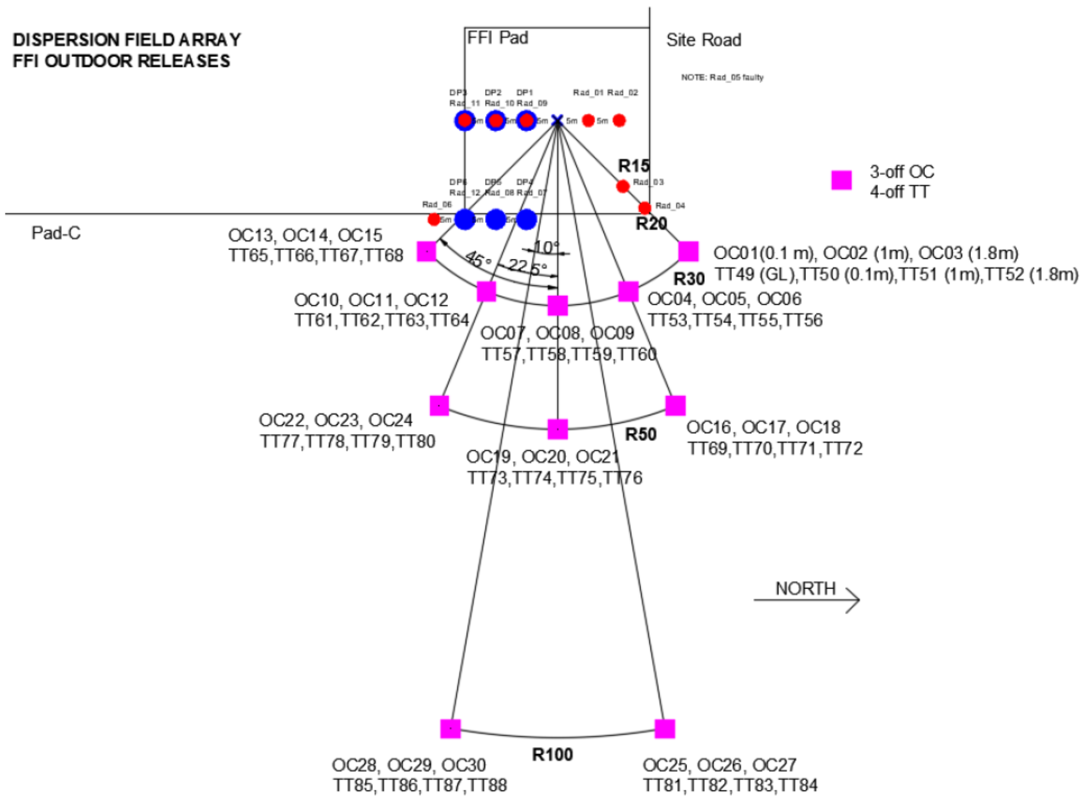


Figure 2.13 Instrument locations in Test 6. Red dots indicate radiometers. Blue circles indicate pressure sensors. Pink squares indicate oxygen sensors and thermocouples. The blue cross indicate the release point of LH_2.

In Test 6, a release without ignition was conducted for about 2 minutes before the release was ignited by fireworks placed 30 m from the release point. The release was continued for another 1 minute after the ignition was initiated. Results for pad temperatures, field temperatures and H_2 concentrations in Test 6 are based on the readings before ignition was initiated. Results for thermal radiation and heat flux are based on the readings after ignition and until the release was stopped. The results for field overpressure are not reviewed in this report. We refer to Figure 148 in Appendix C.06 in the DNV GL Outdoor leakage studies report (Medina et. al, 2020a) for this information.

The pad temperature measurements in Test 6 prior to the ignition indicated that liquid hydrogen was not present on the ground. This was similar to the observations in Test 4, which also used a horizontal release.

The lowest field temperatures measured in Test 6 ranged from -25.7 to +3.8 °C. The lowest temperatures were measured at the sensors closest to the release point (30 m), both in line with and 22.5° angle west relative to the release orientation. The temperatures measured at the others sensors were similar to the ambient temperature, indicating that LH_2 had not reached these areas. The trend was similar to the observations in Test 4, which also used a horizontal release.

The highest maximum H_2 concentrations in Test 6 were 18.6 to 21.0%vol, measured at sensors OC_07, OC_08 and OC_09, located at the same position, but different heights, 30 m from the release point in line with the release orientation. The highest concentrations were measured closest to the ground, which was similar to Test 4, which also had a horizontal release position. The highest average H_2 concentrations in Test 6 ranged from 13.3 to 15.4%vol and were measured at the same sensors as the highest maximum H_2 concentrations, and the same sensors, which showed the highest H_2 concentrations in Test 4. The H_2 concentrations measured 50 and 100 m from the release point in Test 6 were ≤1.8%vol, and were lower than the concentrations measured in Test 4.

The highest maximum thermal radiation measured in Test 6 was around 75 kW/m^2, measured at Rad_09, 5 m from the release point and in 45° angle east relative to the release orientation. The highest average thermal radiation was around 23 kW/m^2, measured at Rad_03, 15 m from the release point and 45° angle west relative to the release orientation. The thermal radiation in Test 6 was lower than the thermal radiation measured in Test 5. Also, the H_2 concentrations measured 50 and 100 m from the release point were lower in Test 5 than in Test 6. The radiometers were placed in different positions in Test 6 (Figure 2.13) and Test 5 (Figure 2.5).

The highest maximum heat flux in Test 6 was around 35 kW/m^2, measured at FLUX_CB9/Cal_9, 1 m from the release point. The heat fluxes measured closer (0.2 and 0.5 m) and further (5 m) from the release point were lower. The highest maximum heat flux in Test 6 was almost ten times lower than the highest maximum heat flux measured in Test 5.

Photos of the jet fire resulting from ignition of the LH_2-release in Test 6 are shown in Figure 2.14.

Figure 2.14 Photos from Test 6 taken during the jet fire resulting from igniton of the LH_2 *release. Top photos are from the south east view. Photo to the left are taken right after ignition. Photo to the right is the fire afterwards. Middle photos are from the west view. Photo to the left are taken right after ignition. Photo to the right is the fire afterwards. Bottom photos are fram the north east view, 18 and 21 secons after recording was started.*

2.3.7 Test 7 – Final release to empty tanker

The seventh test was conducted on Dec 13th, 2019. The test had a run time of 8 minutes. The outflow rate was only 9.7 kg/min (0.162 kg/s), which was lower than the other tests. The pressure in the LH_2-tanker was 0.8 barg. The pressure in the tanker was not raised prior to the release to achieve a higher outflow rate. The release orientation was changed back to vertical downward release, as for Test 1, 2, 3 and 5. The weather conditions for Test 7 are given in Table 2.8.

Table 2.8 Weather conditions Test 7.

Weather conditions	
Wind speed	6.5 ± 1.4 m/s
Wind direction	W (266 ± 11 deg)
Ambient temperature	3.2 °C
Weather	Heavy rain prior to and during test

The pad temperature measurements in Test 7 indicated that liquid hydrogen was observed on the ground 0.2 and 0.5 m from the release point. The lowest temperature measured on the concrete pad in Test 7 was -238.3 °C, measured at sensor TT_16, 0.2 m from the release point.

The field temperatures in Test 7 ranged from -0.2 to +3.3 °C. Generally, no very low temperatures were recorded in Test 7. The temperatures were slightly higher than those recorded in Test 1, which was also a vertical downwards release, but with slightly higher outflow rate than in Test 7.

The highest maximum H_2 concentrations in Test 7 were 2.2 to 2.7%vol, measured at sensors OC_10, OC_11 and OC_12, all located at the same position, but different heights, 30 m from the release point, in 22.5° angle east relative to the release/wind direction. The highest average H_2 concentrations in Test 7 were 0.8 to 0.9%vol, measured at the same sensors as the highest maximum H_2 concentration. The H_2 concentrations measured 50 and 100 m from the release point in Test 7 were ≤1.0%vol. The low concentrations are likely to be related to the low outflow rate. No flammable H_2 concentrations in the field were measured in Test 7.

3 Closed room and ventilation mast studies

This chapter gives an overview of the experimental setup, accomplishment and results from the closed room and ventilation mast leakage tests. The closed room leakage tests were conducted between January 13th and 17th, 2020. Totally 8 leakage tests were performed in the closed room. The tests were carried out in a test facility established at the DNV GL Spadeadam Research and Testing Centre in Cumbria, UK.

A detailed description of the test facility and measurement instrumentation for the closed room and ventilation mast studies is given in "Chapter 4 Experimental Arrangement", and "Appendix A: Experimental arrangement" and "Appendix B: Instrumentation" in the DNV GL Closed room and ventilation mast studies report (Medina et al., 2020b). A brief description of the test setup and measurements is given in Chapter 3.1.

An overview of the closed room and ventilation mast tests is given in Chapter 3.2. The conditions and test results for each test is described in Chapter 3.3. The results, which Chapter 3.3 is based on, are given in "Appendix B Results closed room and ventilation mast tests" of this report. The results are also given in "Appendix C Results" of the DNV GL Closed room and ventilation mast studies report (Medina et al., 2020b).

3.1 Experimental setup and measurements

Briefly, the test setup for the closed room and ventilation mast studies consisted of an enclosure intended to simulate a TCS connected to a ventilation mast. The volume of the enclosure was around 24 m^3, with internal dimensions H2260 x W2960 x D2690 mm. The ventilation mast had a horizontal length of 3 m, a 90 ° bend, and a vertical length of 10.025 m. The diameter of the ventilation mast was 450 mm. The TCS connected to the vent mast on the concrete test pad is shown in Figure 3.1 and Figure 3.2.

Figure 3.1 Test facility with enclosure connected to ventilation mast for the closed room leakage tests. The tripod in front was for the camera filming the experiments.

Figure 3.2 Experimental setup for the closed room and ventilation mast studies.

One side of the TCS was almost completely covered by a polyethylene sheet, as shown in Figure 3.3. The opening with polyethylene sheet covering was intended to simulate a vent panel, which can be found in TCS in reality. The dimensions of the opening was H1600 x W2300.

Figure 3.3 Polyethylene sheet cover seen from the outside and inside of the TCS.

Ambient conditions were recorded in each test. The measurements included wind speed and direction, ambient temperature and humidity. The wind speed and direction were measured with two sensors installed in a mast near the test pad, one sensor ("high") 10 meters above the ground and one sensor ("low") 5 meter above the ground. Only the average result for the "high" sensor is included in this report.

The release orientation in the closed room leakage tests was vertical downwards in all the tests, as shown in Figure 3.4. The initial release nozzle size was 1 inch, but was reduced to ½ inch in Test 10 and the following tests.

Figure 3.4 Vertical downward release orientation in closed room and ventilation mast tests.

The temperature and gas concentration was measured in the TCS and in the field. Inside the TCS, temperatures were recorded at points on the floor, at different heights and locations in the room, and in the ventilation mast. Fifthteen thermocouples (TT_01 to TT_15) were placed on the TCS floor, 10 thermocouples (TT_16 to TT_25) were placed in the TCS to record ambient temperature, and 3 thermocouples (TT_26 to TT_28) were placed in the ventilation mast. To measure gas concentration inside the TCS, 10 oxygen sensors (OC_31 to OC_40) were placed at different heights (0 to 2.26 m) and locations. The recordings from the oxygen sensors were translated to hydrogen concentration based on oxygen depletion.

The locations of the thermocouples and oxygen sensors in the TCS and ventilation mast are shown in Figure 3.5. Photos of the instrumentation inside the TCS is shown in Figure 3.6.

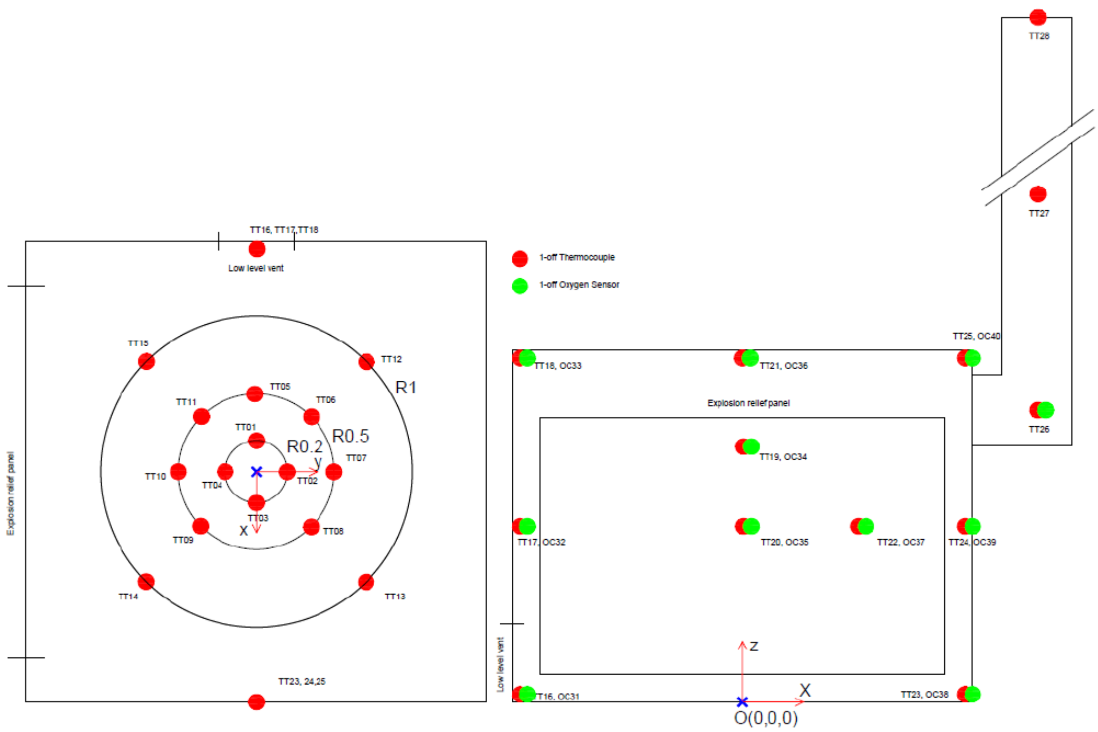


Figure 3.5 *Locations of thermocouples (red dots) and oxygen sensors (green dots). Floor of the TCS to the left. TCS connected to ventilation mast to the right. Blue cross indicate release point of LH_2.*

Figure 3.6 Inside the enclosure. Top left photo shows inlet of LH2 pipe into the closed room. The opening around the inlet was sealed in some of the tests. Top right photo shows the release pipe with release valve and by-pass valve (yellow boxes). The bottom left photo shows the thermocouples on the floor beneath the release point. The bottom right photo shows the vent opening and instrumentation (white boxes) with thermocouples and oxygen sensors. The opening to the vent mast was sealed in some of the tests.

The temperature was measured with 36 thermocouples (TT_49 to TT_80, and TT_85 to TT_88) in the field, at distances 30, 50 and 100 m from the release point, heights 0, 0.1, 1.0 and 1.8 m from the ground, and in different directions from the release point. Gas concentration was measured with 28 oxygen sensors (OC_01 to OC_24, and OC_28 to OC_30) at the same locations as the thermocouples, but only at 0.1, 1.0 and 1.8 m from the ground. In addition, 4 thermocouples (TT_81 to TT_84) and 3 oxygen sensors (OC_25 to OC_27) were placed near the low-level vent opening, where the LH_2-pipe entered the TCS. The locations of the thermocouples and oxygen sensors are shown in Figure 3.7.

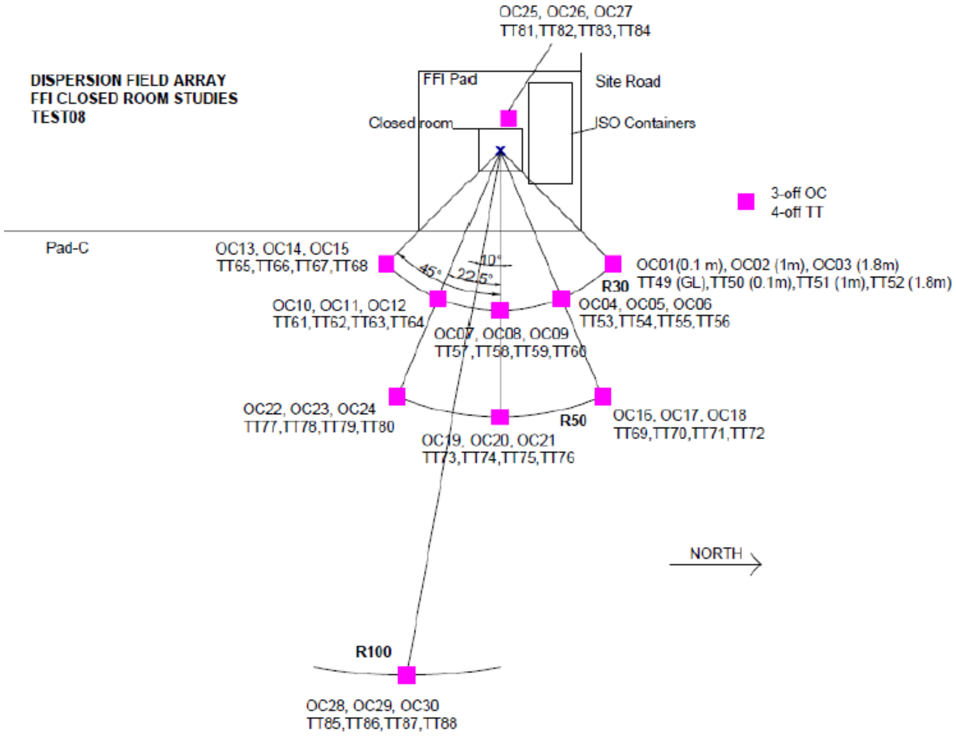


Figure 3.7 Locations of oxygen sensors and thermocouples in the field in Test 8. The oxygen sensors OC16-OC18, OC22-OC24 and OC28-OC30, and the temperature sensors TT6-TT72, TT77-TT80 and TT85-TT88 was moved after the first test in the TCS.

It was decided to move some of the thermocouples and oxygen sensors after the first test in the closed room. The thermocouples TT6-TT72, TT77-TT80 and TT85-TT88 and the oxygen sensors OC16-OC18, OC22-OC24 and OC28-OC30, were moved from the locations 50 and 100 m from the release point to locations in front of the ISO container. The locations of the thermocouples and oxygen sensors for Test 9 to Test 15 are shown in Figure 3.8.

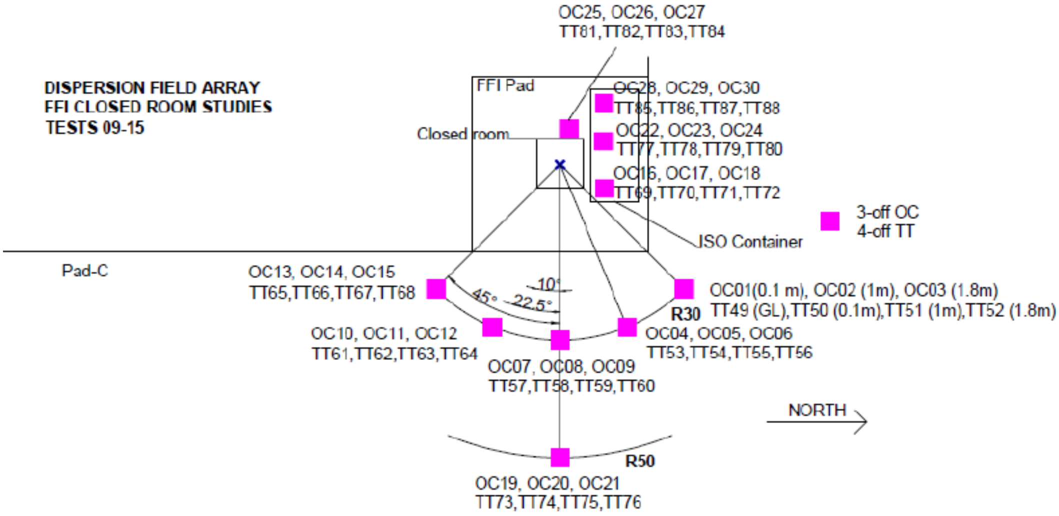


Figure 3.8 Locations of oxygen sensors and thermocouples in the field in Test 9 to Test 15.

3.2 Overview closed room and ventilation mast tests

Totally 8 leakage tests of LH_2 were performed in the closed room. The first five tests were release tests without ignition. Two of these tests included trials with nitrogen purge in the closed room. The last three tests included ignition. An overview of the tests is given in Table 3.1.

Table 3.1 Overview closed room leakage tests.

Test no.	Date and time	Initial tanker pressure (barg)	Outflow rate (kg/min)	Nozzle size (inch)	Ignition	Purge	Obstacles	Sealing	Run time (min)
8	01/13/20, 3.50 pm	1.5	11.0	1	No	Air	No	None	11
9	01/14/20, 3.32 pm	10	32.6	1	No	Air	No	None	11
10	01/15/20, 1.44 pm	10	28.6	½	No	Air	Yes	Low-level vent	10
11	01/16/20, 4.29 pm	10	31.3	½	No	Nitrogen	Yes	Low-level vent Opening to vent mast	9
12	01/16/20, 6.43 pm	10	35.5	½	No	Nitrogen	Yes	Low-level vent Opening to vent mast	5
13	01/16/20, 8.47 pm	10	40.1	½	Yes	Air	Yes	Low-level vent Opening to vent mast	3
14	01/17/20, 9.28 am	10	22.2	½	Yes	Air	Yes	None	2
15	01/17/20, 10.55 am	10	24.6	½	Yes	Air	Yes	Low-level vent Opening to vent mast	6

3.3 Test conditions and results

Chapters 3.3.1 to 3.3.8 give a brief description of the test conditions and results from the closed room and ventilation mast leakage tests. The results for TCS temperature (floor and ambient), vent mast temperature, field temperature and gas concentration (in field, near low-level vent and in TCS), are given. The full results, which this chapter is based on, are given in “Appendix B Results closed room and ventilation mast tests” of this report. The results are also given in “Appendix C Results” of the DNV GL Closed room and ventilation mast studies report (Medina et al., 2020b). The appendix also includes some other information, such as the pipe conditions, details about the wind speed and direction and box/vent flow. This information is not reviewed in this report.

3.3.1 Test 8 – Release without increasing tanker pressure

The first test in the closed room was conducted on Jan 13th, 2020. The test had a run time of 11 minutes. The outflow rate was 11.0 kg/min (0.183 kg/s). As for the outdoor leakage tests, the first test was conducted without increasing the pressure in the LH_2-tanker by the vaporizer. The tanker pressure was 1.5 barg. The weather conditions for Test 8 are given in Table 3.2.

Table 3.2 Weather conditions Test 8.

Weather conditions	
Wind speed	5.6 ± 3.0 m/s
Wind direction	S (176 ± 31 deg)
Ambient temperature	5.9 °C
Weather	Overcast, no rain

The lowest temperatures recorded on the floor of the TCS in Test 8 were -237 °C, at several points, all 0.2 m from the release point. The lowest ambient temperature measured in the TCS was -213 °C, on the floor, 1.48 m from the release point. The lowest temperature measured in the vent mast was -176 °C, at the lowest point of the vent mast (2.6 m). The temperature measured in the middle of the vent mast (6.25 m) was similar (-168 °C), while the temperature measured at the highest point of the vent mast (11 m) was slightly higher (149 °C).

No significant drop in the field temperature was recorded in Test 8. The field temperatures were similar to the ambient temperature given in Table 3.2. The results indicate that cold LH_2 did not spread far from the vent mast. Slightly lower temperatures (-1.9 to +3.8 °C) were measured outside the low-level vent opening, indicating some leakage of LH_2 through this opening.

The highest maximum H_2 concentration measured in the field in Test 8 was 0.1%vol. The results were in accordance with the temperature measurements, which did not indicate any spread of H_2 in the field. Slightly elevated H_2 concentration (max. 0.7%vol) was detected near the low-level vent opening. The results are in accordance with the temperature measurements, which also indicated leakage of LH_2 through the low-level vent opening. The H_2 concentration in the TCS during the release of LH_2 ranged from 47 to ~100%vol, with averages ranging from 67 to ~100 %vol. The TCS was saturated with H_2 within few seconds after the release of LH_2 into the TCS.

Photos of the inside of the TCS after completion of Test 8 are shown in Figure 3.9. Photos of the TCS from the outside are shown in Figure 3.10.

Figure 3.9 Inside of the TCS after completion of Test 8.

Figure 3.10 Outside the TCS after completion of Test 8.

3.3.2 Test 9 – Higher outflow rate

The second test in the closed room, Test 9, was conducted on Jan 14th, 2020. The test had a run time of 11 minutes. The outflow rate was 32.6 kg/min (0.530 kg/s), which was about three times higher than the first test in the closed room. The higher outflow rate was achieved by increasing the LH_2-tanker pressure to 10 barg. The nozzle size was 1 inch, similar to Test 8. The weather conditions for Test 9 are given in Table 3.3.

Table 3.3 Weather conditions Test 9.

Weather conditions	
Wind speed	2.8 ± 0.4 m/s
Wind direction	SSE (151 ± 8 deg)
Ambient temperature	2.8 °C
Weather	Overcast, light intermittent rain

The lowest temperatures measured on the TCS floor in Test 9 were -240 °C, at all the points 0.2 and 0.5 m from the release point. Slightly higher temperatures, ranging from -196 to -215 °C, were measured on the TCS floor 1.0 m from the release point. The lowest ambient temperatures measured in the TCS in Test 9 were -219 °C, at several measuring points. The lowest temperature measured in the vent mast was around -215 °C, about 35 °C lower than in Test 8. As opposed to Test 8, no significant temperature drop throughout the length of the vent mast was observed in Test 9.

Some of the oxygen sensors and thermocouples in the field were moved to positions in front of the ISO container in Test 9 and the following tests. The new positions are shown in Figure 3.8.

No drop in the field temperature was recorded in Test 9. As for Test 8, this indicated that cold H_2 did not spread far from the vent mast. A larger drop in the temperatures around the low-level vent opening was seen in Test 9 than in Test 8. The lowest temperatures measured near the low-level vent ranged from -15 to -91 °C. The larger drop in temperatures outside the low-level vent in Test 9 than in Test 8 is likely to be caused by the higher outflow rate in Test 9.

The highest maximum H_2 concentration measured in the field in Test 9 was 1.4%vol, measured close to the ISO container. The results were in accordance with the temperature measurements, which did not indicate spread of H_2 in the field. Maximum 66%vol H_2 was detected near the low-level vent outside the TCS. This shows how LH_2 spread from the TCS through this opening, which was also seen from the temperature measurements.

The H_2 concentration in the TCS during Test 9 was ~100%vol. The TCS was saturated with H_2 within few seconds after the release of LH_2 into the TCS.

As for Test 8, spread of LH_2 through the low-level vent was observed in Test 9. It was decided to make a few changes in the test setup for the following tests. The release nozzle size was reduced from 1 to ½ inch. The low-level vent opening was sealed to prevent spread of LH_2 through this opening.

A photo taken from the outside of the TCS shortly after completion of Test 9 is shown in Figure 3.11.

Figure 3.11 Photo of test site after completion of Test 9.

3.3.3 Test 10 – Sealing of low-level vent opening and obstacles in TCS

The third test in the closed room, Test 10, was conducted on Jan 15th, 2020. The test had a run time of 10 minutes. The outflow rate in Test 10 was 28.6 kg/min (0.477 kg/s), slightly lower than in Test 9. As for Test 9, the LH_2-tanker pressure was increased to 10 barg prior to the release of LH_2. In Test 10, and the following tests in the closed room, the release nozzle size was reduced from 1 to ½ inch. The weather conditions for Test 10 are given in Table 3.4.

Table 3.4 Weather conditions Test 10.

Weather conditions	
Wind speed	5.9 ± 1.9 m/s
Wind direction	WSW (239 ± 14 deg)
Ambient temperature	6.5 °C
Weather	Sunny intervals

In Test 10, and the following tests in the closed room, obstacles in form a pipe rack and three steel drums filled with water, were placed in the TCS. Photos of the obstacles are shown in Figure 3.12.

Figure 3.12 Obstacles in form a pipe rack and three steel drums filled with water in TCS.

To make the closed room tighter, the low-level vent opening around the inlet of LH_2 was sealed, as shown in Figure 3.13.

Figure 3.13 Sealing to make TCS tight. Blue stand with white boxes to the left shows the thermocouples and oxygen sensors.

The lowest temperatures on the floor of the TCS in Test 10 were around -240 °C, recorded 0.2 and 0.5 m from the release point. The temperatures measured 1.0 m from the release point were slightly higher, ranging from -200 to -210 °C. The lowest ambient temperature measured in the

TCS in Test 10 was -217 °C, similar to the prior tests. The lowest temperature recorded in the vent mast was -212 °C, similar to Test 9. The lowest temperatures measured in the barrels were -121, -137 and -214 °C.

As for the previous tests, no drop in the field temperature was recorded in Test 10. The lowest temperature measured around the low-level vent opening was -6 °C, significantly higher than the temperatures around the low-level vent opening measured in Test 8 and 9. The results shows how the sealing around the LH_2-pipe was efficient for preventing leakage of LH_2 from the TCS.

The highest maximum concentration of H_2 measured in the field was 3.9%vol, at sensor OC_16, in front of the ISO container, 13.84 m from the release point. The “high” H_2 concentrations were only recorded for a short moment. The average H_2 concentration measured in the field during Test 10 was ≤0%vol for all measuring points. Maximum 8.4%vol H_2 was measured outside the low-level vent opening. The concentration was significantly lower than the highest H_2 concentration measured outside the low-level vent opening in Test 9 and 10. The results show that the sealing was not completely tight, and leakage of H_2 may occur through small openings. The H_2 concentration in the TCS in Test 10 reached 100%vol shortly after the release of LH_2 was started, similar to Test 8 and 9.

The temperatures and H_2 concentrations measured in the TCS and the field (apart from the measurements outside the low-level vent opening) were similar in Test 10 and Test 9. Test 9 had a similar (slightly higher) LH_2 outflow rate, larger nozzle size and no obstacles in TCS. Photos of the outside and inside of the TCS after completion of Test 10 are shown in Figure 3.14.

Figure 3.14 Outside and inside of TCS after completion of Test 10.

3.3.4 Test 11 – Nitrogen purge followed by LH_2 release

The fourth test in the closed room, Test 11, was conducted on Jan 16th, 2020. The test had a run time of 9 minutes. The outflow rate was 31.3 kg/min (0.522 kg/s), similar to Test 9 and 10. The LH_2-tanker pressure was increased to 10 barg prior to the release. The nozzle size was ½ inch, similar to Test 10. The weather conditions for Test 11 are given in Table 2.5.

Table 3.5 Weather conditions Test 11.

Weather conditions	
Wind speed	2.6 ± 1.2 m/s
Wind direction	S (187 ± 53 deg)
Ambient temperature	8.6 °C
Weather	Overcast with intermittent rain

In Test 11, the TCS was purged with nitrogen before LH_2 was released into the closed room. After the release of LH_2 was stopped, nitrogen was again purged into the TCS. As for Test 10, the opening around the LH_2 pipe inlet was kept sealed in Test 11. To be able to saturate the TCS with nitrogen, additional foam sealing was used around the existing sealing of the low-level vent in Test 11. In addition to this, a sealing was placed at the opening to the vent mast. This sealing was connected to a device, which allowed for it to be removed from the control room when desired. The sealing of the opening to the vent mast and additional foam sealing around the low-level vent sealing are shown in Figure 3.15.

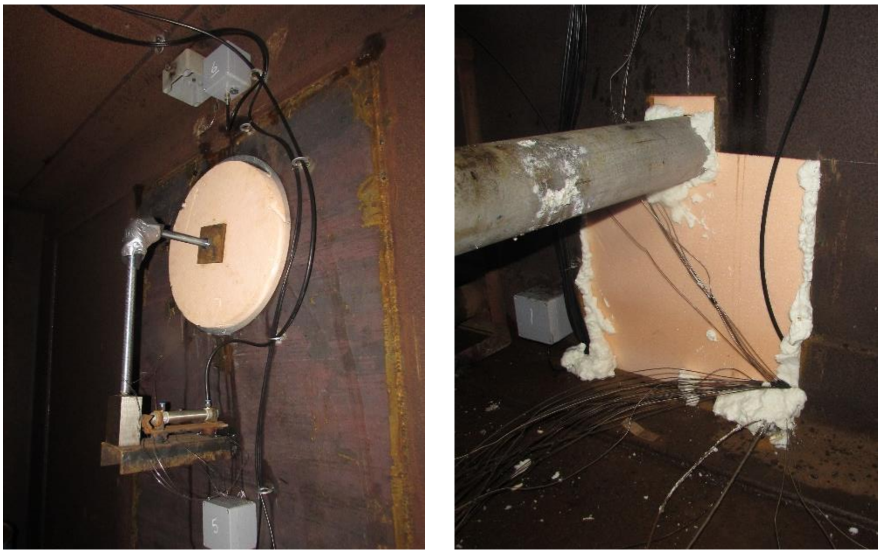


Figure 3.15 Sealing of opening to vent mast to the left. The sealing was connected to a device, which allowed for removal of the sealing from the control room when desired. Additional foam sealing of lower vent opening to the right.

Temperatures around -240 °C were measured at several points, 0.2 and 0.5 m from the release point, on the TCS floor during the release of LH_2 in Test 11. The lowest ambient temperature measured in the TCS was -220 °C. The lowest temperatures in the vent mast ranged from -212 to -195 °C, with the lowest temperature measured closest to the TCS. The lowest temperatures in the barrels were -77, -140 and -220 °C. The temperature difference between the different barrels was greater in Test 11 than in Test 10.

As for the previous tests, no significant drop in the field temperature was recorded in Test 11. The lowest temperature was measured near the low-level vent and was -1.4 °C. Maximum 0.8%vol H_2 was detected in the field measurements in Test 11, in front of the ISO container. The highest H_2 concentration measured outside the low-level vent was 7.2%vol H_2, similar to the concentration measured in Test 10. The increase in H_2 concentration outside the low-level vent in Test 11 only occurred for a short duration around 400 seconds into the release. The slightly elevated H_2 concentration in front of the ISO container was also measured around 400 seconds into the release. The average H_2 concentration measured in the field during Test 10 was

≤0.1%vol, for all measuring points. The oxygen sensors within the TCS were used to confirm the nitrogen purge and no measurements of H_2 concentration in the TCS were done for Test 11.

The polyethylene sheet cover of the TCS tore when LH_2 was released into the closed room filled with N_2. It was decided to apply a double layer of polyethylene to attempt to avoid tearing.

Figure 3.16 The polyethylene sheet ripped when LH_2 was released into the TCS purged with N_2 in Test 11.

3.3.5 Test 12 – LH_2 release followed by nitrogen purge

The fifth test in the closed room, Test 12, was conducted on Jan 16th, 2020. The test had a run time of 5 minutes. The outflow rate was 35.5 kg/min (0.592 kg/s), slightly higher than Test 9, 10 and 11. The pressure in the LH_2-tanker was increased to 10 barg prior to the release of LH_2. The nozzle size was ½ inch, similar as for Test 10, 11 and 12. The weather conditions for Test 12 are given in Table 3.6.

Table 3.6 Weather conditions Test 12.

Weather conditions	
Wind speed	2.7 ± 1.4 m/s
Wind direction	SSW (203 ± 53 deg)
Ambient temperature	8.6 °C
Weather	Overcast with intermittent rain

As for Test 11, the area around the inlet of LH_2 was kept sealed to make the TCS tight. To prevent shearing, a double layer of polyethylene was applied to seal the vent opening. In Test 12, N_2 was purged into the TCS after the TCS was saturated with H_2 from the release of LH_2. Test 12 was a repetition of Test 11, but with an initial LH_2 release into TCS with air atmosphere followed by a nitrogen purge, as opposed to Test 11, which had an initial nitrogen purge into TCS followed by a LH_2 release.

The lowest temperatures on the floor of the TCS in Test 12 were around -240 °C, recorded at several points 0.2 and 0.5 m from the release point. The lowest ambient temperatures in the TCS ranged from -108 to -219 °C. The lowest temperatures in the vent mast ranged from -213 to -193 °C, with the lowest temperature measured closest to the TCS. The temperatures in the TCS and vent mast in Test 12 were similar to those measured in Test 11. The lowest temperatures in the barrels were -120, -151 and -196 °C.

As for the other closed room tests, no drop in the field temperatures was recorded in Test 12. The temperatures measured around the low-level vent were only slightly lower than the ambient temperature. This differed somewhat from Test 11, where a slightly larger drop in the temperature outside the low-level vent was observed.

The highest maximum H_2 concentration detected in the field in Test 12 was 1.0%vol. The maximum H_2 concentrations outside the low-level vent ranged from 0.2 to 0.8%vol. The results support the temperature measurements, which indicated no leakage of H_2 through the low-level vent in Test 12. As for Test 11, the oxygen sensors in the TCS were used to confirm the N_2 purge. No measurements of H_2 in the TCS were done for Test 12.

The release of LH_2 into the TCS was stopped after 5 minutes and the nitrogen purge was initiated. Shortly after the nitrogen purge was initiated, the polyethylene sheet covering sheared, which caused the temperature in the TCS and vent mast to rise quickly. Photos of the TCS with the sheared double polyethylene sheet are shown in Figure 3.17.

Figure 3.17 Photos of TCS after completion of Test 12. The double polyethylene sheet sheared when nitrogen was purged into the TCS saturated with H_2.

3.3.6 Test 13 – First ignited test, TCS sealed

The sixth test in the closed room, Test 13, was conducted on Jan 16th, 2020. The release of LH_2 into the TCS lasted for 3 minutes. After the release was stopped, ignition was initiated. The outflow rate was 40.1 kg/min (0.673 kg/s), slightly higher than in Test 9, 10, 11 and 12. The LH_2-tanker pressure was increased to 10 barg prior to the release of LH_2. The nozzle size was ½ inch, similar as for Test 10, 11 and 12. The weather conditions for Test 13 are given in Table 3.7.

Table 3.7 Weather conditions Test 13.

Weather conditions	
Wind speed	5.0 ± 1.6 m/s
Wind direction	WSW (247 ± 13 deg)
Ambient temperature	6.4 °C
Weather	Overcast with intermittent rain

The TCS was sealed prior to the release of LH_2 into the room in Test 13. The sealing of the low-level vent is shown in Figure 3.18. A thin polystyrene sheet was installed between the two polyethylene sheets to prevent tearing during the release.

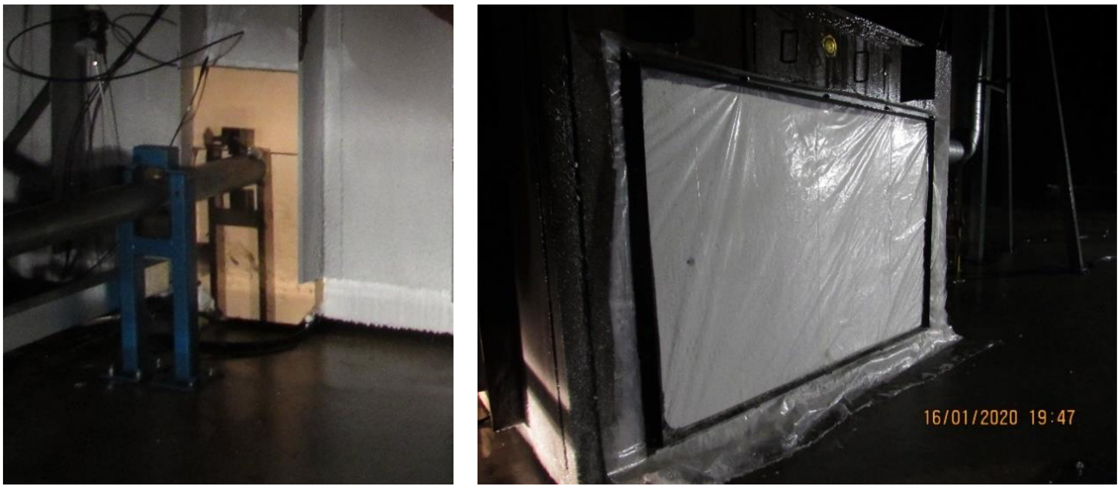


Figure 3.18 Sealing of low-level vent around inlet of LH_2 (left photo) in Test 13. Sealing of vent panel with a double layer of polyethylene with a polystyrene sheet between to the right.

The lowest temperatures measured on the floor of the TCS in Test 13 were around -240 °C, recorded at several measuring point 0.2 and 0.5 m from the release point. The lowest ambient temperatures in the TCS in Test 13 ranged from -67 to -203 °C. The lowest temperatures measured in the barrels in the TCS ranged from -98 to -127 °C. The lowest temperatures in the vent mast ranged from -193 to -148 °C, with the lowest temperature measured closest to the TCS.

As for the previous leakage tests in the closed room, no drop in the field temperatures was recorded during the release of LH_2 in Test 13. The temperatures measured outside the low-level vent were also similar to the ambient temperature. Maximum 0.4%vol H_2 was detected in the field measurements, at sensor OC_24, close to the ISO container, 11.51 m from the release point. The H_2 concentration in the TCS reached close to 100%vol few seconds after the release of LH_2 into the room.

After the release of LH_2 was stopped, ignition was initiated at the top of the vent mast. The positions of the ignition devices at top of the vent mast are shown in Figure 3.19.

Figure 3.19 Location of ignition devices on top of the vent mast.

The TCS was saturated with H_2 at the time of ignition. The H_2 concentration in the TCS decreased gradually for about 28 minutes before an explosion occurred in the TCS. The H_2 concentration in the TCS at the time of explosion ranged from 50 to 80%vol. The temperature in the vent mast at the sensor closest to the TCS (TT_26) raised from -193 °C, at the time when the LH_2-release was stopped, to 400 °C at the time when the explosion occurred. The flame was "stuck" in the 90 ° bend of the mast for some time before it reached the TCS.

The internal overpressure in the TCS during the explosion in Test 13 was <150 mBar (Appendix C.06 in DNV GL Closed room and ventilation mast studies report (Medina et al., 2020b).

It took a long time before the concentration of H_2 in TCS was low enough to allow an explosion to occur. The slow decay in the H_2 concentration is likely to be due to the sealing of the TCS, which prevented airflow through the closed room. It was decided to perform another ignited test where the sealing at the low-level vent was removed in order to increase the airflow through the TCS.

The damage from the burning flame in the bend can be seen at the photo to the bottom right in Figure 3.20.

Figure 3.20 Photos of the TCS and vent mast after completion of Test 13.

3.3.7 Test 14 – Second ignited test, TCS not sealed

The seventh test in the closed room, Test 14, was conducted on Jan 17th, 2020. The release of LH_2 into the TCS lasted for 2 minutes, followed by ignition. The outflow rate of LH_2 into the TCS was 22.2 kg/min (0.370 kg/s), about half of that of Test 13. The pressure in the LH_2-tanker was 10 barg prior to the release of LH_2. The nozzle size was ½ inch, similar as for Test 10, 11, 12 and 13. The weather conditions for Test 14 are given in Table 3.8.

Table 3.8 Weather conditions Test 14.

Weather conditions	
Wind speed	2.6 ± 0.6 m/s
Wind direction	W (259 ± 13 deg)
Ambient temperature	3.2 °C
Weather	Mainly overcast (wet ground)

The sealing of the low-level vent for the inlet of the LH_2-pipe was removed prior to the release of LH_2 into the TCS in Test 14, as shown in Figure 3.21. As for Test 13, a thin polystyrene sheet was installed between the two polyethylene sheets to prevent tearing during the release.

Figure 3.21 Removal of sealing around inlet of LH_2 (left photo) in Test14. Sealing of vent panel with a double layer of polyethylene with a polystyrene sheet between to the right.

The lowest temperatures measured on the TCS floor during the release of LH2 in Test 14 ranged from -224 to -238 °C for the measuring points 0.2 m from the release point. No temperatures below -201 °C were detected further than 0.2 m from the release point. The lowest ambient temperature in the TCS and the lowest temperature in the vent mast recorded during Test 14 was around -150 °C.

As for the previous leakage tests in the TCS, no drop in the field temperatures was recorded during the release of LH2 in Test 14. Outside the low-level vent, the lowest temperature measured was -22.6 °C, indicating leakage through this opening. Maximum 0.7%vol H_2 was detected in the field measurements during the release of LH_2. The highest concentration was measured at sensor OC_17, outside the ISO container, 13.84 m from the release point. Maximum 23.9%vol H_2 was detected near the low-level vent.

Ignition was initiated at the top of the vent mast after the release of LH_2 was stopped, about 120 seconds into the experiment. The positions of the ignition devices at the top of the vent mast were similar as for Test 13, shown in Figure 3.19. The TCS was saturated with H_2 at the time of ignition. The temperature in the vent mast raised quickly (<15 seconds) from around -150 to +400 °C after ignition was initiated, followed by an explosion in the TCS.

The explosion in Test 14 occurred almost immediately after the ignition, as opposed to Test 13 where it took around 30 minutes for the flame to reach from the top of the vent mast to the TCS. The different patterns are likely to be related to the increased ventilation in Test 14 due to removal of the sealing at the low-level vent. The explosion in Test 14 appeared stronger than in Test 13. This is supported by the measurements of overpressure. The internal overpressure in the TCS during the explosion in Test 14 was >2 bar, significantly higher than in Test 13 (Appendix C.07 in DNV GL Closed room and ventilation mast studies report (Medina et al., 2020b). Parts of the vent mast and floor of the TCS were destroyed in Test 14. Photos of the TCS and vent mast after completion of Test 14 are shown in Figure 3.22.

Figure 3.22 TCS and vent mast after completion of Test 14.

3.3.8 Test 15 – Final ignited test, attempt of a worst-case scenario explosion

The final test in the closed room, Test 15, was conducted on Jan 17th 2020. The vent mast and some of the instrumentation were destroyed in Test 14. Test 15 was performed with focus on the explosion event. The opening to the vent mast and the opening around the lower vent inlet were sealed off, making the TCS as tight as possible (no photos available). The release rate of LH_2 into the closed room was 24.6 kg/min (0.410 kg/s). The aim of the test was to initiate ignition when the concentration of H_2 in the room corresponded to a worst-case scenario, i.e. 30%vol H_2. The weather conditions for Test 15 are given in Table 3.9.

Table 3.9 Weather conditions Test 15.

Weather conditions	
Wind speed	2.3 ± 0.6 m/s
Wind direction	WSW (238 ± 11 deg)
Ambient temperature	3.2 °C
Weather	Mainly overcast (wet ground)

In Test 15, LH_2 was first released into the TCS for 3 minutes. The decay of H_2 in the TCS occurred quickly and no ignition was initiated. The release of LH_2 was restarted and kept for another 3 minutes. Following the second release, the decay in H_2 concentration within the TCS was monitored at a point close to the ignitor. The decay in H_2 concentration after the second release occurred very slowly. It was decided to ignite when the H_2 concentration was around 50%vol.

The lowest temperatures measured on the TCS floor during the release of LH_2 was -245 °C, 0.2 m from the release point. The lowest ambient temperature in the TCS measured during Test 15 was around -140 °C. No measurements were done in the vent mast in Test 15.

As for the previous leakage tests in the TCS, no drop in the field temperatures was recorded during the release of LH_2 in Test 15. The lowest temperature measured outside the low-level vent was -84 °C. Maximum 1.5%vol H_2 was detected in the field measurements during the release of LH_2, outside the ISO container, 13.84 m from the release point. Maximum 40.8%vol H_2 was detected near the low-level vent. The results were similar to the results in Test 9, which also was conducted without sealing of the low-level vent.

Photos of the TCS after completion of Test 15 is shown in Figure 3.23. The polyethylene sheet ripped when the gas was ignited. The photo is taken after the sealing of the openings was removed.

Figure 3.23 TCS after completion of Test 15. The vent mast on the photo to the right is lying on the ground after it was destroyed in the prior test. The vent mast is not connected to the TCS.

4 Discussion

The authors acknowledge that there is a vast number of analysis and conclusions that can be drawn from the results. Hence, this report does not represent an exhaustive list of conclusions, but focus on the areas of interest listed under objectives that were raised by the stakeholders.

4.1 Outdoor leakage studies

4.1.1 Formation of a liquid pool caused by leakage of LH_2

Probabilistic risk analysis helps to identify and classify conceivable accident scenarios covering the whole path from the release of hydrogen via propagation of the evolving gas cloud and its potential explosion, to an assessment of the consequences for the environment. Hence, the formation and propagation of a liquid pool caused by a LH_2 spill is of interest to stakeholders. The release of liquid hydrogen in contact with a concrete surface can give rise to pooling of liquid once the substrate is sufficiently cooled (Klebanoff et al., 2016). One of the objectives of the outdoor leakage tests was to provide information about formation, including, propagation and duration, of a liquid pool caused by leakage of LH_2.

Temperatures representative of the dew point/boiling point of hydrogen that was observed on the surface of the concrete indicated that a liquid pool was formed in the tests, which used a vertical downward release orientation. Interpretation of the video footage of the releases was challenging due to condensation of large volumes of water vapor, in and around the release, obscuring the region of the release and forming a visible plume. The liquid pool could not be verified by visual inspection due to formation of fog on the test site. No temperature measurements representative of the hydrogen dew point were observed further than 0.5 m from the release point in any of the tests with a vertical downward release orientation. In the cases of a horizontal release orientation, there were no signs of formation of a liquid pool on the ground, in any of the tests.

There were no signs indicating that the pool of liquid hydrogen remained after the end of the release in any of the tests. Anyway, such a pool would be thin and likely to evaporate almost instantly after the release is stopped. Comparison of the sub-surface temperature-time history in the concrete using simple models supports the presence of liquid hydrogen at the surface. The temperature in the concrete decayed slightly faster than the model predicts for a liquid pool at the surface, but uncertainties in the properties of the concrete could account for these differences. The heat transfer rate would be significantly lower if only cold vapor was present at the concrete surface.

Large-scale deflagration and detonation experiments of hydrogen and air mixtures provide fundamental data needed to address accident scenarios and to help in the evaluation and validation of numerical models.

It was also an objective of the outdoor leakage studies to investigate if the leakage of LH_2 caused condensation or freezing of components in air. Indications of the presence of liquid or solid constituents of air were observed at a maximum of 1 m from the release point on the concrete surface. Similar results were obtained from the leakage tests in the closed room.

The observations are in line with the current understanding of pool formation as explained by e.g. Verfondern and Dienhart, 2007. It should be noted that differences have been observed for the vaporization behavior on dry and wet concrete. The vaporization time is significantly reduced if moisture is present in the ground due to a change of the ice/water properties and the liberation of the solidification enthalpy during ice formation, representing an additional heat source in the ground (Verfonden and Dienhart, 2007). In 1994, the BAM, Germany, conducted small-scale LH_2 release trials (300-350 L/min). After contact of the LH_2 with water surface, a closed pool was formed, clearly visible and hardly covered by the white cloud of condensed water vapor. The “equilibrium” pool radius did not remain constant, but moved forward and backward within the range of 0.4–0.6 m away from the center for the lowest release rate, and 0.3–0.5 m for the highest release rate.

The consequence of the cryogenic spill on substrates like shipbuilding steel substrates seems to be minor, and less than for spills with LNG (Klebanoff et al., 2017). Even the effect of spilling the entire 1200 kg LH_2 fuel complement onto the top deck of the vessel SF-Breeze was shown to be of minor concern (Klebanoff et al., 2017).

4.1.2 Hydrogen concentration within the gas cloud

Hydrogen has a very broad flammability range; 4%vol to 74%vol concentration in air and 4 to 94 percent in oxygen. Hence, keeping air or oxygen from mixing with hydrogen inside confined spaces is very important. Also, it requires only 0.02 mJ of energy to ignite the hydrogen–air mixture, which is less than 7 percent of the energy needed to ignite natural gas. It is therefore important to investigate the distribution of flammable concentration of hydrogen from a spill/leakage. Previous large-scale LH_2 experimental studies did not provide comprehensive information regarding the flow field, and the numerical studies have paid little attention to the dispersion behavior of the plume. Conditions and configuration of the leakage determine the features of the evolving vapor cloud such as cloud composition, release height, initial plume distribution, time-dependent dimensions, or energy balance (Verfonden and Dienhart, 2007).

From the measurements collected from the deployed instruments, the lower flammability limit for hydrogen in air was not exceeded at 50 m from the release point in any of the vertically downwards releases. All measurements were made near the ground level (0.1 to 1.8 m from the ground) so this observation is not exhaustive in that the maximum concentration may exist further from the ground level. Hydrogen, being the lightest existing gas, is more buoyant than air at NTP conditions (293.15 K, 1 atm pressure). However, the low temperature of the gas counteracts the buoyancy. For smaller leaks, hydrogen only needs to heated by a couple of Kelvin in order to be more buoyant than air (Klebanoff et al., 2017). In the current case with low ambient temperature and a relatively large leakage, it will take more time for the gas to be more buoyant than air. This explains why all plumes from the tests appeared of near-neutral buoyancy with no significant lift-off of the visible plume observed in the experiments. This means that flammable concentrations of hydrogen can be transported far away near the ground in the case of wind. In one of the tests, the lower flammability limit was exceeded 50 m from the release point in the case with a horizontal release, but not 100 m from the release point. At 30 meters from the release point, lower concentrations were measured 1.8 m off the ground than 0.1 m off the ground. Results from numerical modelling suggests that a plume with flammable concentrations might exist up to 23 m above the ground when the hydrogen outlet was set at 285 kg/min (at 19.5 K) for 38 s (net liquid phase) (Pu et al., 2919). Flammable concentrations were measured at 22.5° angle from the wind direction at 30 m from the release point, but not at 45° angle, indicating that with the presence of wind, flammable concentrations spread in a narrow space in front of the release point. The hydrogen concentration in the field was observed to be nearly linearly related to the drop in temperature, as might be expected by intuition. The containers that were meant to simulate the vessel played a minor part since the wind direction was not towards them in any of the tests. If this had been the case, higher concentrations in the area in front of the containers is expected due to confinement of the hydrogen. Increased turbulence may enhance the risk even further. The wind direction should be something to consider when performing a bunkering operation in order to avoid flammable concentrations in the case of an accidental spill. Less turbulence is observed at smooth edged obstacles (Xiaoa and Oran, 2020). This is something to consider when designing the shape of the vessel.

4.1.3 Ignition of the gas cloud

In the current tests, no spontaneous ignition was observed. Although spontaneous ignition has been observed for large scale releases (Groethe et al., 2007), it seem to require a sufficiently high pressure boundary between the compressed gaseous fuel and surrounding (lower pressure) air. This can result in a shock wave that can rapidly mix and heat fuel and oxygen, leading to ignition and flame propagation fed by the continuing fuel release (Klebanoff et al., 2017). Hence, spontaneous ignition seems solely to be a concern for high pressure) hydrogen systems (>350 barg), while the tanker pressure in the test was at maximum 10 barg spontaneous ignition was not expected to come into play.

It was of interest to observe any burning, deflagration or detonation of gas cloud when ignited, and energy/pressure from any blast. Ignition of the gas was obtained by igniting fireworks 18 m (Test 5) and 30 m (Test 6) from the release point. There are three phenomena that can follow from ignition of hydrogen; fire, deflagration and detonation. Fire is the term for ordinary combustion, familiar in everyday life where the flame propagates through the unburned fuel/air mix at low speeds (~20 m/s or less). Deflagration is fast combustion where the flame propagates through unburned fuel/air mix rapidly, but at subsonic speeds (~100 to 400 m/s). Detonation is the more properly defined term for extremely fast combustion events where the flame propagates through the unburned fuel/air mix at supersonic speeds (>700 m/s) (Klebanoff et al., 2017). Whilst the measurements in the current study were discrete, nothing about the shape of the pressure time histories indicated that any fast deflagration or detonation occurred anywhere or at any time in either ignited event.

After the initial fireball, the thermal radiation from the ignited experiments trended as expected (i.e. falling thermal radiation with the square of the distance from the source). Some burning of plastic obstacles (e.g. barrel) needs to be accounted for when interpreting the results from the vertically downwards release in Test 5. The fraction of the heat radiated (Fr) from the fire appears higher in Test 5 than in Test 6 and is likely significantly influenced by the burning barrel.

The horizontal release in Test 6 showed lower fraction of the heat energy being radiated using the same point source approximation for most sensors. Two sensors showing higher Fr might be explained by the direction of the jet being directed closer to these sensors by the ambient wind.

Harm from thermal radiation needs to consider the time-based dose, which is received by the person involved. This means that response and escape times need to be considered alongside the thermal radiation levels when assessing consequence. Distances to long-term tolerable levels of 1 to 2 kW/m^2 in the downwards release was beyond the maximum distance that sensors were deployed. Nominal extrapolation of the r^2 relationship indicates that these low thermal thresholds are in the region of 30 m from the release.

Comparison of observed thermal field with a point source assumption for Fr of 5-10% is what might be expected from a ~700 g/s hydrocarbon fire. The results in Test 6 seem to support the assertion that the thermal radiation properties of the hydrogen flames observed in these experiments can be replicated using point source approximation of the flame and general Fr factors as would be used for hydrocarbon fires (i.e. based on mass flow).

Steel calorimeter blocks within the fire suggest a maximum total heat flux (convective and radiative) within the fire of 300 kW/m^2 by interpretation of the rate of change of temperature within the block. For all scenarios investigated, the highest observed peak overpressure was between 28 and 30 mbar in the ignited horizontal release (Test 6). In the downwards orientation, the maximum observed overpressure in the ignition event was lower than 15 mbar. The results from the tests correlated well with the CFD-approach suggested by Hansen, 2020 (ref?).

4.2 Closed room and ventilation mast studies

The closed room and ventilation mast studies were intended to simulate spill in tank connection space (TCS) connected to a ventilation mast. The accidental release of hydrogen in a confined environment differs from the open atmosphere and semi-confined cases in the fact that the leakage is located in a room. The released hydrogen mixes with the room atmosphere, the hydrogen-air mixture builds up in the room or disperses outwards through venting holes. For leaks involving LH_2, vaporization of cold hydrogen vapor towards the atmosphere causes moisture condensation forming a fog. This vaporization process usually occurs rapidly, forming a flammable mixture (BHRS, 2020).

Outflow rates between 11 and 40 kg/min were achieved using variations of release orifice diameter and starting pressure in the bulk tanker the liquid hydrogen was supplied in.

4.2.1 Concentration of H_2 in TCS

One of the objectives of the leakage tests in the closed room was to provide information about the concentration of H_2 in the TCS due to leakage of LH_2. In all the leakage tests in the closed room, the temperature and gas accumulation measurements in the closed room support an assertion of a near 100%vol hydrogen concentration build-up within ~ 30 seconds from the onset of the release. The concentration throughout the room remain high for the duration of the release. Shortly after the end of the release, flammable concentrations are measured in the box. Reliable decay data are however not available, because the polyethylene film covering of the explosion relief panel became brittle because of the low temperature and burst before the completion of the tests.

4.2.2 Pressure build-up in TCS due to evaporation of LH_2

The tests were not designed to measure pressure build-up in the TCS since the box was not completely tight. The TCS was vented to the atmosphere through both the low-level vent and the ventilation mast during the entire release in some of the tests (Test 8 and Test 9). One or both of the openings were sealed in some of the tests (Test 10, 11 and 12), but there was still some signs of leakage through the openings. None of the experiments showed evidence of any significant pressure increase in the TCS due to the release and evaporation of liquid hydrogen. The fluctuations of the box pressure were on the order of a few millibars, which we consider to be negible.

4.2.3 Flow rate of H_2 out of ventilation mast

The flow rate of H_2 out of the vent mast was another objective of the leakage tests in cold room. The flow rate of H2 out of the vent mast was not measured directly, but estimated based on the supply rate. Assuming 100%vol hydrogen in the TCS, the mass flow out of the vent mast was between 0.180 kg/s and 0.673 kg/s. In some of the tests, the box was also vented at a point near to the ground, hence the numbers represent maximal values.

4.2.4 Spread of H_2, especially downwards, from the ventilation mast

In none of the tests, flammable concentrations of hydrogen were measured in the field. The oxygen sensors deployed near to ground level in the field (0 to 1.8 m from the ground) recorded only short duration, low concentration hydrogen peaks. With a moderately strong wind, concentrations below 0.5%vol were observed in a 30 m radius from the release point, with some trace amounts below 0.1%vol observed at 50 m from the release point in the closed room. Hydrogen was not detected near ground level 100 m from the release point in closed room in any of the experiments.

Hydrogen concentrations on top of a pair of ISO containers set to the north of the vent mast detected up to 1.0%vol hydrogen in short periods in experiments conducted in a southerly wind direction. Near to the low-level vent of the closed room, higher (flammable) concentrations of hydrogen were observed, sometimes as high as 60%vol, but only for short durations.

Temperature measurements in the field support the observations above. No significant or obvious temperature fluctuations were recorded in the field near to ground level in any experiment, except close to the low-level vent on the side of the TCS. In some cases, the plume was observed to migrate below the top of the vent mast. The almost neutral buoyancy of the plume observed in the outdoor tests could explain why the concentrations measured on the ground were low.

4.2.5 Clogging of ventilation mast

Clogging of the ventilation mast due to solidification of moisture in the atmosphere is a safety concern and it was of interest to investigate if releases of LH_2 into the closed room could cause clogging of the vent mast. No clogging of the vent mast due to solidification of moisture in the atmosphere was observed in any of the tests. Clogging of the vent mast would lead to pressure build-up in the TCS. This was not observed. Deposition of some frost on the outer surface of the vent mast was observed, indicating freezing of components in the air outside the vent mast.

4.2.6 Unwanted inflow of oxygen into TCS

A question raised by the stakeholders regarded whether freezing of components within the TCS could create a negative pressure that would lead to unwanted inflow of oxygen from the ambient air. The low variations in the pressure within the TCS during the release does not point in this direction. The saturation by hydrogen during the release also support that unwanted inflow of oxygen is not an issue. However, when the release stops and hydrogen is ventilated through the mast, hydrogen will be replaced by air diluting the hydrogen gas. In the ignited tests, oxygen is drawn through the vent mast due to a burn back effect.

4.2.7 Effects on the TCS structure due to leakage of LH_2

Evidence of liquid or frozen air components on the surface of the enclosure floor remained for long periods after the release was stopped. No evidence of liquid hydrogen remained in the TCS 30-40 seconds after the release was stopped. In all the tests, the maximum extent of liquid hydrogen (evidenced by temperature measurements) on the steel floor of the closed room was 1.0 m from the release point, with 0.5 m being the general observation. No visual damage was observed on the steel floor due to the cryogenic effects of hydrogen. Liquid hydrogen has a very low vaporization enthalpy of 0.92 kJ/mol, causing less cooling of a substrate than LNG (Klebanoff et. al. 2016).

4.2.8 Explosion resulting from ignition after leakage of LH_2 in TCS

Electrostatic charges can occur when mechanical separation or abrasion of similar or different substances takes place. It can also occur when a gas, containing droplets or dust particles, flows past the surface of a solid, for example, valve openings, hoses or pipe connections. If accumulated, electric charges are suddenly released, the resulting electric spark can be sufficiently strong to ignite hydrogen (BRHS, 2020). This is a concern with regards to leakage of liquid hydrogen in TCS. No spontaneous ignition was observed in any of the leakage tests in the closed room. In two of the tests (Test 13 and 14), ignition was initiated at the top of the vent mast.

In the first ignited experiment, the low-level vent was sealed and not available for significant air ingress. After ignition at the top of the mast was initiated, the release was isolated and it took around 30 minutes before a low severity explosion event occurred in the closed room. This happened due to a burn back effect where oxygen is sucked through the vent mast following the combustion front. The TCS should be as air tight as possible and should contain detectors that can discover a leakage quickly. Purging the hydrogen out the vent mast after a leakage is stopped, e.g. with nitrogen, can keep the hydrogen from mixing with air to reach flammable concentrations.

The second ignited experiment had the low-level vent left open for air ingress. In this experiment, only 10-15 seconds elapsed between ignition at the top of the mast (plus release isolation) and a severe explosion event (~2 bar overpressure).

5 Conclusions

The objectives of the current tests was to contribute to the understanding of the behaviour of LH_2 for safe introduction of LH_2 as a fuel in the marine sector.

To simulate spill of LH_2 from a bunkering operation, large-scale outdoor releases of LH_2 were performed. The objectives of the outdoor leakage tests were to provide information about formation of a liquid pool of LH_2 on the ground, hydrogen concentration within the gas cloud originating from the leakage, if the release of LH_2 caused solidification of components in air, and consequences of ignition of the gas cloud with H_2.

To simulate leakage of LH_2 in the technical room connected to the LH_2 tank (TCS), releases of LH_2 in a closed room connected to a ventilation mast, were performed. The objectives of the closed room leakage tests were to provide information about the concentration of H_2 in the TCS after leakage of LH_2, potential inflow of oxygen into TCS due to negative pressure, the flow rate of H_2 out of, and the spread of H_2 downwards from, the ventilation mast, clogging of ventilation mast due to solidification of components in air, and consequences of explosion in TCS.

The outflow rate of LH_2 in the outdoor leakage tests ranged from 9.7 to 49.9 kg/min. The release orientation was either vertical downwards on the ground or horizontal. Two of the tests included ignition of the H_2 gas cloud resulting from the release of LH_2.

A liquid pool of LH_2 was formed on the ground during the release of LH_2 in all the tests where the release orientation was vertically downwards on the ground. The radius of the liquid pool was limited to 0.5 to 1.0 m from the release point. The pool disappeared immediately when the release of LH_2 was stopped. No liquid pool of LH_2 was formed in any of the tests with a horizontal release orientation.

Flammable concentrations of H_2 was detected in a narrow space in front of the release point for the outdoor leakage tests with outflow rates of LH_2 ranging from 28.2 to 49.9 kg/min. No flammable concentrations of H_2 was detected in the field in the tests where the outflow rate of LH_2 was 13.5 and 9.7 kg/min. Horizontal releases of LH_2 caused further spread of the H_2 than vertical downwards releases. In the tests with horizontal release orientation, flammable H_2 concentrations were detected 50 m, but not 100 m, from the release point. In the tests with vertical downwards release orientation, flammable H_2 concentrations were only detected 30 m from the release point. The flammable H_2 concentrations were not detected outside a 45° angle, relative to the wind/release direction, from the release point, in any of the tests. The hydrogen plume spread along the ground with neutral buoyancy.

The release of LH_2 caused condensation and freezing of components in air on the ground around the release point for the vertically downward releases. The hydrogen cloud itself did not cause any condensation or freezing of components in air.

Ignition of the gas cloud with H_2 caused a combustion blast followed by a fire, but no fast deflagration or detonation occurred anywhere or at any time in either of the two ignited tests. The maximum total heat flux (convective and radiative) within the fire was estimated to 300 kW/m^2.

Totally 8 leakage tests in the closed room connected to the ventilation mast were performed. The release rates ranged from 11 to 40.1 kg/min. The last three tests included ignition, two at top of the ventilation mast and one inside the closed room.

A near 100%vol hydrogen concentration was build up in the TCS within ~30 seconds from the onset of the release of LH_2 in all the tests in the closed room.

Negative pressure in the TCS due to cooling caused by the release of LH_2 did not seem to be a situation in the current tests. It should be noted that the TCS was open to the environment via the ventilation mast, hence alteration in pressure was not anticipated.

The flow rate of H_2 out of the ventilation mast was estimated from 0.180 kg/s (Test 8) to 0.673 kg/s (Test 13). The outflow rate in Test 8 was 11 kg/min, while it was 40 kg/min in Test 13. The hydrogen plume seemed to have neutral buoyancy, thus, it may spread below the level of the top of the ventilation mast. No significant hydrogen levels were detected at ground level in any of the closed room and ventilation mast tests.

No clogging of the ventilation mast was observed in any of the closed room and ventilation mast tests. Based on this, it is unlikely that releases of LH_2 into TCS will lead to clogging of the ventilation mast due to solidification of components in the atmosphere, at least for ventilation masts with similar dimensions as in these tests.

Ignition on top of the ventilation mast caused an explosion in the TCS in both the tests where the gas cloud was ignited, but the course of the event and severity of the explosion depended on the air-flow through the TCS. In the test where the TCS was sealed, it took around 30 minutes from the ignition was initiated until a low severity explosion event in the TCS occurred. In the test where the low-level vent of the TCS was left open for air ingress, only 10-15 seconds elapsed between initiation of ignition at the top of the mast until a severe explosion event in the TCS occurred. The TCS should be as air tight as possible and should contain detectors that can discover a leakage quickly.

References

Bauwens, C. R., Dorofeev, S. B. (2014) CFD modeling and consequence analysis of an accidental hydrogen release in a large scale facility. International Journal of Hydrogen Energy. 39; 20447-20454.

Biennal Report on Hydrogen Safety (BRHS), v2. (2020) http://www.hysafe.org/BRHS (Accessed 23.11.2020).

Chirivella, J. E., Witcofski, R. D. (1986) Experimental results from fast 1500-gallon LH2 spills. American Institute of Chemical Engineering Symposium Series. 82;120-140.

Coates, A. M., Mathias, L. D., Cantwell, B. J. (2019) Numerical investigation of the effect of obstacle shape on deflagration to detonation transition in a hydrogen–air mixture. Combustion and Flame 209; 278-290.

Coquel, F., Marmignon, C. (2013) Review of hydrogen storage techniques for on board vehicle applications. International Journal of Hydrogen Energy. 38;14595-14617.

Groethea M., Meriloa, E., Coltona, J. Chibab, S., Satoc, Y., Iwabuchic, H. (2007) Large-scale hydrogen deflagrations and detonations. International Journal of Hydrogen Energy 32; 2125 – 2133.

Hajji, Y., Bouteraa, M., Elcafsi, A., Belghith, A., Bournot, P., Kallel, F. (2015) Natural ventilation of hydrogen during a leak in a residential garage. Renewable & Sustainable Energy Reviews. 50; 810-818.

Hedley, D., Hawksworth, S. J., Rattigan, W., Brentnall, R., Allen, J. (2014) Large scale passive ventilation trials of hydrogen. International Journal of Hydrogen Energy. 39(35); 20325-20330.

Hooker, P., Willoughby, D. B., Royle, M. (2011) Experimental releases of liquid hydrogen, Proceedings of 4th International Conference on Hydrogen Safety; 2011. San Francisco, Paper 160.

Klebanoff. L. E., Pratt, J. W., LaFleur, C. B. (2017) Comparison of the safety-related physical and combustion properties of liquid hydrogen and liquid natural gas in the context of the SF-BREEZE high-speed fuel-cell ferry. International Journal of Hydrogen Energy 42; 757-774

Kobayashi, H., Naruo, Y., Maru, Y., Takesaki, Y., Miyanabe, K. (2018) Experiment of cryo-compressed (90-MPa) hydrogen leakage diffusion. International Journal of Hydrogen Energy. 43; 17928-17937.

Marinescu-Pasoi, L., Sturm, B., (1994) Messung der Ausbreitung einer Wasserstoff- und Propangaswolke in bebauten Gelande und Gasspezifische Ausbreitungversuche. Battelle Ingenieurtechnik GmbH. Reports R-68.202 and R-68.264

Medina, C. H., Halford, A., Stene, J. & Allason, D. (2020a) Data report: Outdoor leakage studies. Report no. 853182, Rev. 2. DNV GL Oil and Gas. Spadeadam Testing and Research

Medina, C. H., Allason, D., Johnson, M. & Tomlin, G. (2020b) Data Report: Closed room and ventilation mast studies. Report no. 902696, Rev. 2. DNV GL Oil and Gas. Spadeadam Testing and Research.

NCE Maritime CleanTech (2020) Norwegian future value chains for liquid hydrogen https://maritimecleantech.no/wp-content/uploads/2016/11/Report-liquid-hydrogen.pdf

Pu, L., Shao, X., Zhang, S., Lei, G., Li, Y. (2015) Plume dispersion behaviour and hazard identification for large quantities of liquid hydrogen leakage. Asia-Pacific Journal of Chemical Engineering. 14(2); e2299.

Rhodes, R. (2011) Explosive Lessons in Hydrogen Safety. Ask Magazine 41; 46-50. https://www.nasa.gov/pdf/513855main_ASK_41s_explosive.pdf

Sakamoto, J., Sato, R., Nakayama, J., Kasai, N., Shibutani, T., Miyake, A. (2016) Leakage-type-based analysis of accidents involving hydrogen fueling stations in Japan and USA. International Journal of Hydrogen Energy. 41; 21564-21570.

Schmidtchen, U., Marinescupasoi, L., Verfondern, K., Nickel, V., Sturm, B., Dienhart, B. (1994) Simulation of accidental spills of cryogenic hydrogen in a residential area. Cryogenics. 34(1); 401-404.

Singh, S., Jain, S, Venkateswaran, P. S., Tiwari, A. K., Nouni, M. R., Pandey, J. K., Goel, S. (2015) Hydrogen: A sustainable fuel for future of the transport sector. Renew Sustain Energy 51: 623-633.

Sklavounos, S., Rigas, F. (2005) Fuel gas dispersion under cryogenic release conditions. Energy Fuel. 19; 2535-2544.

Statharas, J. C., Venetsanos, A. G., Bartzis, J. G., Wurtz, J., Schmidtchen, U. (2000) Analysis of data from spilling experiments performed with liquid hydrogen. Journal of Hazardous Material. 77(1); 57-75.

Venetsanos, A.G., Papanikolaou, E., Bartzis, J. G. (2010) The ADREA-HF CFD code for consequence assessment of hydrogen applications. International Journal of Hydrogen Energy. 35(8); 3908-3918.

Verfondern, K., Dienhart, B. (2007) Pool spreading and vaporization of liquid hydrogen. International Journal of Hydrogen Energy. 32; 2106-2117.

Witcofski, R. D., Chirivella, J. E. (1984) Experimental and analytical analyses of the mechanisms governing the dispersion of flammable clouds formed by liquid hydrogen spills. International Journal of Hydrogen Energy. 1984(9); 425-435.

Xiaoa, H., Oran, E. S. (2020) Flame acceleration and deflagration-to-detonation transition in hydrogen-air mixture in a channel with an array of obstacles of different shapes. Combustion and Flame. 220; 378-393.

Xue, R., Ruan, Y., Liu, X., Chen, L., Zhang, X., Hou, Y., Chen, S. (2018) Experimental study of liquid nitrogen spray characteristics in atmospheric environment. Applied Thermal Engineering. 142; 717-722.

Appendix

A Results outdoor leakage tests

The results for Test 1 to Test 7 are given in this appendix.

DNV·GL

FFI: LH2 Releases

Notes

Removed 0.1 bar offset on P02
Maybe offset in temperature - no measurements reaach liquid temp, need to investigate

Test Name	Test01	
Hole Size	25,4	mm
Orientation	Downwards	

FOR PLOTS

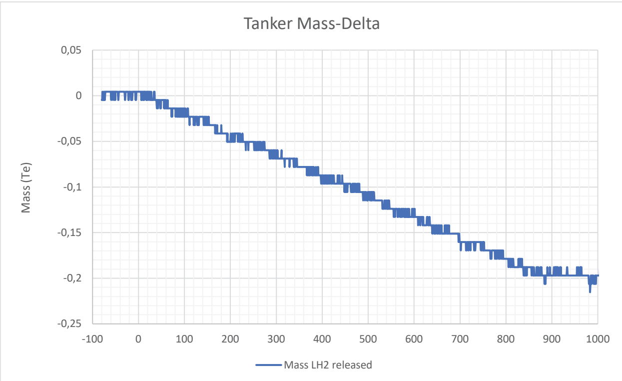
Start Time	-80	sec
End Time	1750	sec

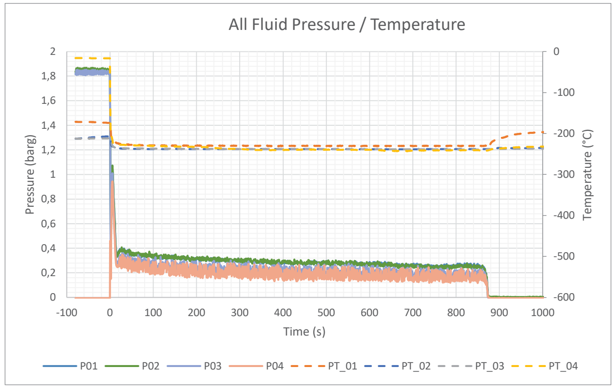
Date 11.12.2019

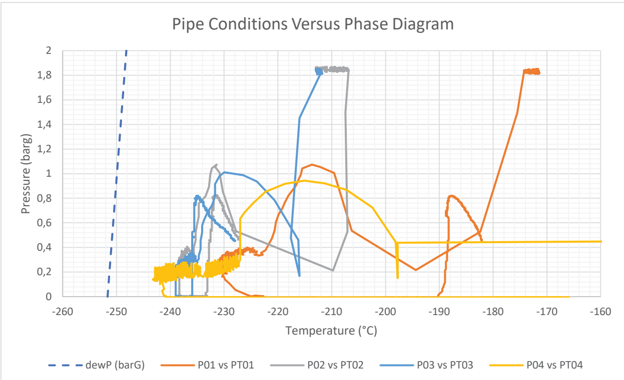
FOR AVERAGING

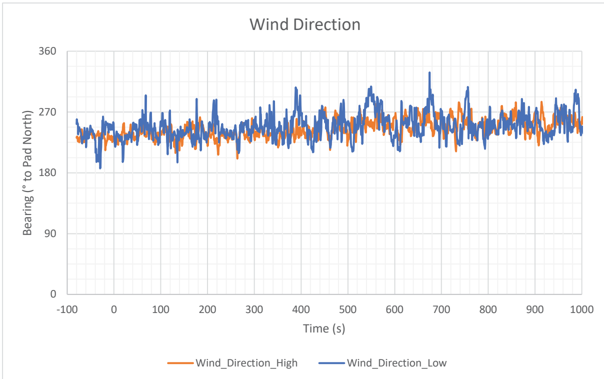
Start	200	sec
End	850	sec

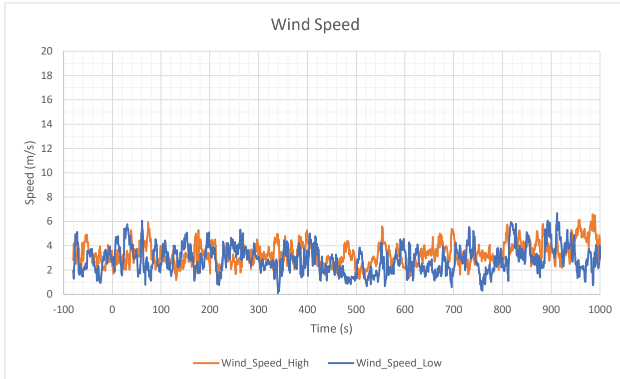
Sensor	Average	Max	Min	STDEV	units
Mass LH2 released	-	-0,041	-0,197	-	Te
P01	0,28	0,33	0,24	0,02	Barg
P02	0,28	0,33	0,23	0,02	Barg
P03	0,21	0,30	0,16	0,03	Barg
P04	0,18	0,28	0,12	0,04	Barg
PT_01	-230,3	-228,8	-231,3	0,4	°C
PT_02	-238,3	-238,0	-238,5	0,2	°C
PT_03	-238,5	-237,4	-239,0	0,4	°C
PT_04	-239,7	-232,7	-243,3	2,1	°C
MassFlow	0,228				kg/s
Wind_Direction_High	246,4	284,5	201,0	13,8	0,0
Wind_Direction_Low	251,3	328,6	209,0	19,3	Deg
Wind_Speed_High	3,2	5,7	1,2	0,8	m/s
Wind_Speed_Low	2,7	5,9	0,1	1,1	m/s









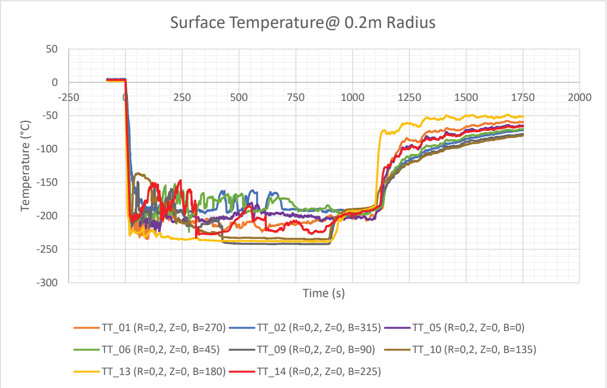


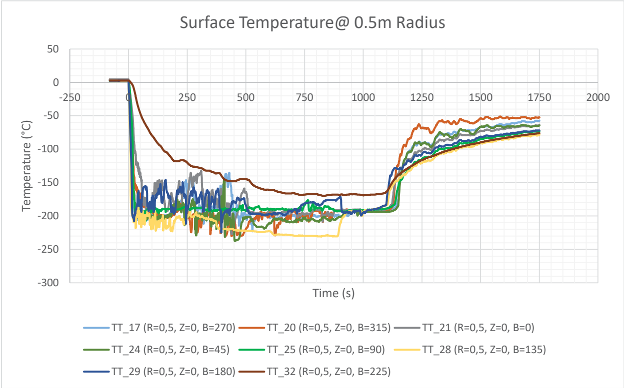
Pad Temperature

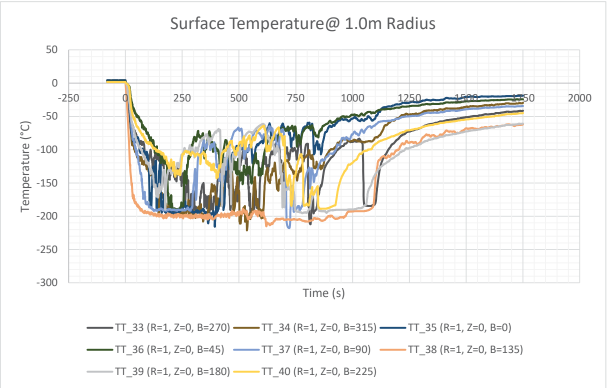
Test Name	Test01		FOR AVERAGING		
Hole Size	25,4	mm	Start	100	sec
Orientation	Downwards		End	900	sec

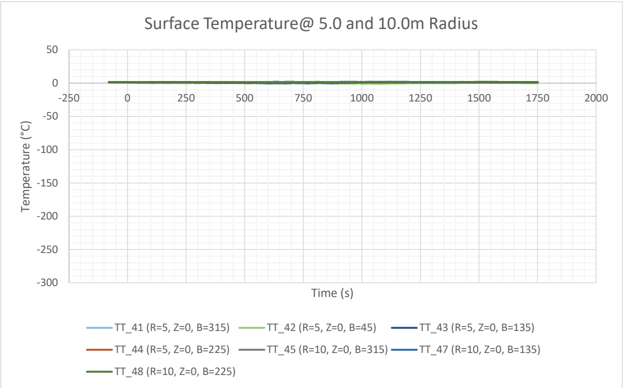
Notes:
Looks like Liquid observed on surface @1.0m but not 5.0m
TT_31 Looks to have seen some cryogen ingress down its hole
Note centre and bearing of array needs to be clarified (300mm to east)

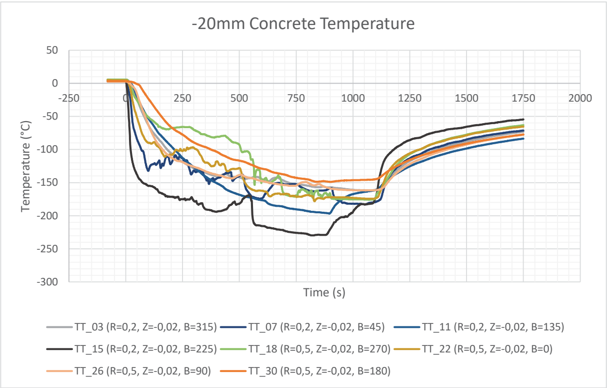
Sensor	Average	Max	Min	STDEV	units
TT_01 (R=0,2, Z=0, B=270)	-211,4	-196,8	-223,6	4,6	°C
TT_02 (R=0,2, Z=0, B=315)	-185,5	-161,6	-196,1	10,1	°C
TT_03 (R=0,2, Z=-0,02, B=315)	-140,1	-105,6	-156,9	11,7	°C
TT_04 (R=0,2, Z=-0,03, B=315)	-96,1	-41,8	-122,8	20,4	°C
TT_05 (R=0,2, Z=0, B=0)	-199,6	-179,9	-213,6	6,5	°C
TT_06 (R=0,2, Z=0, B=45)	-181,5	-152,1	-223,8	10,3	°C
TT_07 (R=0,2, Z=-0,02, B=45)	-146,8	-108,5	-174,3	16,6	°C
TT_08 (R=0,2, Z=-0,03, B=45)	-130,4	-81,9	-156,0	21,1	°C
TT_09 (R=0,2, Z=0, B=90)	-229,0	-159,5	-242,1	18,8	°C
TT_10 (R=0,2, Z=0, B=135)	-227,3	-188,7	-235,0	10,5	°C
TT_11 (R=0,2, Z=-0,02, B=135)	-162,3	-94,9	-194,8	27,9	°C
TT_12 (R=0,2, Z=-0,03, B=135)	-129,4	-57,6	-170,0	32,3	°C
TT_13 (R=0,2, Z=0, B=180)	-236,8	-232,9	-238,3	1,4	°C
TT_14 (R=0,2, Z=0, B=225)	-207,9	-146,3	-232,4	19,8	°C
TT_15 (R=0,2, Z=-0,02, B=225)	-199,7	-169,1	-229,8	21,4	°C
TT_16 (R=0,2, Z=-0,03, B=225)	-94,5	-48,9	-131,5	20,5	°C
TT_17 (R=0,5, Z=0, B=270)	-190,4	-135,1	-225,7	17,9	°C
TT_18 (R=0,5, Z=-0,02, B=270)	-114,4	-65,7	-172,7	39,5	°C
TT_19 (R=0,5, Z=-0,03, B=270)	-59,5	-18,0	-107,3	27,6	°C
TT_20 (R=0,5, Z=0, B=315)	-204,3	-178,4	-231,1	11,1	°C
TT_21 (R=0,5, Z=0, B=0)	-185,2	-132,2	-226,9	18,1	°C
TT_22 (R=0,5, Z=-0,02, B=0)	-141,5	-96,4	-178,1	27,4	°C
TT_23 (R=0,5, Z=-0,03, B=0)	-67,6	-19,2	-112,3	30,3	°C
TT_24 (R=0,5, Z=0, B=45)	-204,4	-145,5	-237,1	12,4	°C
TT_25 (R=0,5, Z=0, B=90)	-189,1	-176,4	-193,3	2,5	°C
TT_26 (R=0,5, Z=-0,02, B=90)	-140,9	-111,9	-154,9	11,8	°C
TT_27 (R=0,5, Z=-0,03, B=90)	-76,6	-24,6	-105,4	22,5	°C
TT_28 (R=0,5, Z=0, B=135)	-219,3	-193,6	-230,8	10,8	°C
TT_29 (R=0,5, Z=0, B=180)	-184,2	-149,4	-224,7	12,2	°C
TT_30 (R=0,5, Z=-0,02, B=180)	-116,6	-66,2	-148,6	23,2	°C
TT_31 (R=0,5, Z=-0,03, B=180)	-203,5	-193,3	-227,8	5,8	°C
TT_32 (R=0,5, Z=0, B=225)	-149,6	-116,1	-169,8	17,1	°C
TT_33 (R=1, Z=0, B=270)	-143,9	-83,3	-212,3	34,2	°C
TT_34 (R=1, Z=0, B=315)	-162,1	-100,6	-221,1	31,9	°C
TT_35 (R=1, Z=0, B=0)	-124,8	-59,4	-215,8	52,3	°C
TT_36 (R=1, Z=0, B=45)	-104,8	-63,1	-190,3	34,6	°C
TT_37 (R=1, Z=0, B=90)	-124,4	-64,6	-217,9	46,3	°C
TT_38 (R=1, Z=0, B=135)	-201,3	-189,0	-215,1	4,7	°C
TT_39 (R=1, Z=0, B=180)	-115,5	-61,1	-195,5	40,8	°C
TT_40 (R=1, Z=0, B=225)	-112,1	-63,9	-186,1	30,3	°C
TT_41 (R=5, Z=0, B=315)	1,7	1,8	1,5	0,1	°C
TT_42 (R=5, Z=0, B=45)	0,2	0,3	-0,6	0,1	°C
TT_43 (R=5, Z=0, B=135)	1,6	1,8	1,6	0,0	°C
TT_44 (R=5, Z=0, B=225)	1,3	1,4	1,1	0,1	°C
TT_45 (R=10, Z=0, B=315)	1,8	1,9	1,8	0,0	°C
TT_46 (R=10, Z=0, B=45)	-11,9	4,1	-160,1	22,3	°C
TT_47 (R=10, Z=0, B=135)	0,3	1,0	-0,4	0,4	°C
TT_48 (R=10, Z=0, B=225)	0,4	1,2	-0,2	0,4	°C

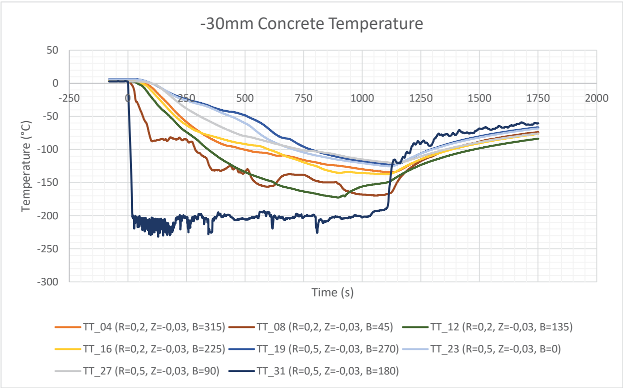












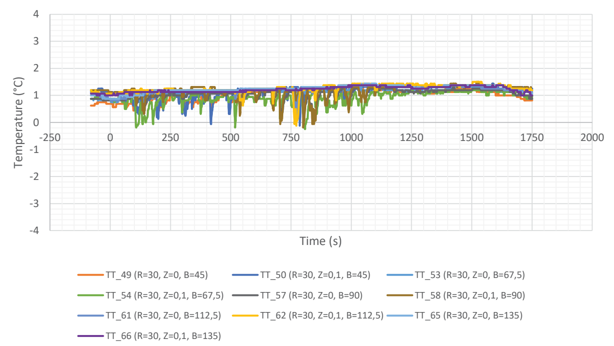
Notes: Greater temperature drop seen at 30m than 50m
Greater temperature drop observed at 1.0 and 1.8m than at 0.0 / 0.1m

Field Temperature

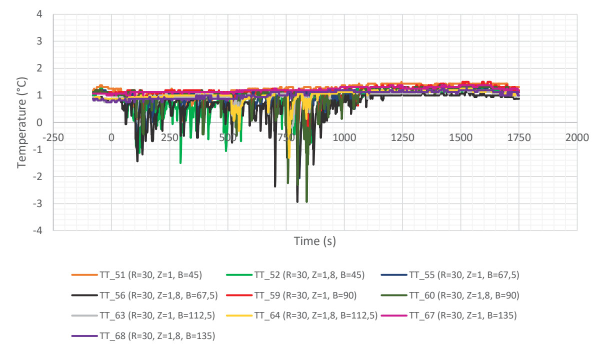
Test Name	Test01		FOR AVERAGING		
Hole Size	25,4	mm	Start	100	sec
Orientation	Downwards		End	900	sec

Sensor	Average	Max	Min	STDEV	units
TT_49 (R=30, Z=0, B=45)	1,0	1,1	0,4	0,2	°C
TT_50 (R=30, Z=0,1, B=45)	1,0	1,3	-0,1	0,3	°C
TT_51 (R=30, Z=1, B=45)	1,0	1,3	0,0	0,3	°C
TT_52 (R=30, Z=1,8, B=45)	0,7	1,1	-1,5	0,5	°C
TT_53 (R=30, Z=0, B=67,5)	1,1	1,2	1,1	0,1	°C
TT_54 (R=30, Z=0,1, B=67,5)	0,8	1,1	-0,3	0,2	°C
TT_55 (R=30, Z=1, B=67,5)	0,9	1,2	-2,1	0,4	°C
TT_56 (R=30, Z=1,8, B=67,5)	0,5	0,9	-2,9	0,5	°C
TT_57 (R=30, Z=0, B=90)	1,0	1,2	0,1	0,2	°C
TT_58 (R=30, Z=0,1, B=90)	1,1	1,3	-0,2	0,3	°C
TT_59 (R=30, Z=1, B=90)	1,0	1,3	-0,8	0,4	°C
TT_60 (R=30, Z=1,8, B=90)	0,8	1,2	-2,9	0,5	°C
TT_61 (R=30, Z=0, B=112,5)	1,2	1,3	0,2	0,1	°C
TT_62 (R=30, Z=0,1, B=112,5)	1,2	1,3	-0,1	0,2	°C
TT_63 (R=30, Z=1, B=112,5)	0,9	1,1	-0,3	0,3	°C
TT_64 (R=30, Z=1,8, B=112,5)	0,9	1,1	-1,3	0,3	°C
TT_65 (R=30, Z=0, B=135)	1,2	1,3	1,2	0,0	°C
TT_66 (R=30, Z=0,1, B=135)	1,2	1,3	1,1	0,0	°C
TT_67 (R=30, Z=1, B=135)	1,2	1,3	1,1	0,0	°C
TT_68 (R=30, Z=1,8, B=135)	1,0	1,1	0,8	0,1	°C
TT_69 (R=50, Z=0, B=67,5)	1,4	1,5	1,3	0,0	°C
TT_70 (R=50, Z=0,1, B=67,5)	1,2	1,4	0,6	0,2	°C
TT_71 (R=50, Z=1, B=67,5)	1,1	1,3	0,4	0,2	°C
TT_72 (R=50, Z=1,8, B=67,5)	0,7	0,9	-0,4	0,2	°C
TT_73 (R=50, Z=0, B=90)	1,5	1,5	1,4	0,0	°C
TT_74 (R=50, Z=0,1, B=90)	1,4	1,4	0,6	0,1	°C
TT_75 (R=50, Z=1, B=90)	1,1	1,3	0,6	0,1	°C
TT_76 (R=50, Z=1,8, B=90)	1,0	1,2	0,1	0,2	°C
TT_77 (R=50, Z=0, B=112,5)	1,0	1,1	0,9	0,1	°C
TT_78 (R=50, Z=0,1, B=112,5)	1,5	1,5	1,4	0,0	°C
TT_79 (R=50, Z=1, B=112,5)	1,4	1,4	1,3	0,0	°C
TT_80 (R=50, Z=1,8, B=112,5)	1,1	1,3	1,0	0,0	°C
TT_81 (R=100, Z=0, B=80)	1,4	1,5	1,3	0,0	°C
TT_82 (R=100, Z=0,1, B=80)	1,4	1,6	0,9	0,1	°C
TT_83 (R=100, Z=1, B=80)	1,2	1,3	0,6	0,1	°C
TT_84 (R=100, Z=1,8, B=80)	0,8	0,9	0,1	0,1	°C
TT_85 (R=100, Z=0, B=100)	1,4	1,4	1,3	0,0	°C
TT_86 (R=100, Z=0,1, B=100)	1,2	1,3	1,1	0,1	°C
TT_87 (R=100, Z=1, B=100)	1,4	1,4	1,3	0,0	°C
TT_88 (R=100, Z=1,8, B=100)	0,9	1,0	0,8	0,1	°C

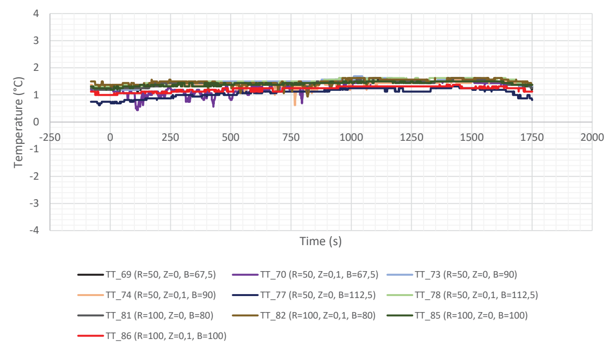
30m Radius, 0.0m and 0.1m high Field Temperature



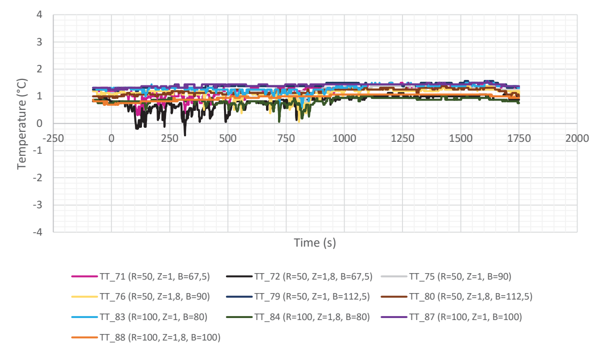
30m Radius, 1.0m and 1.8m high Field Temperature



50m and 100m Radius, 0.0m and 0.1m high Field Temperature



50m and 100m Radius, 1.0m and 1.8m high Field Temperature

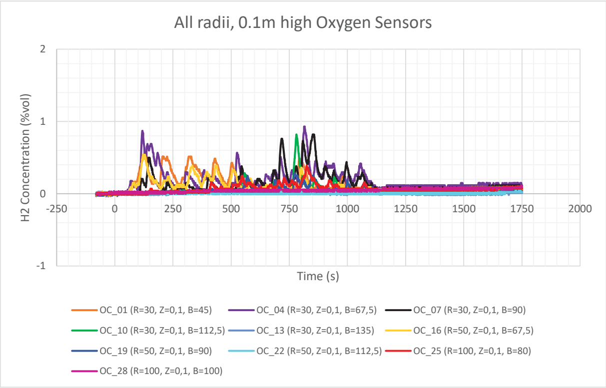


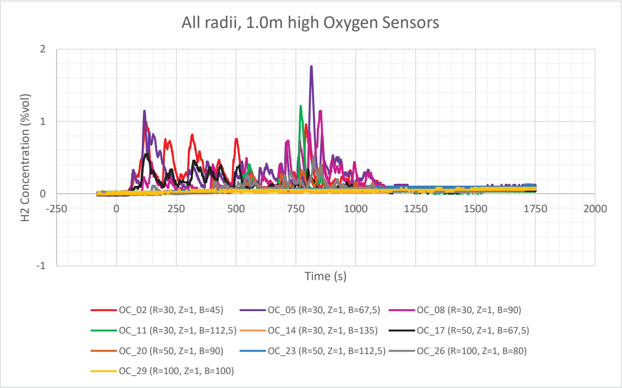
Gas Concentrations

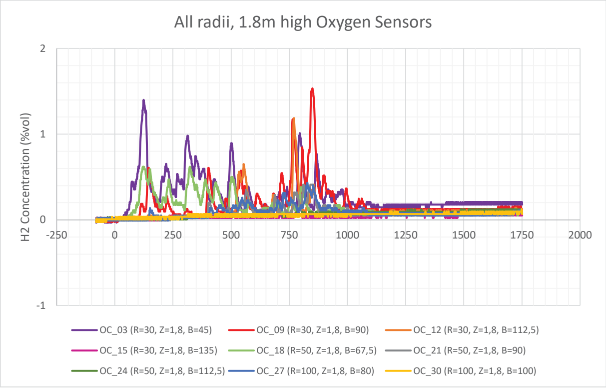
Test Name	Test01		FOR AVERAGING		
Hole Size	25,4	mm	Start	100	sec
Orientation	Downwards		End	900	sec

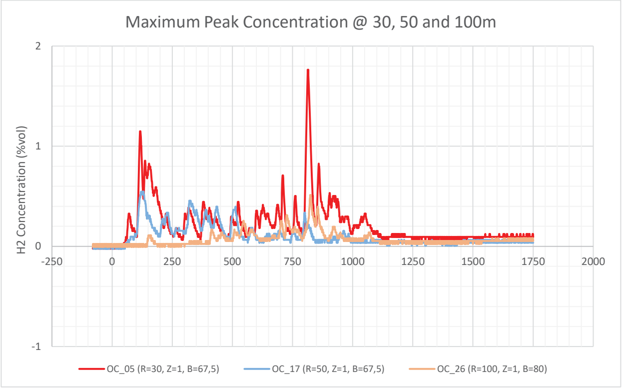
Notes: Maximum peak concentration observed in line with wind direction, decays with distance from source

Sensor	Average	Max	Min	STDEV	units
OC_01 (R=30, Z=0,1, B=45)	0,2	0,5	0,0	0,1	%vol
OC_02 (R=30, Z=1, B=45)	0,3	1,0	0,1	0,2	%vol
OC_03 (R=30, Z=1,8, B=45)	0,4	1,0	0,1	0,2	%vol
OC_04 (R=30, Z=0,1, B=67,5)	0,2	0,9	0,1	0,1	%vol
OC_05 (R=30, Z=1, B=67,5)	0,3	1,8	0,1	0,2	%vol
OC_06 (R=30, Z=1,8, B=67,5)	0,4	1,3	-0,6	0,3	%vol
OC_07 (R=30, Z=0,1, B=90)	0,2	0,8	0,0	0,2	%vol
OC_08 (R=30, Z=1, B=90)	0,2	1,1	0,0	0,2	%vol
OC_09 (R=30, Z=1,8, B=90)	0,3	1,5	0,0	0,3	%vol
OC_10 (R=30, Z=0,1, B=112,5)	0,1	0,8	0,0	0,1	%vol
OC_11 (R=30, Z=1, B=112,5)	0,1	1,2	0,0	0,2	%vol
OC_12 (R=30, Z=1,8, B=112,5)	0,1	1,2	0,0	0,2	%vol
OC_13 (R=30, Z=0,1, B=135)	0,0	0,0	0,0	0,0	%vol
OC_14 (R=30, Z=1, B=135)	0,0	0,1	0,0	0,0	%vol
OC_15 (R=30, Z=1,8, B=135)	0,0	0,1	0,0	0,0	%vol
OC_16 (R=50, Z=0,1, B=67,5)	0,1	0,4	0,0	0,1	%vol
OC_17 (R=50, Z=1, B=67,5)	0,2	0,5	0,0	0,1	%vol
OC_18 (R=50, Z=1,8, B=67,5)	0,2	0,6	0,1	0,1	%vol
OC_19 (R=50, Z=0,1, B=90)	0,1	0,3	0,0	0,1	%vol
OC_20 (R=50, Z=1, B=90)	0,1	0,4	0,0	0,1	%vol
OC_21 (R=50, Z=1,8, B=90)	0,1	0,4	0,0	0,1	%vol
OC_22 (R=50, Z=0,1, B=112,5)	0,0	0,0	0,0	0,0	%vol
OC_23 (R=50, Z=1, B=112,5)	0,0	0,1	0,0	0,0	%vol
OC_24 (R=50, Z=1,8, B=112,5)	0,0	0,1	0,0	0,0	%vol
OC_25 (R=100, Z=0,1, B=80)	0,1	0,4	0,0	0,1	%vol
OC_26 (R=100, Z=1, B=80)	0,1	0,5	0,0	0,1	%vol
OC_27 (R=100, Z=1,8, B=80)	0,1	0,4	0,0	0,1	%vol
OC_28 (R=100, Z=0,1, B=100)	0,0	0,1	0,0	0,0	%vol
OC_29 (R=100, Z=1, B=100)	0,0	0,1	0,0	0,0	%vol
OC_30 (R=100, Z=1,8, B=100)	0,0	0,1	0,0	0,0	%vol









DNV·GL

FFI: LH2 Releases

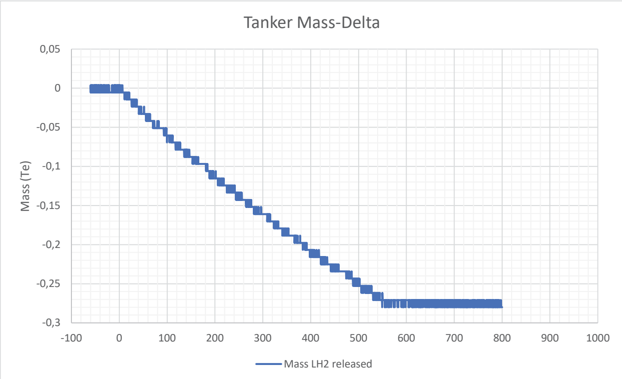
Notes

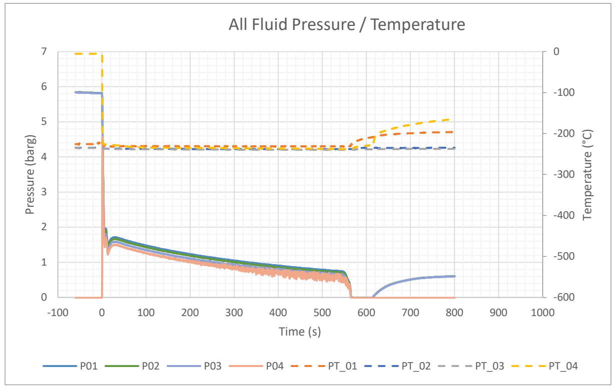
Removed 0.1 bar offset on P02
Maybe offset in temperature - no measurements reaach liquid temp, need to investigate

Test Name: Test02
Hole Size: 25,4 mm
Orientation: Downwards

FOR PLOTS
Start Time: -60 sec
End Time: 800 sec

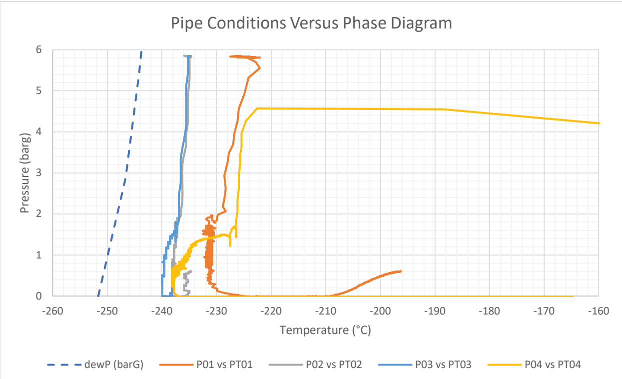
Date: 12.12.2019

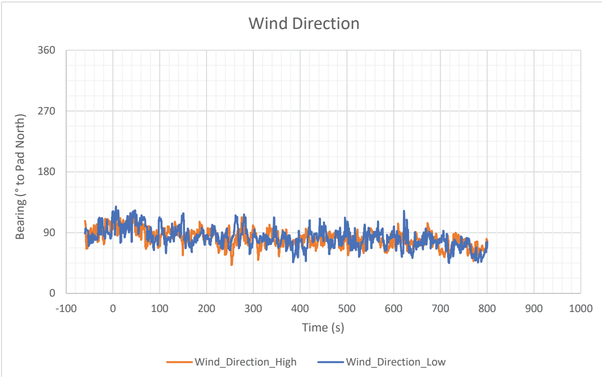


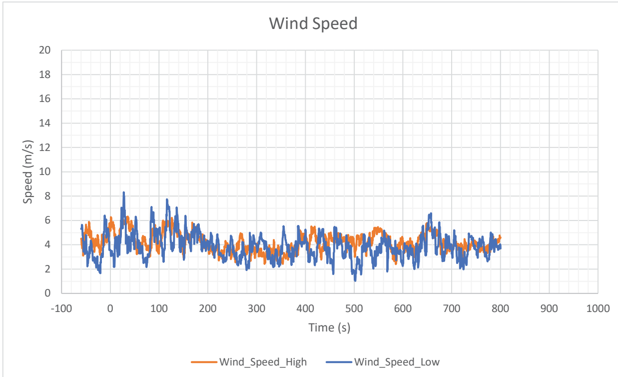


FOR AVERAGING
Start: 100 sec
End: 500 sec

Sensor	Average	Max	Min	STDEV	units
Mass LH2 released	-	-0,060	-0,253	-	Te
P01	1,07	1,48	0,78	0,20	Barg
P02	1,03	1,43	0,73	0,20	Barg
P03	0,95	1,35	0,61	0,19	Barg
P04	0,87	1,27	0,48	0,19	Barg
PT_01	-231,3	-230,5	-232,3	0,3	°C
PT_02	-237,8	-237,5	-238,1	0,2	°C
PT_03	-239,3	-238,5	-239,9	0,3	°C
PT_04	-236,0	-233,8	-238,1	0,9	°C
MassFlow	0,473				kg/s
Wind_Direction_High	81,9	112,8	41,9	10,4	0,0
Wind_Direction_Low	82,7	118,6	46,1	12,2	Deg
Wind_Speed_High	4,1	6,2	2,4	0,8	m/s
Wind_Speed_Low	3,9	7,7	1,6	1,0	m/s





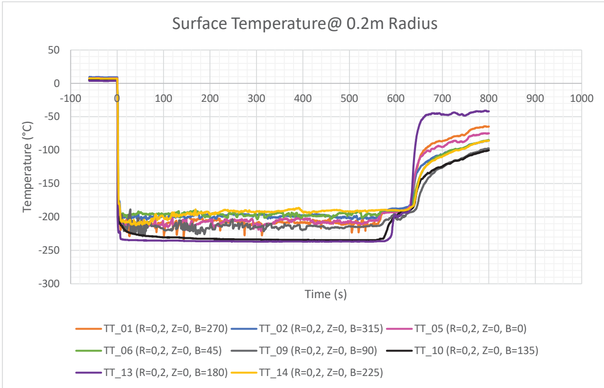


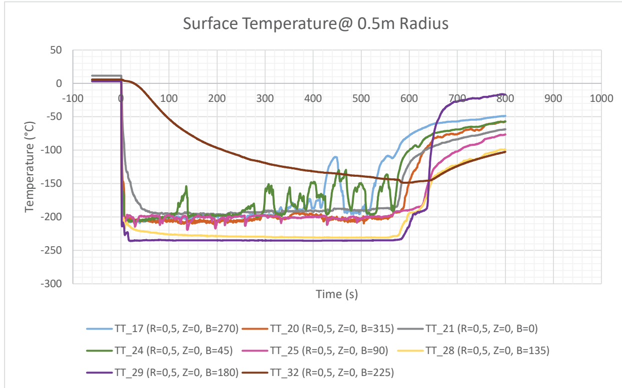
Pad Temperature

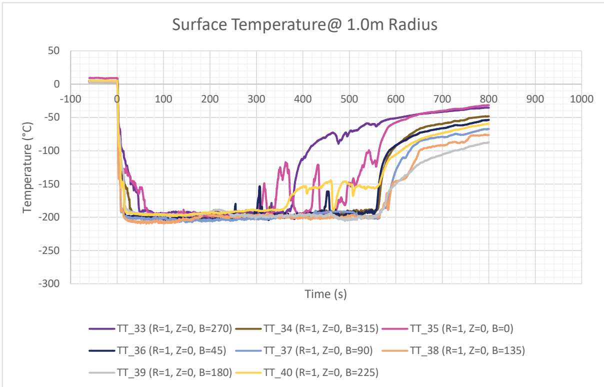
Test Name	Test02		FOR AVERAGING		
Hole Size	25,4	mm	Start	100	sec
Orientation	Downwards		End	500	sec

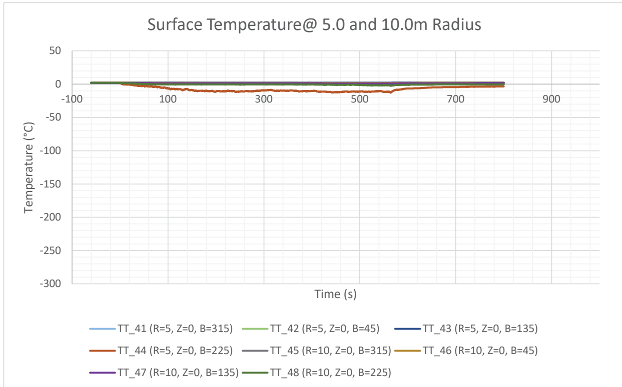
Notes: Looks like Liquid observed on surface @1.0m but not 5.0m.
LH2 not observed further than 0.5m
Note centre and bearing of array needs to be clarified (300mm to east)

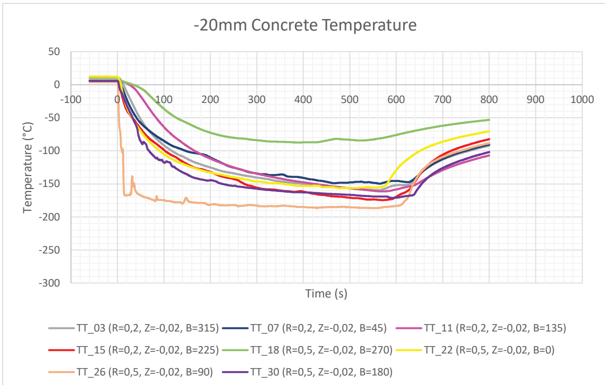
Sensor	Average	Max	Min	STDEV	units
TT_01 (R=0,2, Z=0, B=270)	-208,1	-199,4	-233,4	4,0	°C
TT_02 (R=0,2, Z=0, B=315)	-198,4	-194,0	-203,8	1,9	°C
TT_03 (R=0,2, Z=-0,02, B=315)	-135,9	-91,7	-156,6	16,9	°C
TT_04 (R=0,2, Z=-0,03, B=315)	-79,1	-19,9	-111,7	25,5	°C
TT_05 (R=0,2, Z=0, B=0)	-207,7	-201,0	-221,1	3,7	°C
TT_06 (R=0,2, Z=0, B=45)	-196,3	-190,3	-203,6	2,4	°C
TT_07 (R=0,2, Z=-0,02, B=45)	-126,7	-84,9	-148,9	18,4	°C
TT_08 (R=0,2, Z=-0,03, B=45)	-109,6	-61,4	-136,3	20,4	°C
TT_09 (R=0,2, Z=0, B=90)	-215,0	-203,1	-225,8	3,4	°C
TT_10 (R=0,2, Z=0, B=135)	-233,3	-230,4	-234,5	1,2	°C
TT_11 (R=0,2, Z=-0,02, B=135)	-127,4	-64,1	-156,6	24,4	°C
TT_12 (R=0,2, Z=-0,03, B=135)	-88,8	-20,6	-128,3	29,3	°C
TT_13 (R=0,2, Z=0, B=180)	-236,4	-235,3	-236,9	0,4	°C
TT_14 (R=0,2, Z=0, B=225)	-192,6	-186,4	-204,6	3,1	°C
TT_15 (R=0,2, Z=-0,02, B=225)	-147,2	-98,6	-170,8	19,7	°C
TT_16 (R=0,2, Z=-0,03, B=225)	-70,3	-12,1	-106,1	26,6	°C
TT_17 (R=0,5, Z=0, B=270)	-188,1	-110,1	-204,3	21,0	°C
TT_18 (R=0,5, Z=-0,02, B=270)	-76,9	-36,6	-87,4	12,8	°C
TT_19 (R=0,5, Z=-0,03, B=270)	-45,0	-5,1	-62,3	16,5	°C
TT_20 (R=0,5, Z=0, B=315)	-203,0	-193,8	-210,5	4,1	°C
TT_21 (R=0,5, Z=0, B=0)	-192,6	-187,3	-197,8	2,4	°C
TT_22 (R=0,5, Z=-0,02, B=0)	-141,4	-104,8	-156,4	13,6	°C
TT_23 (R=0,5, Z=-0,03, B=0)	-48,2	3,5	-82,7	25,7	°C
TT_24 (R=0,5, Z=0, B=45)	-180,7	-129,6	-201,4	18,9	°C
TT_25 (R=0,5, Z=0, B=90)	-201,3	-196,9	-219,3	3,4	°C
TT_26 (R=0,5, Z=-0,02, B=90)	-182,2	-170,9	-186,8	3,1	°C
TT_27 (R=0,5, Z=-0,03, B=90)	-53,0	-2,7	-88,0	25,2	°C
TT_28 (R=0,5, Z=0, B=135)	-229,4	-226,1	-231,3	1,3	°C
TT_29 (R=0,5, Z=0, B=180)	-235,2	-234,7	-235,6	0,2	°C
TT_30 (R=0,5, Z=-0,02, B=180)	-152,8	-115,8	-166,5	13,0	°C
TT_31 (R=0,5, Z=-0,03, B=180)	-210,1	-202,8	-224,7	2,9	°C
TT_32 (R=0,5, Z=0, B=225)	-112,1	-53,2	-138,9	23,1	°C
TT_33 (R=1, Z=0, B=270)	-162,7	-72,3	-195,9	47,6	°C
TT_34 (R=1, Z=0, B=315)	-197,4	-184,3	-204,1	2,4	°C
TT_35 (R=1, Z=0, B=0)	-185,6	-117,1	-200,5	20,3	°C
TT_36 (R=1, Z=0, B=45)	-197,7	-153,3	-205,1	7,2	°C
TT_37 (R=1, Z=0, B=90)	-200,5	-190,1	-207,8	4,5	°C
TT_38 (R=1, Z=0, B=135)	-200,2	-194,2	-209,3	2,9	°C
TT_39 (R=1, Z=0, B=180)	-196,8	-188,6	-205,6	3,0	°C
TT_40 (R=1, Z=0, B=225)	-180,9	-144,6	-198,1	17,6	°C
TT_41 (R=5, Z=0, B=315)	1,8	1,9	1,2	0,1	°C
TT_42 (R=5, Z=0, B=45)	2,0	2,1	1,4	0,1	°C
TT_43 (R=5, Z=0, B=135)	2,0	2,3	1,8	0,1	°C
TT_44 (R=5, Z=0, B=225)	-10,2	-6,3	-12,6	1,2	°C
TT_45 (R=10, Z=0, B=315)	2,2	2,3	2,1	0,1	°C
TT_46 (R=10, Z=0, B=45)	1,5	1,7	1,4	0,1	°C
TT_47 (R=10, Z=0, B=135)	1,3	1,4	1,1	0,1	°C
TT_48 (R=10, Z=0, B=225)	-0,5	-0,3	-1,3	0,2	°C

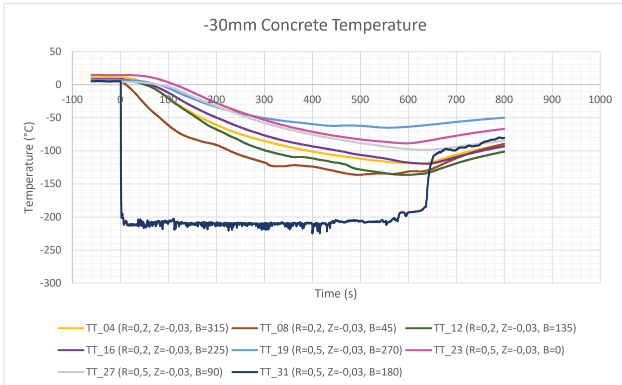




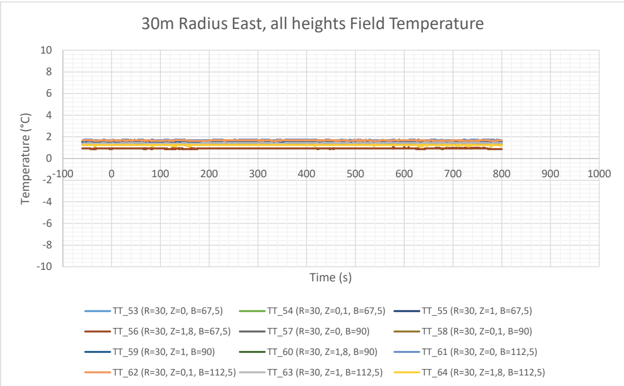


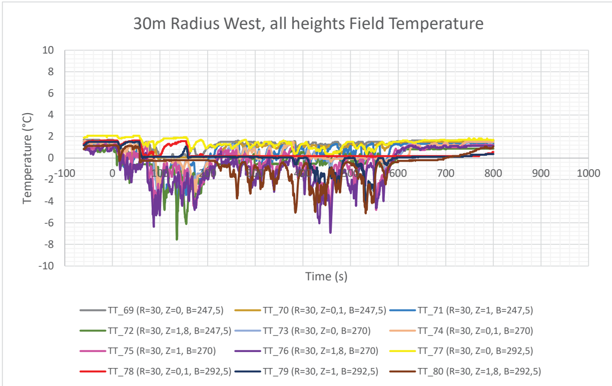


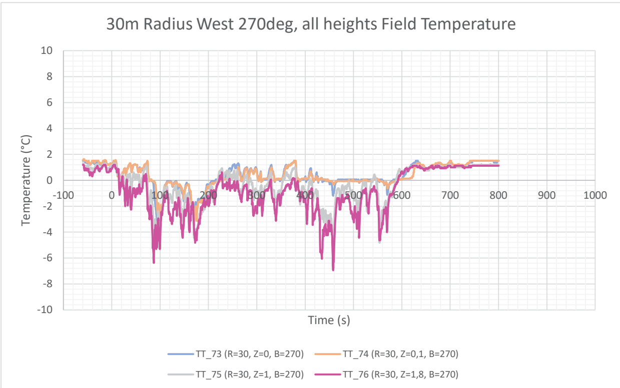


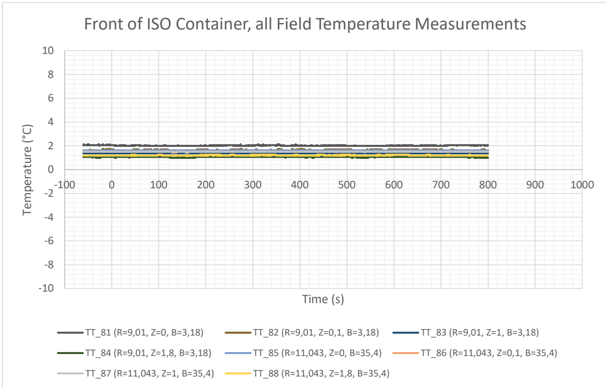


Notes: Temperature drop only observed at 30m west, minimum observation -7.6°C









Field Temperature

Test Name: Test02
Hole Size: 25,4 mm
Orientation: Downwards

FOR AVERAGING
Start: 100 sec
End: 500 sec

Sensor	Average	Max	Min	STDEV	units
TT_49 (R=30, Z=0, B=45)	1,7	1,8	1,6	0,1	°C
TT_50 (R=30, Z=0,1, B=45)	1,6	1,7	1,5	0,0	°C
TT_51 (R=30, Z=1, B=45)	1,6	1,6	1,6	0,0	°C
TT_52 (R=30, Z=1,8, B=45)	1,3	1,3	1,3	0,0	°C
TT_53 (R=30, Z=0, B=67,5)	1,6	1,7	1,6	0,0	°C
TT_54 (R=30, Z=0,1, B=67,5)	1,4	1,4	1,3	0,0	°C
TT_55 (R=30, Z=1, B=67,5)	1,3	1,3	1,3	0,0	°C
TT_56 (R=30, Z=1,8, B=67,5)	0,9	0,9	0,9	0,0	°C
TT_57 (R=30, Z=0, B=90)	1,6	1,7	1,6	0,0	°C
TT_58 (R=30, Z=0,1, B=90)	1,6	1,6	1,6	0,0	°C
TT_59 (R=30, Z=1, B=90)	1,5	1,5	1,4	0,0	°C
TT_60 (R=30, Z=1,8, B=90)	1,3	1,3	1,3	0,0	°C
TT_61 (R=30, Z=0, B=112,5)	1,7	1,8	1,7	0,0	°C
TT_62 (R=30, Z=0,1, B=112,5)	1,7	1,8	1,6	0,0	°C
TT_63 (R=30, Z=1, B=112,5)	1,4	1,4	1,4	0,0	°C
TT_64 (R=30, Z=1,8, B=112,5)	1,2	1,3	1,1	0,0	°C
TT_65 (R=30, Z=0, B=135)	1,9	1,9	1,9	0,0	°C
TT_66 (R=30, Z=0,1, B=135)	1,7	1,8	1,7	0,0	°C
TT_67 (R=30, Z=1, B=135)	1,6	1,6	1,5	0,0	°C
TT_68 (R=30, Z=1,8, B=135)	1,1	1,2	1,1	0,0	°C
TT_69 (R=30, Z=0, B=247,5)	1,1	1,6	-0,1	0,5	°C
TT_70 (R=30, Z=0,1, B=247,5)	0,8	1,4	0,1	0,5	°C
TT_71 (R=30, Z=1, B=247,5)	0,0	1,4	-4,8	1,3	°C
TT_72 (R=30, Z=1,8, B=247,5)	-0,8	0,7	-7,6	1,3	°C
TT_73 (R=30, Z=0, B=270)	0,0	1,5	-3,4	0,8	°C
TT_74 (R=30, Z=0,1, B=270)	-0,1	1,5	-3,5	0,8	°C
TT_75 (R=30, Z=1, B=270)	-1,0	1,0	-5,3	1,2	°C
TT_76 (R=30, Z=1,8, B=270)	-1,8	0,6	-6,9	1,3	°C
TT_77 (R=30, Z=0, B=292,5)	1,2	1,9	0,3	0,4	°C
TT_78 (R=30, Z=0,1, B=292,5)	0,3	1,6	0,1	0,4	°C
TT_79 (R=30, Z=1, B=292,5)	-0,2	1,1	-3,3	0,7	°C
TT_80 (R=30, Z=1,8, B=292,5)	-1,3	-0,2	-5,1	1,1	°C
TT_81 (R=9,01, Z=0, B=3,18)	2,0	2,1	2,0	0,0	°C
TT_82 (R=9,01, Z=0,1, B=3,18)	1,6	1,8	1,6	0,0	°C
TT_83 (R=9,01, Z=1, B=3,18)	1,4	1,4	1,4	0,0	°C
TT_84 (R=9,01, Z=1,8, B=3,18)	1,1	1,1	1,0	0,0	°C
TT_85 (R=11,043, Z=0, B=35,4)	1,6	1,6	1,6	0,0	°C
TT_86 (R=11,043, Z=0,1, B=35,4)	1,5	1,5	1,4	0,0	°C
TT_87 (R=11,043, Z=1, B=35,4)	1,5	1,5	1,4	0,0	°C
TT_88 (R=11,043, Z=1,8, B=35,4)	1,2	1,3	1,1	0,0	°C

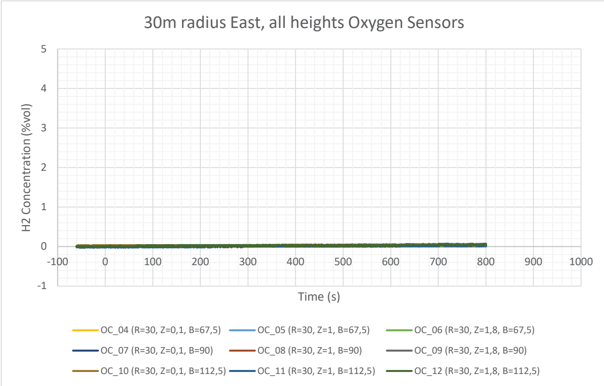
DNV·GL

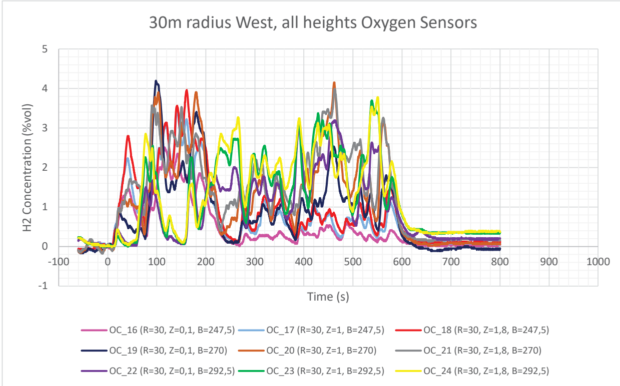
Gas Concentrations

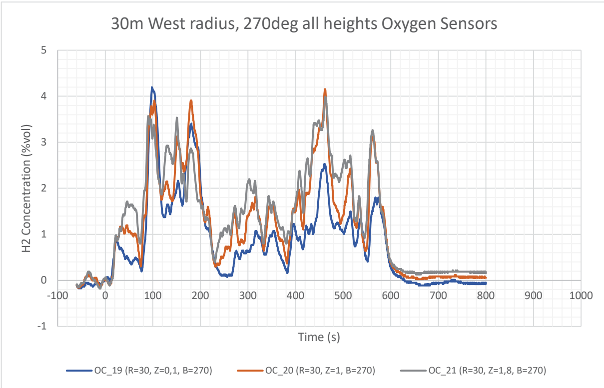
Test Name	Test02			FOR AVERAGING	
Hole Size	25,4	mm	Start	100	sec
Orientation	Downwards		End	500	sec

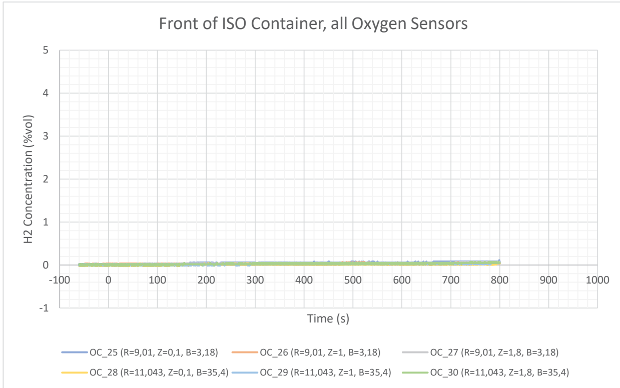
Notes: OC06 removed. No gas detected on East side @ any distance or height
No gas detected at ISO container
Max. ~4%vol detected at 30m west

Sensor	Average	Max	Min	STDEV	units
OC_01 (R=30, Z=0,1, B=45)	0,0	0,0	0,0	0,0	%vol
OC_02 (R=30, Z=1, B=45)	0,0	0,0	0,0	0,0	%vol
OC_03 (R=30, Z=1,8, B=45)	0,0	0,0	0,0	0,0	%vol
OC_04 (R=30, Z=0,1, B=67,5)	0,0	0,1	0,0	0,0	%vol
OC_05 (R=30, Z=1, B=67,5)	0,0	0,0	0,0	0,0	%vol
OC_06 (R=30, Z=1,8, B=67,5)	0,0	0,0	0,0	0,0	%vol
OC_07 (R=30, Z=0,1, B=90)	0,0	0,0	0,0	0,0	%vol
OC_08 (R=30, Z=1, B=90)	0,0	0,0	0,0	0,0	%vol
OC_09 (R=30, Z=1,8, B=90)	0,0	0,0	0,0	0,0	%vol
OC_10 (R=30, Z=0,1, B=112,5)	0,0	0,1	0,0	0,0	%vol
OC_11 (R=30, Z=1, B=112,5)	0,0	0,0	0,0	0,0	%vol
OC_12 (R=30, Z=1,8, B=112,5)	0,0	0,0	0,0	0,0	%vol
OC_13 (R=30, Z=0,1, B=135)	0,0	0,0	0,0	0,0	%vol
OC_14 (R=30, Z=1, B=135)	0,0	0,0	0,0	0,0	%vol
OC_15 (R=30, Z=1,8, B=135)	0,0	0,0	0,0	0,0	%vol
OC_16 (R=30, Z=0,1, B=247,5)	0,7	2,5	0,0	0,7	%vol
OC_17 (R=30, Z=1, B=247,5)	1,1	3,5	0,1	0,9	%vol
OC_18 (R=30, Z=1,8, B=247,5)	1,3	4,0	0,1	1,0	%vol
OC_19 (R=30, Z=0,1, B=270)	1,3	4,1	0,1	0,9	%vol
OC_20 (R=30, Z=1, B=270)	1,8	4,2	0,3	0,9	%vol
OC_21 (R=30, Z=1,8, B=270)	2,0	4,0	0,4	0,8	%vol
OC_22 (R=30, Z=0,1, B=292,5)	1,4	3,2	0,1	0,8	%vol
OC_23 (R=30, Z=1, B=292,5)	1,7	3,4	0,1	0,9	%vol
OC_24 (R=30, Z=1,8, B=292,5)	1,8	3,3	0,1	0,8	%vol
OC_25 (R=9,01, Z=0,1, B=3,18)	0,0	0,1	0,0	0,0	%vol
OC_26 (R=9,01, Z=1, B=3,18)	0,0	0,1	0,0	0,0	%vol
OC_27 (R=9,01, Z=1,8, B=3,18)	0,0	0,0	0,0	0,0	%vol
OC_28 (R=11,043, Z=0,1, B=35,4)	0,0	0,0	0,0	0,0	%vol
OC_29 (R=11,043, Z=1, B=35,4)	0,0	0,0	0,0	0,0	%vol
OC_30 (R=11,043, Z=1,8, B=35,4)	0,0	0,0	0,0	0,0	%vol









Notes

Maybe offset in temperature - no measurements reaach liquid temp, need to investigate

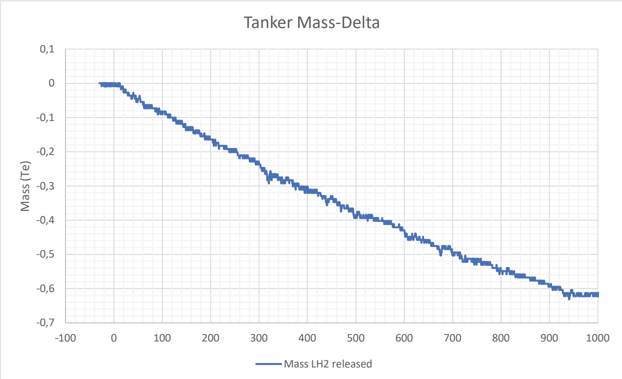
FFI: LH2 Releases

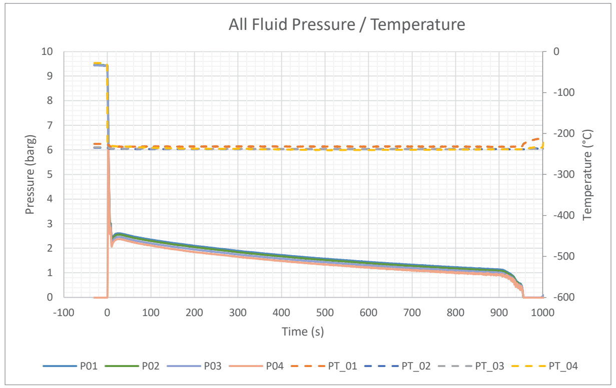
Test Name	Test03	
Hole Size	25,4	mm
Orientation	Downwards	

FOR PLOTS

Start Time	-30	sec
End Time	1300	sec

Date 13.12.2019

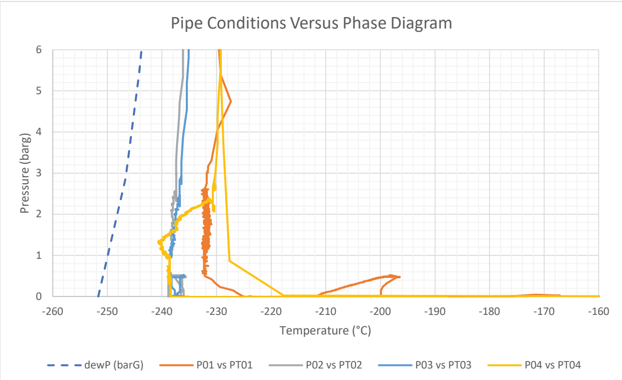


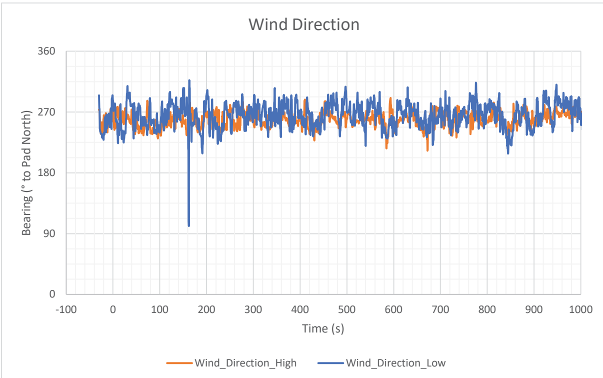


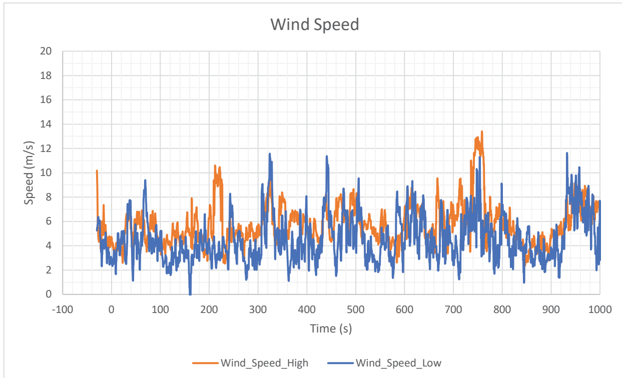
FOR AVERAGING

Start	100	sec
End	900	sec

Sensor	Average	Max	Min	STDEV	units
Mass LH2 released	-	-0,082	-0,595	-	Te
P01	1,63	2,35	1,13	0,34	Barg
P02	1,57	2,29	1,09	0,34	Barg
P03	1,48	2,20	0,99	0,33	Barg
P04	1,39	2,11	0,89	0,33	Barg
PT_01	-231,9	-230,9	-232,6	0,3	°C
PT_02	-238,1	-237,8	-238,4	0,1	°C
PT_03	-237,9	-237,1	-238,6	0,4	°C
PT_04	-238,7	-234,7	-240,6	1,4	°C
MassFlow	0,630				kg/s
Wind_Direction_High	258,7	290,9	212,7	10,7	0,0
Wind_Direction_Low	264,7	317,1	101,1	18,7	Deg
Wind_Speed_High	5,8	13,4	2,4	1,8	m/s
Wind_Speed_Low	4,4	11,6	-0,2	1,9	m/s





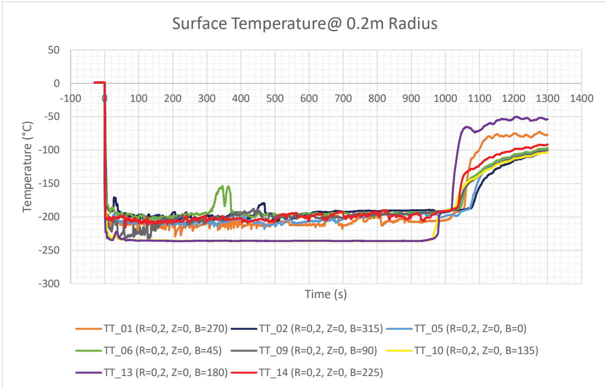


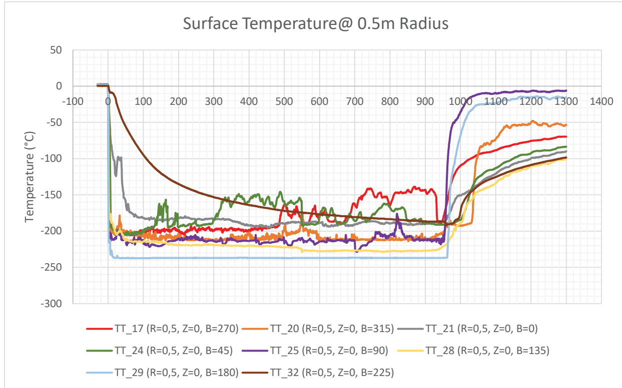
Pad Temperature

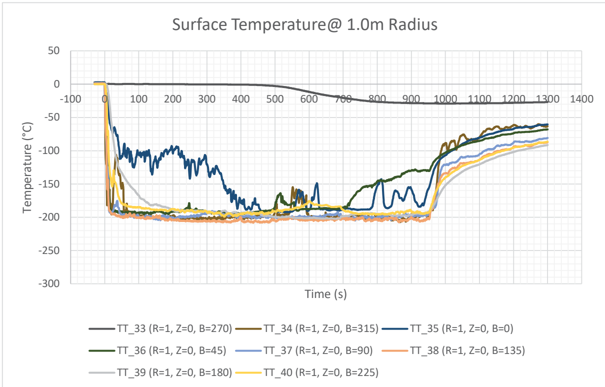
Test Name	Test03			FOR AVERAGING		
Hole Size	25,4	mm		Start	100	sec
Orientation	Downwards			End	500	sec

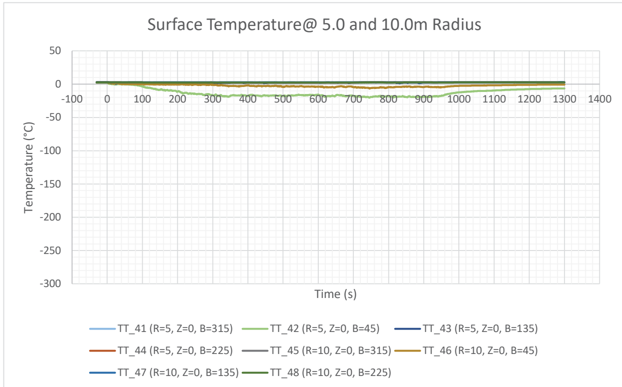
Notes: Looks like Liquid observed on surface @1.0m but not 5.0m.
LH2 not observed further than 0.5m
Note centre and bearing of array needs to be clarified (300mm to east)

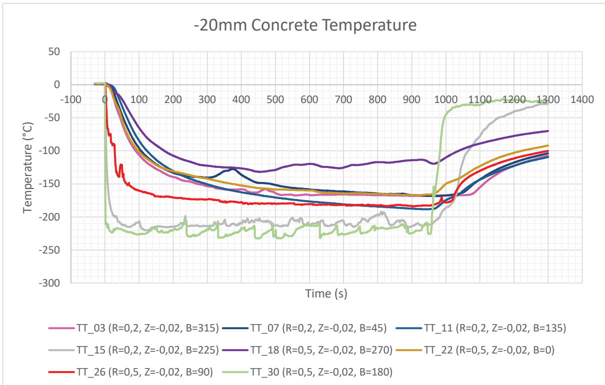
Sensor	Average	Max	Min	STDEV	units
TT_01 (R=0,2, Z=0, B=270)	-212,1	-203,3	-229,3	3,5	°C
TT_02 (R=0,2, Z=0, B=315)	-198,3	-179,2	-206,4	5,1	°C
TT_03 (R=0,2, Z=-0,02, B=315)	-147,7	-106,4	-163,9	14,6	°C
TT_04 (R=0,2, Z=-0,03, B=315)	-102,1	-38,8	-130,7	25,2	°C
TT_05 (R=0,2, Z=0, B=0)	-207,7	-198,8	-218,0	2,9	°C
TT_06 (R=0,2, Z=0, B=45)	-193,2	-153,5	-205,9	11,8	°C
TT_07 (R=0,2, Z=-0,02, B=45)	-134,1	-96,1	-151,7	11,9	°C
TT_08 (R=0,2, Z=-0,03, B=45)	-128,8	-87,8	-144,9	12,4	°C
TT_09 (R=0,2, Z=0, B=90)	-203,6	-187,4	-232,8	8,6	°C
TT_10 (R=0,2, Z=0, B=135)	-235,6	-234,9	-236,0	0,3	°C
TT_11 (R=0,2, Z=-0,02, B=135)	-144,2	-84,8	-170,5	22,2	°C
TT_12 (R=0,2, Z=-0,03, B=135)	-97,4	-27,9	-132,4	28,4	°C
TT_13 (R=0,2, Z=0, B=180)	-235,7	-235,1	-236,1	0,2	°C
TT_14 (R=0,2, Z=0, B=225)	-204,8	-197,8	-211,5	2,6	°C
TT_15 (R=0,2, Z=-0,02, B=225)	-211,6	-198,6	-220,2	4,0	°C
TT_16 (R=0,2, Z=-0,03, B=225)	-211,4	-204,7	-219,4	2,3	°C
TT_17 (R=0,5, Z=0, B=270)	-197,1	-163,3	-205,6	5,3	°C
TT_18 (R=0,5, Z=-0,02, B=270)	-115,2	-65,4	-131,8	16,6	°C
TT_19 (R=0,5, Z=-0,03, B=270)	-64,8	-11,8	-91,4	22,4	°C
TT_20 (R=0,5, Z=0, B=315)	-209,5	-196,0	-213,9	2,8	°C
TT_21 (R=0,5, Z=0, B=0)	-186,2	-178,9	-195,3	4,2	°C
TT_22 (R=0,5, Z=-0,02, B=0)	-139,9	-101,5	-158,4	14,4	°C
TT_23 (R=0,5, Z=-0,03, B=0)	-62,3	-6,4	-97,6	25,8	°C
TT_24 (R=0,5, Z=0, B=45)	-173,7	-145,6	-200,6	17,0	°C
TT_25 (R=0,5, Z=0, B=90)	-214,0	-205,3	-221,8	3,1	°C
TT_26 (R=0,5, Z=-0,02, B=90)	-173,7	-160,3	-180,6	5,1	°C
TT_27 (R=0,5, Z=-0,03, B=90)	-67,1	-13,4	-100,4	24,5	°C
TT_28 (R=0,5, Z=0, B=135)	-219,1	-213,9	-222,5	2,0	°C
TT_29 (R=0,5, Z=0, B=180)	-237,0	-236,8	-237,3	0,1	°C
TT_30 (R=0,5, Z=-0,02, B=180)	-222,6	-206,1	-232,4	5,4	°C
TT_31 (R=0,5, Z=-0,03, B=180)	-205,1	-195,9	-208,0	2,0	°C
TT_32 (R=0,5, Z=0, B=225)	-147,6	-94,8	-172,1	19,9	°C
TT_33 (R=1, Z=0, B=270)	-0,5	0,2	-2,9	0,7	°C
TT_34 (R=1, Z=0, B=315)	-199,9	-190,3	-204,9	1,7	°C
TT_35 (R=1, Z=0, B=0)	-139,8	-92,8	-192,8	33,9	°C
TT_36 (R=1, Z=0, B=45)	-191,9	-178,8	-195,5	2,3	°C
TT_37 (R=1, Z=0, B=90)	-198,4	-190,6	-204,6	2,6	°C
TT_38 (R=1, Z=0, B=135)	-204,7	-196,7	-208,4	2,3	°C
TT_39 (R=1, Z=0, B=180)	-190,0	-167,1	-199,7	6,3	°C
TT_40 (R=1, Z=0, B=225)	-191,8	-184,8	-199,3	3,1	°C
TT_41 (R=5, Z=0, B=315)	2,6	2,8	1,8	0,1	°C
TT_42 (R=5, Z=0, B=45)	-14,1	-3,0	-19,1	4,0	°C
TT_43 (R=5, Z=0, B=135)	1,8	2,7	-0,1	0,6	°C
TT_44 (R=5, Z=0, B=225)	2,4	2,5	1,1	0,2	°C
TT_45 (R=10, Z=0, B=315)	2,7	2,8	2,6	0,0	°C
TT_46 (R=10, Z=0, B=45)	-1,6	-0,2	-4,0	1,1	°C
TT_47 (R=10, Z=0, B=135)	2,6	2,8	2,5	0,1	°C
TT_48 (R=10, Z=0, B=225)	2,4	2,6	2,3	0,1	°C

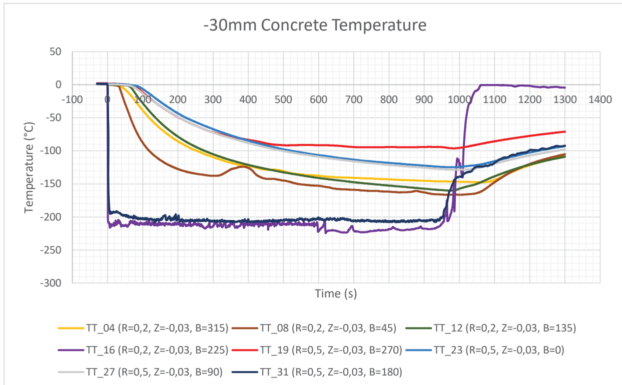








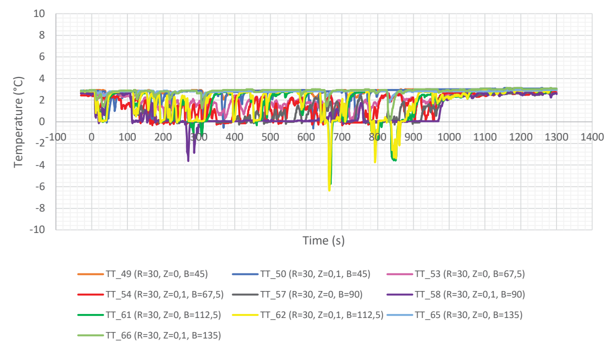




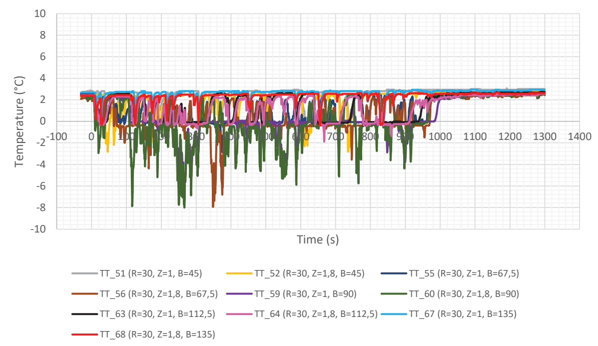
DNV·GL

Notes: Greater temperature drop observed at 30 m, 1 and 1.8 m high

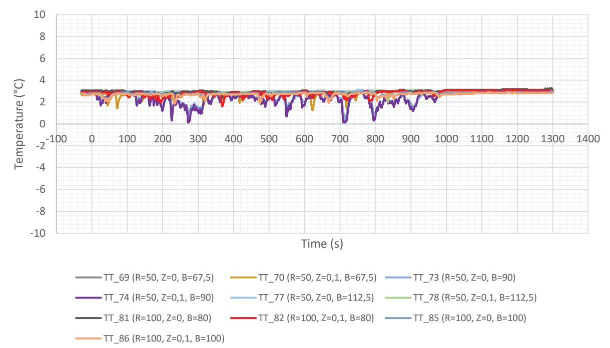
30m Radius, 0.0 and 0.1 m high Field Temperature



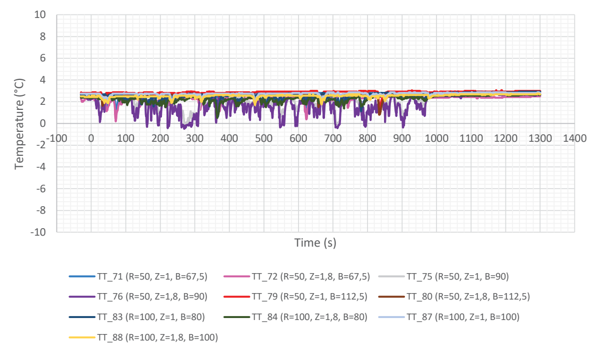
30m Radius, 1 m and 1.8 m high Field Temperature



50 m and 100 m Radius, 0.0 m and 0.1 m high Field Temperature



50 m and 100 m Radius, 1 m and 1.8 m high Field Temperature



Field Temperature

Test Name: Test03
Hole Size: 25,4 mm
Orientation: Downwards

FOR AVERAGING
Start: 100 sec
End: 500 sec

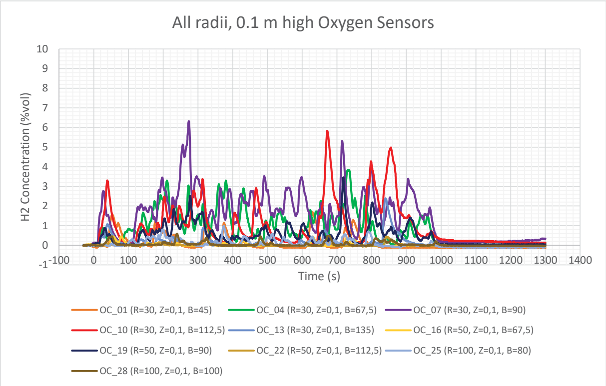
Sensor	Average	Max	Min	STDEV	units
TT_49 (R=30, Z=0, B=45)	2,7	2,9	2,1	0,2	°C
TT_50 (R=30, Z=0,1, B=45)	2,5	2,9	-0,6	0,6	°C
TT_51 (R=30, Z=1, B=45)	2,3	2,9	0,0	0,6	°C
TT_52 (R=30, Z=1,8, B=45)	1,8	2,6	-2,3	1,0	°C
TT_53 (R=30, Z=0, B=67,5)	1,7	2,5	0,3	0,5	°C
TT_54 (R=30, Z=0,1, B=67,5)	0,8	2,4	-0,3	0,8	°C
TT_55 (R=30, Z=1, B=67,5)	0,3	2,0	-2,9	0,7	°C
TT_56 (R=30, Z=1,8, B=67,5)	-0,3	2,1	-7,9	1,5	°C
TT_57 (R=30, Z=0, B=90)	0,4	2,6	-0,3	0,6	°C
TT_58 (R=30, Z=0,1, B=90)	0,1	2,6	-3,6	0,7	°C
TT_59 (R=30, Z=1, B=90)	-0,6	2,5	-7,3	1,4	°C
TT_60 (R=30, Z=1,8, B=90)	-1,4	2,4	-8,0	2,0	°C
TT_61 (R=30, Z=0, B=112,5)	1,5	2,9	-1,3	1,1	°C
TT_62 (R=30, Z=0,1, B=112,5)	1,7	2,9	-0,1	1,1	°C
TT_63 (R=30, Z=1, B=112,5)	1,0	2,6	-0,4	1,0	°C
TT_64 (R=30, Z=1,8, B=112,5)	0,8	2,3	-0,7	1,0	°C
TT_65 (R=30, Z=0, B=135)	2,8	2,9	2,3	0,1	°C
TT_66 (R=30, Z=0,1, B=135)	2,8	3,0	1,3	0,2	°C
TT_67 (R=30, Z=1, B=135)	2,6	2,8	0,2	0,3	°C
TT_68 (R=30, Z=1,8, B=135)	2,2	2,6	-0,3	0,5	°C
TT_69 (R=50, Z=0, B=67,5)	2,9	3,0	2,6	0,0	°C
TT_70 (R=50, Z=0,1, B=67,5)	2,7	2,9	1,8	0,2	°C
TT_71 (R=50, Z=1, B=67,5)	2,6	2,8	1,4	0,2	°C
TT_72 (R=50, Z=1,8, B=67,5)	2,2	2,4	1,1	0,2	°C
TT_73 (R=50, Z=0, B=90)	2,3	2,8	0,6	0,4	°C
TT_74 (R=50, Z=0,1, B=90)	2,2	2,8	0,1	0,6	°C
TT_75 (R=50, Z=1, B=90)	1,8	2,7	-0,1	0,6	°C
TT_76 (R=50, Z=1,8, B=90)	1,4	2,6	-0,5	0,8	°C
TT_77 (R=50, Z=0, B=112,5)	3,0	3,0	2,8	0,0	°C
TT_78 (R=50, Z=0,1, B=112,5)	2,9	3,0	2,5	0,1	°C
TT_79 (R=50, Z=1, B=112,5)	2,8	2,9	2,4	0,1	°C
TT_80 (R=50, Z=1,8, B=112,5)	2,6	2,6	2,2	0,1	°C
TT_81 (R=100, Z=0, B=80)	2,9	3,1	2,4	0,1	°C
TT_82 (R=100, Z=0,1, B=80)	2,7	3,0	1,6	0,2	°C
TT_83 (R=100, Z=1, B=80)	2,4	2,8	0,6	0,3	°C
TT_84 (R=100, Z=1,8, B=80)	2,1	2,4	0,5	0,3	°C
TT_85 (R=100, Z=0, B=100)	2,7	2,9	2,1	0,1	°C
TT_86 (R=100, Z=0,1, B=100)	2,7	2,8	1,9	0,2	°C
TT_87 (R=100, Z=1, B=100)	2,7	2,8	2,0	0,1	°C
TT_88 (R=100, Z=1,8, B=100)	2,5	2,7	1,7	0,1	°C

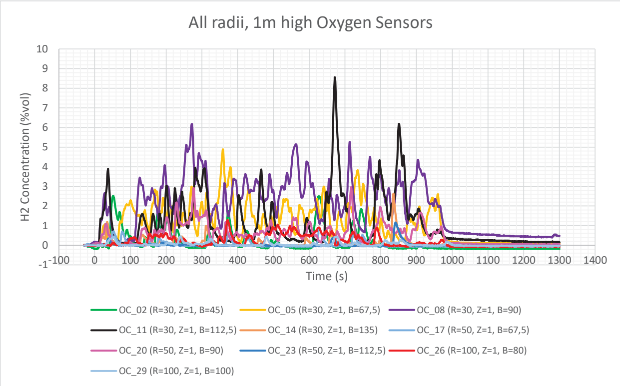
Gas Concentrations

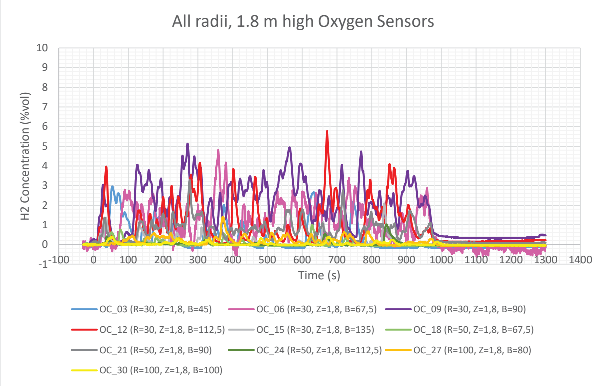
Test Name	Test03		FOR AVERAGING		
Hole Size	25,4	mm	Start	100	sec
Orientation	Downwards		End	500	sec

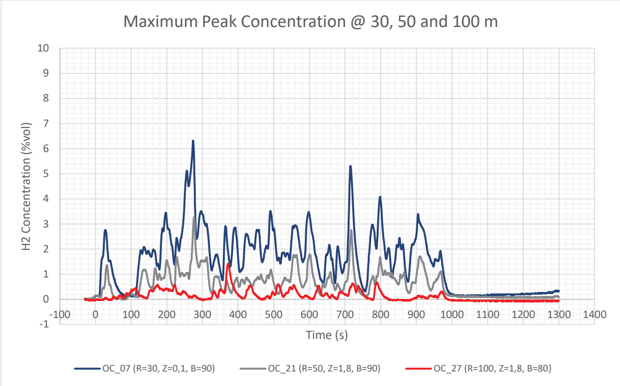
Notes: Peak concentrations observed @ 30 m
Max. ~6%vol detected at 30m west

Sensor	Average	Max	Min	STDEV	units
OC_01 (R=30, Z=0,1, B=45)	0,2	1,3	-0,1	0,4	%vol
OC_02 (R=30, Z=1, B=45)	0,3	1,7	-0,2	0,4	%vol
OC_03 (R=30, Z=1,8, B=45)	0,5	2,0	-0,2	0,6	%vol
OC_04 (R=30, Z=0,1, B=67,5)	1,5	3,3	0,2	0,8	%vol
OC_05 (R=30, Z=1, B=67,5)	1,7	4,9	0,2	0,9	%vol
OC_06 (R=30, Z=1,8, B=67,5)	1,3	4,8	-0,6	1,0	%vol
OC_07 (R=30, Z=0,1, B=90)	2,3	6,3	0,1	1,1	%vol
OC_08 (R=30, Z=1, B=90)	2,7	6,2	0,2	1,1	%vol
OC_09 (R=30, Z=1,8, B=90)	2,6	5,1	0,4	1,0	%vol
OC_10 (R=30, Z=0,1, B=112,5)	1,1	3,4	0,0	0,8	%vol
OC_11 (R=30, Z=1, B=112,5)	1,3	4,0	0,0	1,0	%vol
OC_12 (R=30, Z=1,8, B=112,5)	1,2	4,2	0,0	1,0	%vol
OC_13 (R=30, Z=0,1, B=135)	0,1	0,9	0,0	0,2	%vol
OC_14 (R=30, Z=1, B=135)	0,1	1,0	0,0	0,2	%vol
OC_15 (R=30, Z=1,8, B=135)	0,2	0,9	0,0	0,2	%vol
OC_16 (R=50, Z=0,1, B=67,5)	0,0	0,3	-0,1	0,1	%vol
OC_17 (R=50, Z=1, B=67,5)	0,1	0,6	-0,1	0,1	%vol
OC_18 (R=50, Z=1,8, B=67,5)	0,1	0,5	-0,1	0,1	%vol
OC_19 (R=50, Z=0,1, B=90)	0,7	2,5	0,0	0,5	%vol
OC_20 (R=50, Z=1, B=90)	0,8	2,9	0,1	0,5	%vol
OC_21 (R=50, Z=1,8, B=90)	0,9	3,3	0,1	0,5	%vol
OC_22 (R=50, Z=0,1, B=112,5)	0,0	0,2	0,0	0,0	%vol
OC_23 (R=50, Z=1, B=112,5)	0,0	0,1	0,0	0,0	%vol
OC_24 (R=50, Z=1,8, B=112,5)	0,0	0,2	0,0	0,0	%vol
OC_25 (R=100, Z=0,1, B=80)	0,2	1,0	-0,1	0,2	%vol
OC_26 (R=100, Z=1, B=80)	0,3	1,3	-0,1	0,3	%vol
OC_27 (R=100, Z=1,8, B=80)	0,3	1,4	0,0	0,2	%vol
OC_28 (R=100, Z=0,1, B=100)	0,1	0,6	0,0	0,1	%vol
OC_29 (R=100, Z=1, B=100)	0,1	0,5	0,0	0,1	%vol
OC_30 (R=100, Z=1,8, B=100)	0,0	0,3	0,0	0,1	%vol









DNV·GL

Notes

Maybe offset in temperature - no measurements reach liquid temp, need to investigate

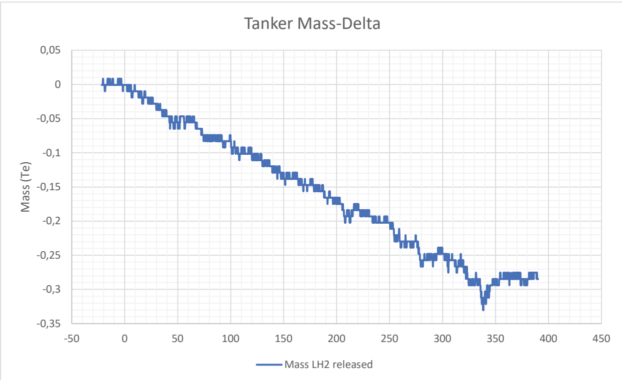
FFI: LH2 Releases

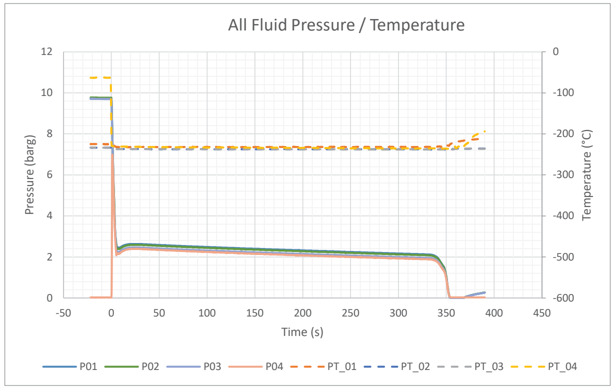
Test Name	Test04	
Hole Size	25,4	mm
Orientation	Horizontal	

FOR PLOTS

Start Time	-20	sec
End Time	390	sec

Date 13.12.2019

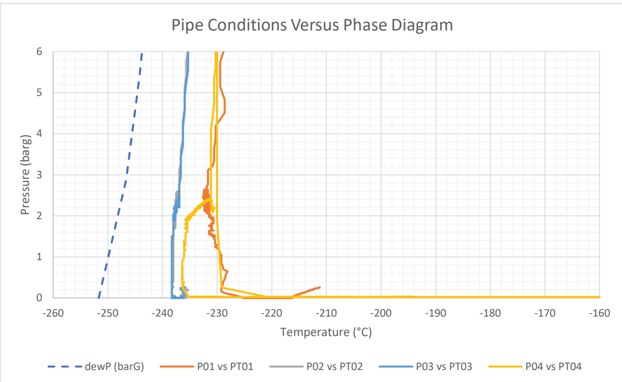


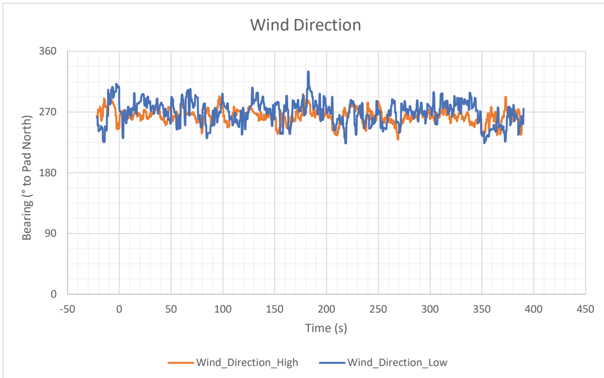


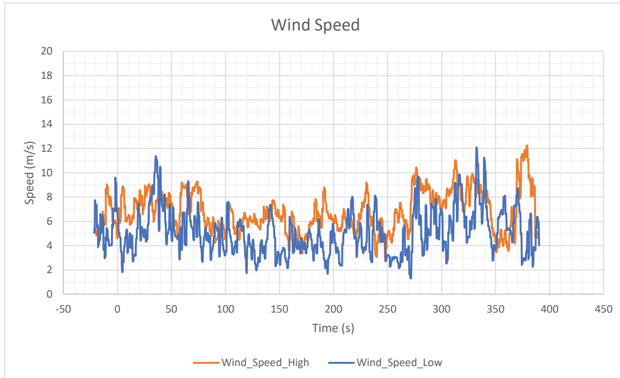
FOR AVERAGING

Start	50	sec
End	300	sec

Sensor	Average	Max	Min	STDEV	units
Load_Cell	-	-0,019	-0,294	-	Te
P01	2,36	2,63	2,10	0,15	Barg
P02	2,32	2,59	2,06	0,15	Barg
P03	2,19	2,46	1,94	0,15	Barg
P04	2,12	2,40	1,87	0,15	Barg
PT_01	-232,0	-231,1	-232,6	0,2	°C
PT_02	-237,4	-237,1	-237,8	0,2	°C
PT_03	-237,5	-236,9	-238,0	0,3	°C
PT_04	-234,0	-231,4	-235,8	1,1	°C
MassFlow	0,828				kg/s
Wind_Direction_High	264,1	296,6	229,1	10,1	0,0
Wind_Direction_Low	271,0	330,6	223,5	15,9	Deg
Wind_Speed_High	6,7	11,0	2,8	1,6	m/s
Wind_Speed_Low	5,0	12,1	1,3	1,9	m/s





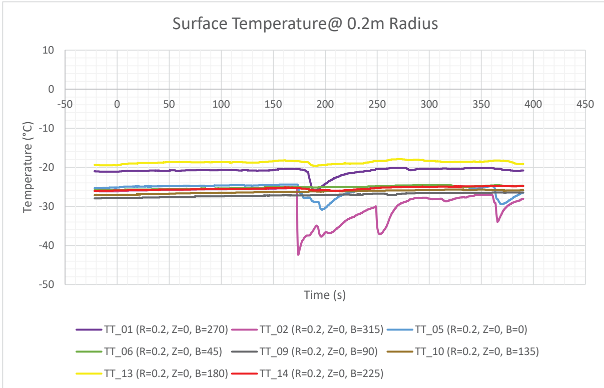


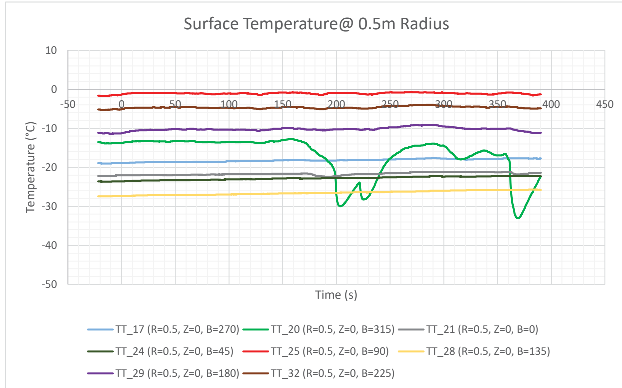
Pad Temperature

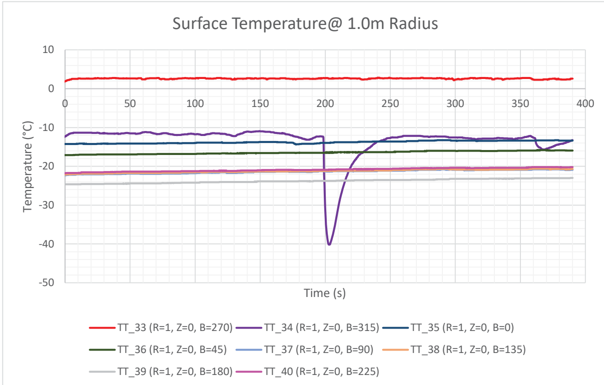
Test Name	Test04		FOR AVERAGING	
Hole Size	25,4	mm	Start	25 sec
Orientation	Horizontal		End	335 sec

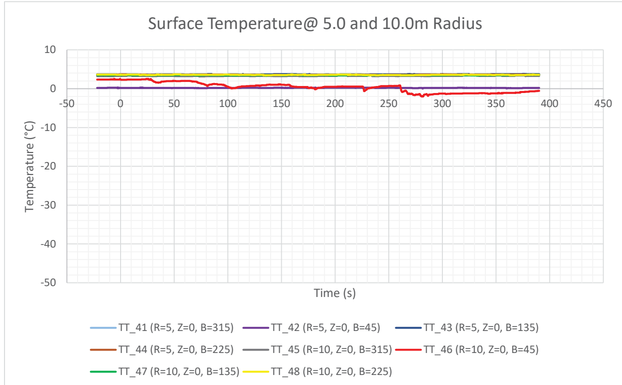
Notes: LH2 not observed on concrete pad
Note centre and bearing of array needs to be clarified (300mm to east)

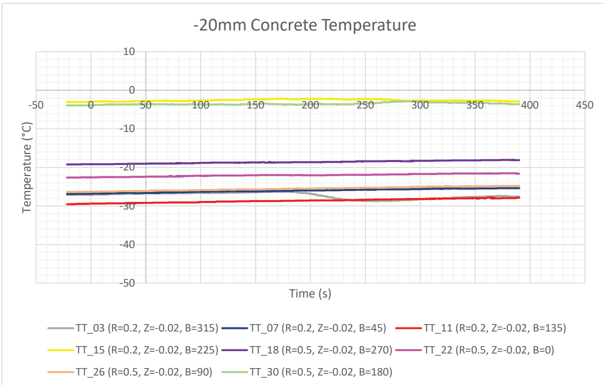
Sensor	Average	Max	Min	STDEV	units
TT_01 (R=0.2, Z=0, B=270)	-21,0	-20,1	-25,9	1,1	°C
TT_02 (R=0.2, Z=0, B=315)	-29,0	-25,3	-42,4	4,3	°C
TT_03 (R=0.2, Z=-0.02, B=315)	-27,3	-26,3	-28,8	0,9	°C
TT_04 (R=0.2, Z=-0.03, B=315)	-27,8	-27,3	-28,4	0,4	°C
TT_05 (R=0.2, Z=0, B=0)	-25,4	-24,4	-30,9	1,4	°C
TT_06 (R=0.2, Z=0, B=45)	-25,1	-24,5	-25,7	0,3	°C
TT_07 (R=0.2, Z=-0.02, B=45)	-26,1	-25,4	-26,7	0,4	°C
TT_08 (R=0.2, Z=-0.03, B=45)	-26,3	-25,7	-26,9	0,4	°C
TT_09 (R=0.2, Z=0, B=90)	-27,1	-26,5	-27,7	0,3	°C
TT_10 (R=0.2, Z=0, B=135)	-26,2	-25,6	-26,9	0,3	°C
TT_11 (R=0.2, Z=-0.02, B=135)	-28,7	-28,0	-29,3	0,4	°C
TT_12 (R=0.2, Z=-0.03, B=135)	-29,8	-29,2	-30,4	0,4	°C
TT_13 (R=0.2, Z=0, B=180)	-18,7	-17,9	-19,6	0,3	°C
TT_14 (R=0.2, Z=0, B=225)	-25,4	-24,9	-26,0	0,3	°C
TT_15 (R=0.2, Z=-0.02, B=225)	-2,5	-2,2	-3,0	0,2	°C
TT_16 (R=0.2, Z=-0.03, B=225)	-1,6	-0,8	-4,6	1,0	°C
TT_17 (R=0.5, Z=0, B=270)	-18,2	-17,6	-18,7	0,3	°C
TT_18 (R=0.5, Z=-0.02, B=270)	-18,7	-18,2	-19,1	0,3	°C
TT_19 (R=0.5, Z=-0.03, B=270)	-21,0	-20,6	-21,6	0,3	°C
TT_20 (R=0.5, Z=0, B=315)	-16,3	-12,8	-30,0	4,5	°C
TT_21 (R=0.5, Z=0, B=0)	-21,7	-21,2	-22,5	0,3	°C
TT_22 (R=0.5, Z=-0.02, B=0)	-22,0	-21,6	-22,5	0,2	°C
TT_23 (R=0.5, Z=-0.03, B=0)	-24,4	-23,8	-24,9	0,3	°C
TT_24 (R=0.5, Z=0, B=45)	-22,8	-22,3	-23,4	0,3	°C
TT_25 (R=0.5, Z=0, B=90)	-1,0	-0,7	-1,5	0,2	°C
TT_26 (R=0.5, Z=-0.02, B=90)	-25,5	-24,9	-26,1	0,4	°C
TT_27 (R=0.5, Z=-0.03, B=90)	-28,6	-27,9	-29,2	0,4	°C
TT_28 (R=0.5, Z=0, B=135)	-26,6	-25,9	-27,1	0,4	°C
TT_29 (R=0.5, Z=0, B=180)	-10,1	-9,1	-10,6	0,4	°C
TT_30 (R=0.5, Z=-0.02, B=180)	-3,5	-2,9	-3,9	0,2	°C
TT_31 (R=0.5, Z=-0.03, B=180)	-23,0	-22,3	-23,8	0,4	°C
TT_32 (R=0.5, Z=0, B=225)	-4,6	-3,9	-5,1	0,3	°C
TT_33 (R=1, Z=0, B=270)	2,6	2,8	2,2	0,1	°C
TT_34 (R=1, Z=0, B=315)	-13,5	-10,9	-40,2	5,0	°C
TT_35 (R=1, Z=0, B=0)	-13,8	-13,3	-14,4	0,3	°C
TT_36 (R=1, Z=0, B=45)	-16,5	-16,0	-16,9	0,3	°C
TT_37 (R=1, Z=0, B=90)	-21,4	-20,8	-22,1	0,4	°C
TT_38 (R=1, Z=0, B=135)	-21,3	-20,6	-21,9	0,3	°C
TT_39 (R=1, Z=0, B=180)	-23,8	-23,2	-24,6	0,4	°C
TT_40 (R=1, Z=0, B=225)	-20,9	-20,4	-21,6	0,4	°C
TT_41 (R=5, Z=0, B=315)	3,4	3,5	3,4	0,0	°C
TT_42 (R=5, Z=0, B=45)	0,2	0,3	0,0	0,0	°C
TT_43 (R=5, Z=0, B=135)	3,7	3,8	3,6	0,0	°C
TT_44 (R=5, Z=0, B=225)	3,6	3,7	3,5	0,0	°C
TT_45 (R=10, Z=0, B=315)	3,3	3,4	3,2	0,0	°C
TT_46 (R=10, Z=0, B=45)	0,4	2,5	-2,0	1,1	°C
TT_47 (R=10, Z=0, B=135)	3,5	3,6	3,3	0,0	°C
TT_48 (R=10, Z=0, B=225)	3,5	3,7	3,4	0,1	°C

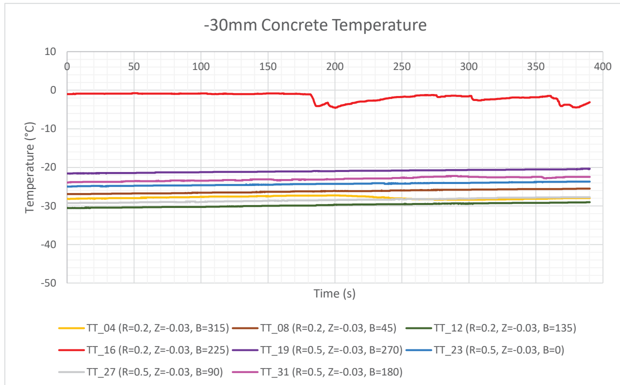










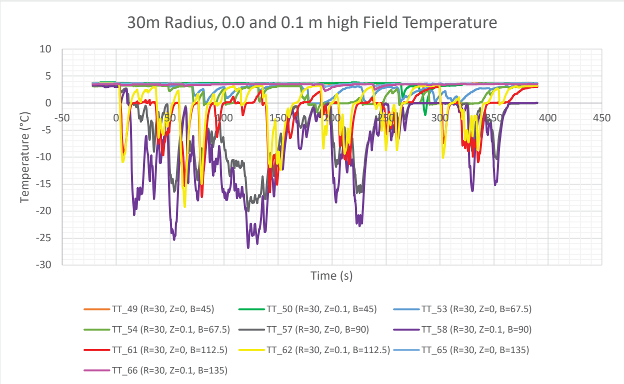


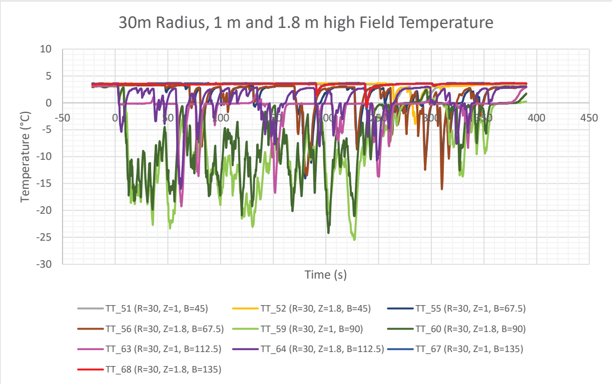
DNV·GL

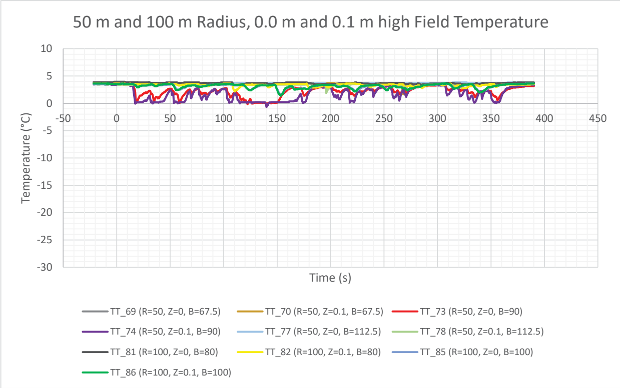
Notes: Greater temperature drop observed at 30 m, both at low and high level. At 50m and 100m greater temperature drop achieved at high level (1m and 1.8m)

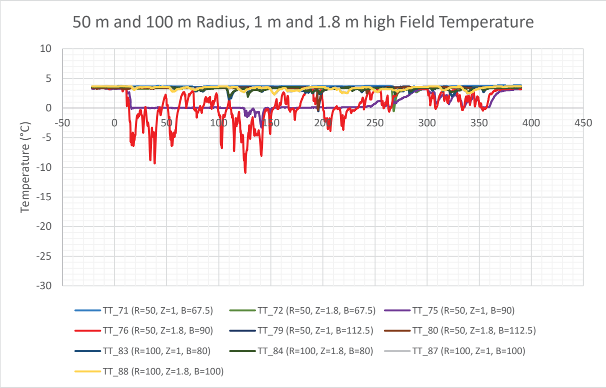
Field Temperature

Test Name	Test04		FOR AVERAGING		
Hole Size	25,4	mm	Start	25	sec
Orientation	Horizontal		End	335	sec









Sensor	Average	Max	Min	STDEV	units
TT_49 (R=30, Z=0, B=45)	3,6	3,7	2,1	0,2	°C
TT_50 (R=30, Z=0.1, B=45)	3,5	3,8	-2,2	0,7	°C
TT_51 (R=30, Z=1, B=45)	3,1	3,6	-0,1	0,8	°C
TT_52 (R=30, Z=1.8, B=45)	3,2	3,7	-3,9	0,9	°C
TT_53 (R=30, Z=0, B=67.5)	2,2	3,5	-0,3	1,1	°C
TT_54 (R=30, Z=0.1, B=67.5)	1,2	3,3	-1,7	1,4	°C
TT_55 (R=30, Z=1, B=67.5)	0,6	3,3	-14,1	3,3	°C
TT_56 (R=30, Z=1.8, B=67.5)	0,7	3,4	-16,1	3,5	°C
TT_57 (R=30, Z=0, B=90)	-5,8	0,0	-20,1	5,4	°C
TT_58 (R=30, Z=0.1, B=90)	-8,8	0,1	-26,8	7,4	°C
TT_59 (R=30, Z=1, B=90)	-9,6	2,1	-25,5	6,5	°C
TT_60 (R=30, Z=1.8, B=90)	-7,2	2,4	-24,2	6,0	°C
TT_61 (R=30, Z=0, B=112.5)	-2,5	3,0	-17,4	4,2	°C
TT_62 (R=30, Z=0.1, B=112.5)	-1,1	3,3	-19,3	4,3	°C
TT_63 (R=30, Z=1, B=112.5)	-1,6	2,0	-19,3	3,4	°C
TT_64 (R=30, Z=1.8, B=112.5)	0,0	3,0	-16,0	3,2	°C
TT_65 (R=30, Z=0, B=135)	3,5	3,7	3,0	0,1	°C
TT_66 (R=30, Z=0.1, B=135)	3,4	3,6	2,3	0,2	°C
TT_67 (R=30, Z=1, B=135)	3,5	3,7	-1,3	0,4	°C
TT_68 (R=30, Z=1.8, B=135)	3,4	3,6	-0,8	0,4	°C
TT_69 (R=50, Z=0, B=67.5)	3,6	3,8	3,3	0,1	°C
TT_70 (R=50, Z=0.1, B=67.5)	3,6	3,7	1,7	0,2	°C
TT_71 (R=50, Z=1, B=67.5)	3,6	3,8	1,3	0,2	°C
TT_72 (R=50, Z=1.8, B=67.5)	3,3	3,5	-0,6	0,3	°C
TT_73 (R=50, Z=0, B=90)	2,1	3,3	-0,1	0,9	°C
TT_74 (R=50, Z=0.1, B=90)	1,6	3,5	-0,7	1,1	°C
TT_75 (R=50, Z=1, B=90)	0,5	3,3	-3,3	1,0	°C
TT_76 (R=50, Z=1.8, B=90)	0,1	3,3	-10,9	2,7	°C
TT_77 (R=50, Z=0, B=112.5)	3,7	3,8	2,9	0,1	°C
TT_78 (R=50, Z=0.1, B=112.5)	3,4	3,6	1,9	0,1	°C
TT_79 (R=50, Z=1, B=112.5)	3,5	3,6	-0,6	0,3	°C
TT_80 (R=50, Z=1.8, B=112.5)	3,4	3,6	-0,3	0,3	°C
TT_81 (R=100, Z=0, B=80)	3,7	3,9	3,3	0,1	°C
TT_82 (R=100, Z=0.1, B=80)	3,4	3,6	2,2	0,2	°C
TT_83 (R=100, Z=1, B=80)	3,2	3,6	1,4	0,4	°C
TT_84 (R=100, Z=1.8, B=80)	3,2	3,5	1,9	0,3	°C
TT_85 (R=100, Z=0, B=100)	3,1	3,6	1,6	0,4	°C
TT_86 (R=100, Z=0.1, B=100)	3,1	3,6	1,4	0,4	°C
TT_87 (R=100, Z=1, B=100)	3,3	3,7	2,3	0,3	°C
TT_88 (R=100, Z=1.8, B=100)	3,3	3,7	2,3	0,3	°C

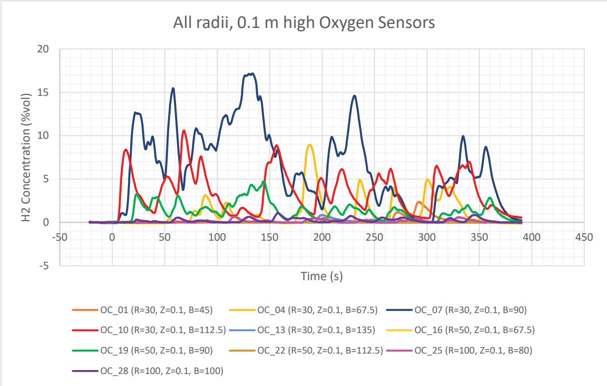
Gas Concentrations

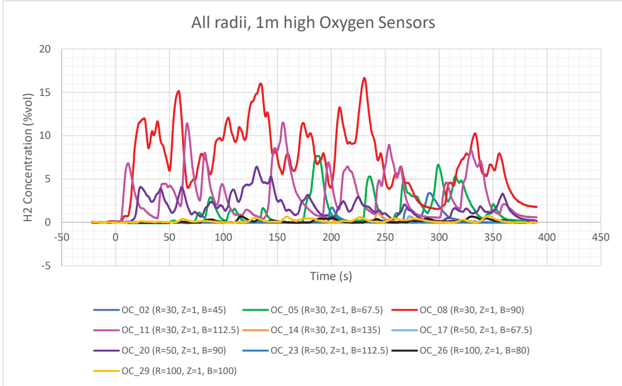
Test Name	Test04		FOR AVERAGING		
Hole Size	25,4	mm	Start	25	sec
Orientation	Horizontal		End	300	sec

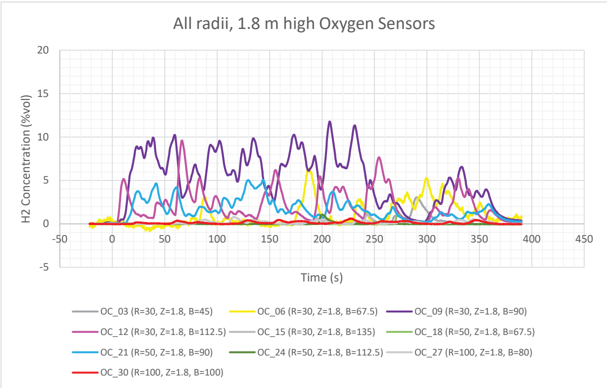
Notes:

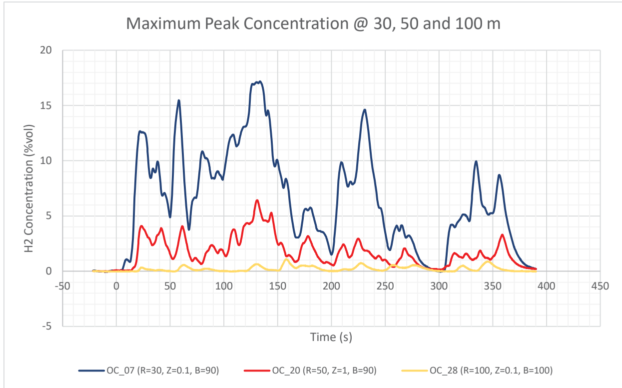
Higher H2 concentration at low level. Peak concentrations observed @ 30m
Max. ~17%vol detected at 30m west

Sensor	Average	Max	Min	STDEV	units
OC_01 (R=30, Z=0.1, B=45)	0,1	2,4	0,0	0,5	%vol
OC_02 (R=30, Z=1, B=45)	0,2	3,4	0,0	0,7	%vol
OC_03 (R=30, Z=1.8, B=45)	0,2	3,1	0,0	0,6	%vol
OC_04 (R=30, Z=0.1, B=67.5)	1,2	9,0	-0,1	1,8	%vol
OC_05 (R=30, Z=1, B=67.5)	1,3	7,7	-0,1	1,8	%vol
OC_06 (R=30, Z=1.8, B=67.5)	0,9	6,4	-0,9	1,4	%vol
OC_07 (R=30, Z=0.1, B=90)	7,7	17,2	0,0	4,4	%vol
OC_08 (R=30, Z=1, B=90)	8,4	16,7	1,6	3,6	%vol
OC_09 (R=30, Z=1.8, B=90)	6,1	11,8	0,2	2,8	%vol
OC_10 (R=30, Z=0.1, B=112.5)	3,5	10,6	0,5	2,3	%vol
OC_11 (R=30, Z=1, B=112.5)	3,4	11,5	0,4	2,7	%vol
OC_12 (R=30, Z=1.8, B=112.5)	2,5	9,6	0,1	2,0	%vol
OC_13 (R=30, Z=0.1, B=135)	0,1	0,9	0,0	0,2	%vol
OC_14 (R=30, Z=1, B=135)	0,1	1,1	0,0	0,2	%vol
OC_15 (R=30, Z=1.8, B=135)	0,0	1,1	0,0	0,2	%vol
OC_16 (R=50, Z=0.1, B=67.5)	0,0	0,3	0,0	0,0	%vol
OC_17 (R=50, Z=1, B=67.5)	0,0	0,7	-0,1	0,1	%vol
OC_18 (R=50, Z=1.8, B=67.5)	0,0	1,1	0,0	0,1	%vol
OC_19 (R=50, Z=0.1, B=90)	1,5	4,7	0,1	1,0	%vol
OC_20 (R=50, Z=1, B=90)	2,1	6,4	0,2	1,3	%vol
OC_21 (R=50, Z=1.8, B=90)	2,0	5,1	0,2	1,2	%vol
OC_22 (R=50, Z=0.1, B=112.5)	0,0	0,5	0,0	0,1	%vol
OC_23 (R=50, Z=1, B=112.5)	0,1	1,7	0,0	0,2	%vol
OC_24 (R=50, Z=1.8, B=112.5)	0,0	1,1	0,0	0,2	%vol
OC_25 (R=100, Z=0.1, B=80)	0,1	0,6	0,0	0,2	%vol
OC_26 (R=100, Z=1, B=80)	0,1	0,7	0,0	0,2	%vol
OC_27 (R=100, Z=1.8, B=80)	0,2	0,8	0,0	0,2	%vol
OC_28 (R=100, Z=0.1, B=100)	0,2	1,1	0,0	0,2	%vol
OC_29 (R=100, Z=1, B=100)	0,2	0,7	0,0	0,2	%vol
OC_30 (R=100, Z=1.8, B=100)	0,2	0,6	0,0	0,1	%vol









DNV·GL

FFI: LH2 Releases

Notes

First ignited test, 2 minutes unignited release. On activation of ignition sources, system experienced voltage interference which caused the valves to close momentarily (110-200 s). Once the flow was re-established for 2 minutes, ignition was achieved ca.325 s (firework @18 m from release). Ignited release continued for a further 60 s. Maybe offset in temperature - no measurements reach liquid temp, need to investigate

Test Name	Test05	
Hole Size	25,4	mm
Orientation	Downwards	

FOR PLOTS

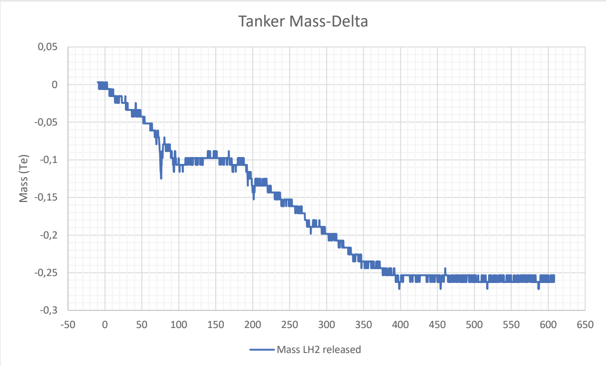
Start Time	-10	sec
End Time	820	sec

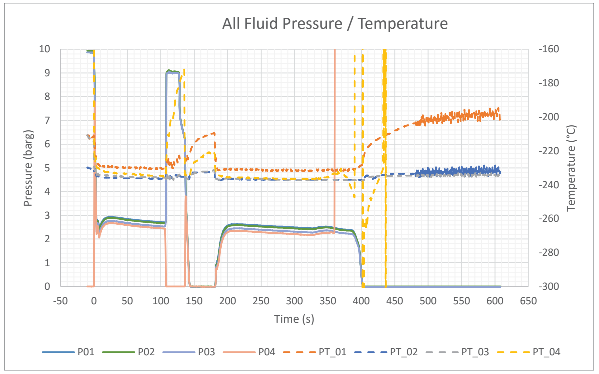
Date 13.12.2019

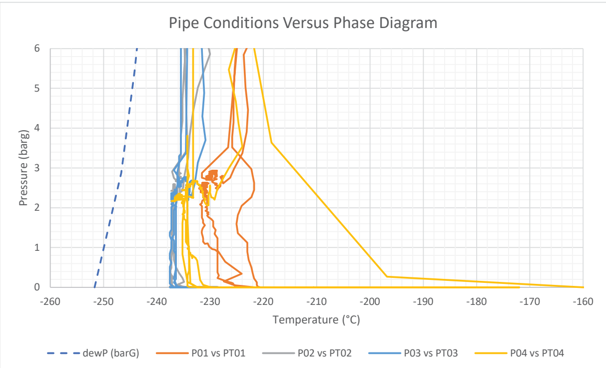
FOR AVERAGING

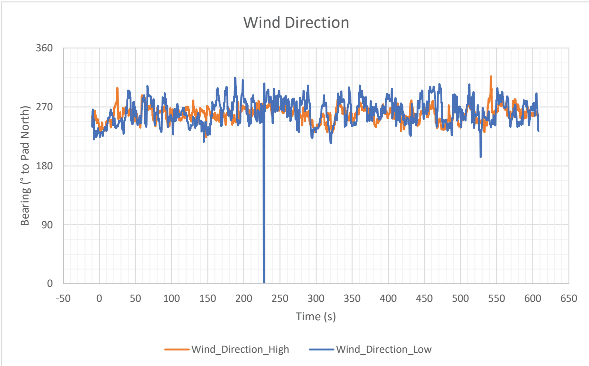
Start	225	sec
End	325	sec

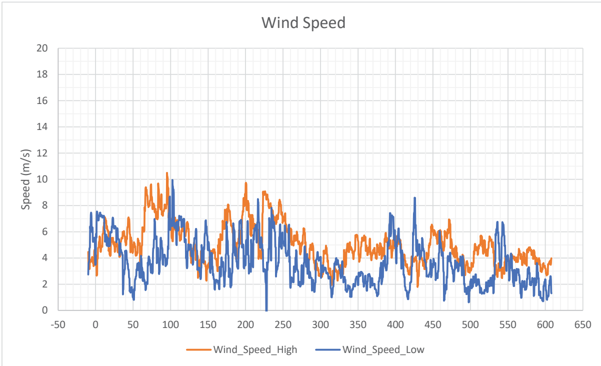
Sensor	Average	Max	Min	STDEV	units
Mass LH2 released	-	-0,143	-0,217	-	Te
P01	2,53	2,62	2,46	0,05	Barg
P02	2,49	2,57	2,41	0,05	Barg
P03	2,35	2,44	2,28	0,05	Barg
P04	2,25	2,34	2,17	0,05	Barg
PT_01	-231,4	-230,6	-232,0	0,3	°C
PT_02	-236,9	-236,6	-236,9	0,1	°C
PT_03	-236,9	-236,3	-237,3	0,2	°C
PT_04	-236,3	-235,7	-236,9	0,3	°C
MassFlow		0,739			kg/s
Wind_Direction_High	257,2	276,6	231,2	12,2	0,0
Wind_Direction_Low	262,2	306,1	2,1	32,1	Deg
Wind_Speed_High	5,2	9,1	1,9	1,9	m/s
Wind_Speed_Low	3,5	7,8	-0,6	1,4	m/s









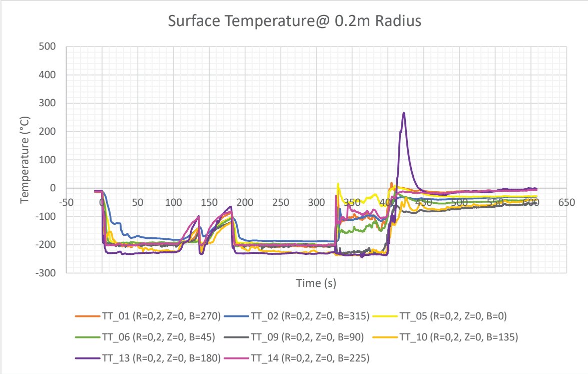


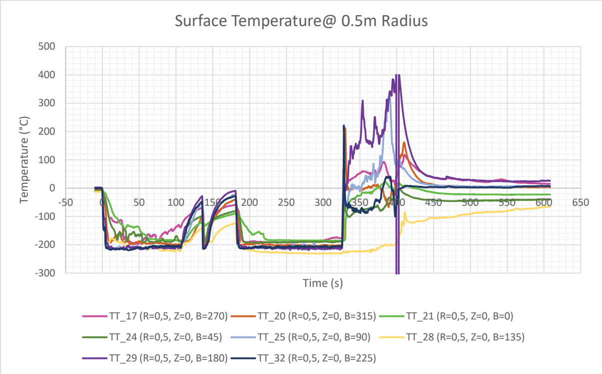
Pad Temperature

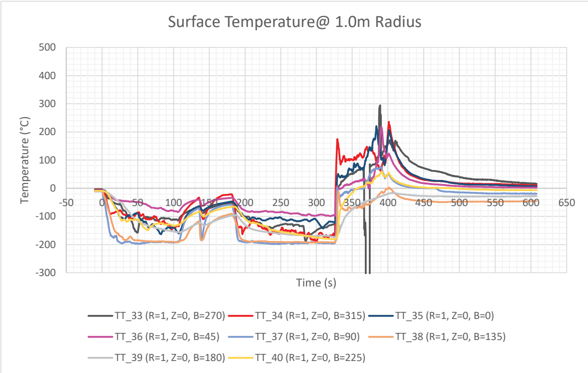
Test Name	Test05		FOR AVERAGING		
Hole Size	25,4	mm	Start	200	sec
Orientation	Downwards		End	325	sec

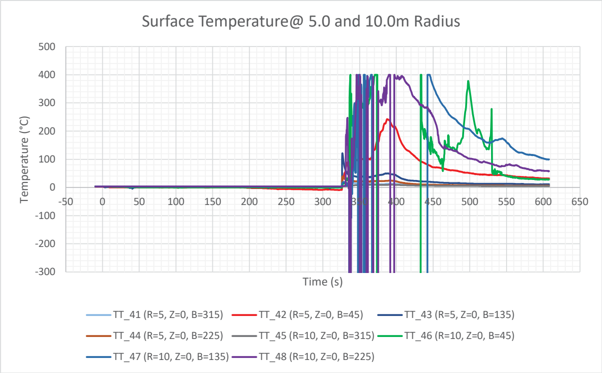
Notes: Liquid temperatures observed at 0.2 m and 0.5 m prior to ignition
Note centre and bearing of array needs to be clarified (300mm to east)

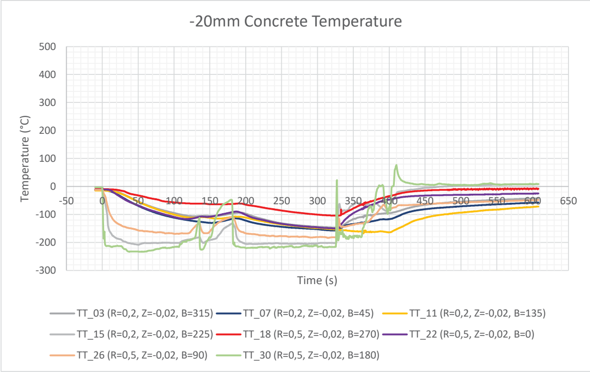
Sensor	Average	Max	Min	STDEV	units
TT_01 (R=0,2, Z=0, B=270)	-205,4	-200,5	-209,8	1,9	°C
TT_02 (R=0,2, Z=0, B=315)	-186,8	-184,0	-188,2	0,9	°C
TT_03 (R=0,2, Z=-0,02, B=315)	-131,2	-97,4	-147,2	14,0	°C
TT_04 (R=0,2, Z=-0,03, B=315)	-90,9	-70,3	-108,8	12,0	°C
TT_05 (R=0,2, Z=0, B=0)	-198,6	-192,8	-203,1	2,4	°C
TT_06 (R=0,2, Z=0, B=45)	-198,6	-195,3	-206,1	2,3	°C
TT_07 (R=0,2, Z=-0,02, B=45)	-144,8	-121,9	-157,1	9,2	°C
TT_08 (R=0,2, Z=-0,03, B=45)	-140,8	-115,8	-154,2	10,2	°C
TT_09 (R=0,2, Z=0, B=90)	-204,1	-196,4	-215,1	2,6	°C
TT_10 (R=0,2, Z=0, B=135)	-223,7	-205,9	-230,9	5,9	°C
TT_11 (R=0,2, Z=-0,02, B=135)	-137,3	-111,3	-153,5	11,8	°C
TT_12 (R=0,2, Z=-0,03, B=135)	-101,3	-82,9	-117,9	10,8	°C
TT_13 (R=0,2, Z=0, B=180)	-230,2	-225,5	-232,6	1,6	°C
TT_14 (R=0,2, Z=0, B=225)	-201,0	-197,3	-203,3	1,1	°C
TT_15 (R=0,2, Z=-0,02, B=225)	-204,0	-201,5	-206,0	1,2	°C
TT_16 (R=0,2, Z=-0,03, B=225)	-212,7	-204,6	-216,4	2,0	°C
TT_17 (R=0,5, Z=0, B=270)	-187,6	-173,6	-192,5	5,3	°C
TT_18 (R=0,5, Z=-0,02, B=270)	-88,4	-65,0	-104,3	11,9	°C
TT_19 (R=0,5, Z=-0,03, B=270)	-46,0	-36,3	-58,9	7,2	°C
TT_20 (R=0,5, Z=0, B=315)	-201,0	-191,8	-206,4	2,5	°C
TT_21 (R=0,5, Z=0, B=0)	-180,5	-154,6	-186,0	9,2	°C
TT_22 (R=0,5, Z=-0,02, B=0)	-134,0	-101,3	-150,6	13,3	°C
TT_23 (R=0,5, Z=-0,03, B=0)	-203,0	-197,2	-210,0	2,2	°C
TT_24 (R=0,5, Z=0, B=45)	-190,4	-186,7	-192,6	1,2	°C
TT_25 (R=0,5, Z=0, B=90)	-209,4	-195,6	-214,8	4,0	°C
TT_26 (R=0,5, Z=-0,02, B=90)	-177,8	-167,9	-183,8	3,9	°C
TT_27 (R=0,5, Z=-0,03, B=90)	-75,1	-62,6	-88,7	8,1	°C
TT_28 (R=0,5, Z=0, B=135)	-228,4	-219,1	-231,4	2,9	°C
TT_29 (R=0,5, Z=0, B=180)	-212,0	-204,5	-219,3	2,3	°C
TT_30 (R=0,5, Z=-0,02, B=180)	-216,1	-210,8	-222,0	2,4	°C
TT_31 (R=0,5, Z=-0,03, B=180)	-194,7	-190,8	-199,9	2,1	°C
TT_32 (R=0,5, Z=0, B=225)	-207,5	-203,3	-212,5	1,9	°C
TT_33 (R=1, Z=0, B=270)	-134,8	-100,3	-187,6	16,1	°C
TT_34 (R=1, Z=0, B=315)	-154,3	-111,9	-188,8	16,9	°C
TT_35 (R=1, Z=0, B=0)	-113,5	-100,6	-141,5	8,1	°C
TT_36 (R=1, Z=0, B=45)	-89,0	-78,6	-99,1	5,8	°C
TT_37 (R=1, Z=0, B=90)	-194,6	-186,4	-198,6	2,1	°C
TT_38 (R=1, Z=0, B=135)	-190,6	-186,3	-193,1	1,5	°C
TT_39 (R=1, Z=0, B=180)	-160,9	-129,6	-173,3	9,5	°C
TT_40 (R=1, Z=0, B=225)	-155,2	-106,9	-181,2	20,3	°C
TT_41 (R=5, Z=0, B=315)	3,5	3,6	3,5	0,0	°C
TT_42 (R=5, Z=0, B=45)	-5,9	-1,6	-9,3	2,2	°C
TT_43 (R=5, Z=0, B=135)	2,0	3,5	-3,3	1,3	°C
TT_44 (R=5, Z=0, B=225)	3,1	3,3	2,9	0,1	°C
TT_45 (R=10, Z=0, B=315)	3,4	3,4	3,4	0,0	°C
TT_46 (R=10, Z=0, B=45)	-0,3	-0,1	-0,8	0,2	°C
TT_47 (R=10, Z=0, B=135)	3,2	3,3	3,1	0,1	°C
TT_48 (R=10, Z=0, B=225)	3,3	3,4	3,2	0,1	°C

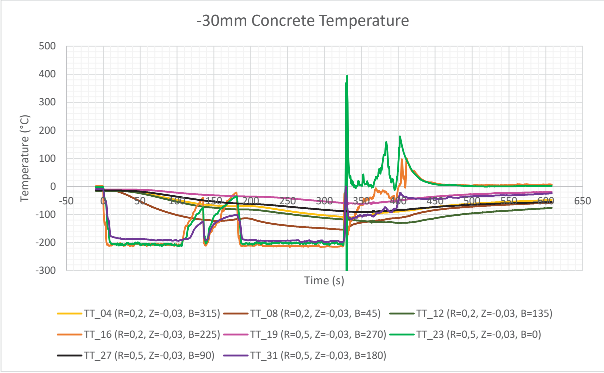








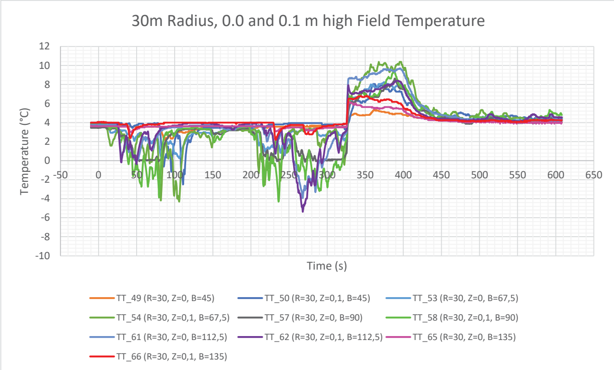


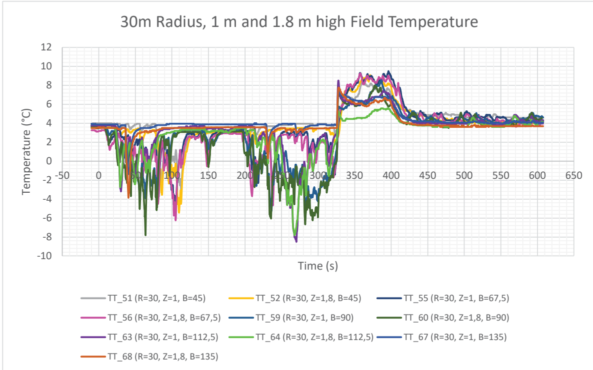


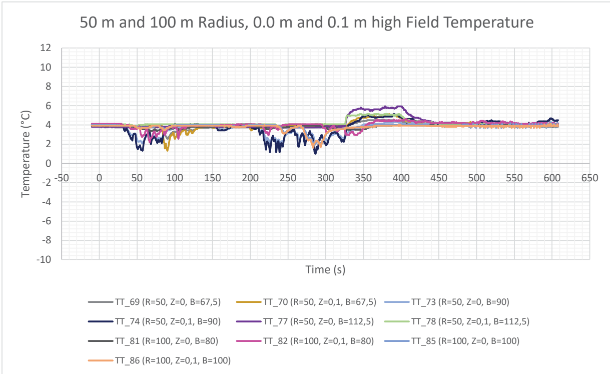
Notes: Greater temperature drop observed at 30 m, both at low and high level. At 50m and 100m greater temperature drop achieved at high level (1m and 1.8m)

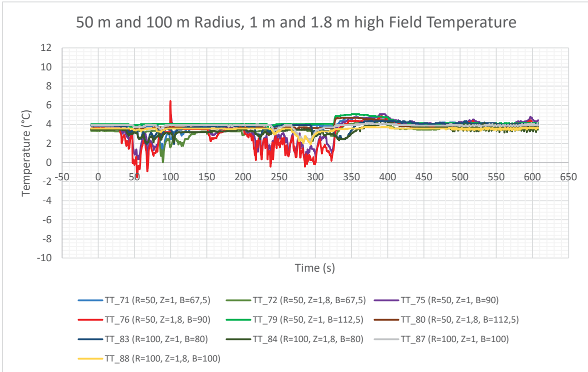
Field Temperature

Test Name	Test05		FOR AVERAGING		
Hole Size	25,4	mm	Start	200	sec
Orientation	Downwards		End	325	sec









Sensor	Average	Max	Min	STDEV	units
TT_49 (R=30, Z=0, B=45)	3,6	3,7	3,4	0,1	°C
TT_50 (R=30, Z=0,1, B=45)	3,8	3,9	3,3	0,2	°C
TT_51 (R=30, Z=1, B=45)	3,7	3,9	2,7	0,3	°C
TT_52 (R=30, Z=1,8, B=45)	3,2	3,5	1,8	0,4	°C
TT_53 (R=30, Z=0, B=67,5)	2,6	3,3	0,8	0,7	°C
TT_54 (R=30, Z=0,1, B=67,5)	2,0	3,4	-2,6	1,5	°C
TT_55 (R=30, Z=1, B=67,5)	1,6	3,2	-3,4	1,5	°C
TT_56 (R=30, Z=1,8, B=67,5)	1,1	2,9	-4,7	1,6	°C
TT_57 (R=30, Z=0, B=90)	0,8	3,1	-0,1	0,9	°C
TT_58 (R=30, Z=0,1, B=90)	-0,2	3,2	-4,3	1,7	°C
TT_59 (R=30, Z=1, B=90)	-1,2	2,8	-5,3	1,7	°C
TT_60 (R=30, Z=1,8, B=90)	-2,1	2,5	-6,7	2,0	°C
TT_61 (R=30, Z=0, B=112,5)	1,0	3,8	-3,9	2,1	°C
TT_62 (R=30, Z=0,1, B=112,5)	1,1	4,0	-5,4	2,6	°C
TT_63 (R=30, Z=1, B=112,5)	0,5	3,7	-8,5	3,0	°C
TT_64 (R=30, Z=1,8, B=112,5)	0,1	3,5	-7,8	2,8	°C
TT_65 (R=30, Z=0, B=135)	3,5	3,6	3,1	0,1	°C
TT_66 (R=30, Z=0,1, B=135)	3,6	4,0	2,2	0,4	°C
TT_67 (R=30, Z=1, B=135)	3,7	4,0	0,9	0,4	°C
TT_68 (R=30, Z=1,8, B=135)	3,3	3,6	0,3	0,4	°C
TT_69 (R=50, Z=0, B=67,5)	3,7	3,8	3,6	0,0	°C
TT_70 (R=50, Z=0,1, B=67,5)	3,9	4,0	3,4	0,1	°C
TT_71 (R=50, Z=1, B=67,5)	3,9	3,9	3,5	0,1	°C
TT_72 (R=50, Z=1,8, B=67,5)	3,3	3,4	2,8	0,1	°C
TT_73 (R=50, Z=0, B=90)	2,9	3,9	2,0	0,4	°C
TT_74 (R=50, Z=0,1, B=90)	2,7	4,1	1,0	0,7	°C
TT_75 (R=50, Z=1, B=90)	2,1	3,9	0,3	0,8	°C
TT_76 (R=50, Z=1,8, B=90)	1,5	3,6	-0,4	0,9	°C
TT_77 (R=50, Z=0, B=112,5)	3,8	3,9	3,7	0,0	°C
TT_78 (R=50, Z=0,1, B=112,5)	4,0	4,1	3,7	0,1	°C
TT_79 (R=50, Z=1, B=112,5)	4,0	4,1	3,3	0,1	°C
TT_80 (R=50, Z=1,8, B=112,5)	3,6	3,7	2,9	0,1	°C
TT_81 (R=100, Z=0, B=80)	3,8	3,9	3,6	0,1	°C
TT_82 (R=100, Z=0,1, B=80)	3,8	4,1	2,9	0,3	°C
TT_83 (R=100, Z=1, B=80)	3,6	3,9	2,4	0,4	°C
TT_84 (R=100, Z=1,8, B=80)	3,2	3,5	2,3	0,2	°C
TT_85 (R=100, Z=0, B=100)	3,4	4,0	1,9	0,6	°C
TT_86 (R=100, Z=0,1, B=100)	3,4	4,0	1,6	0,6	°C
TT_87 (R=100, Z=1, B=100)	3,5	4,0	2,0	0,5	°C
TT_88 (R=100, Z=1,8, B=100)	3,2	3,6	1,9	0,4	°C

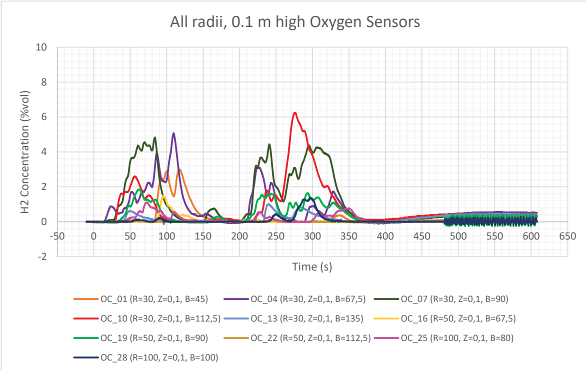
Gas Concentrations

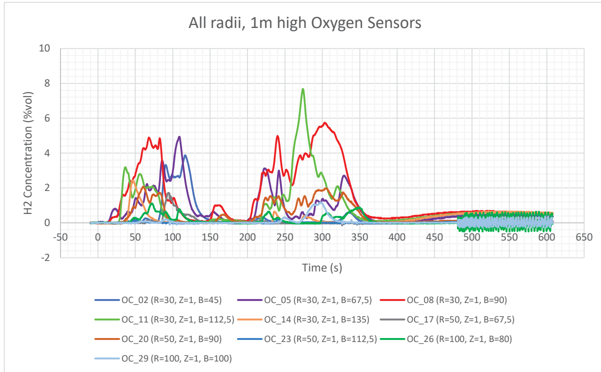
Test Name: Test05
Hole Size: 25,4 mm
Orientation: Downwards

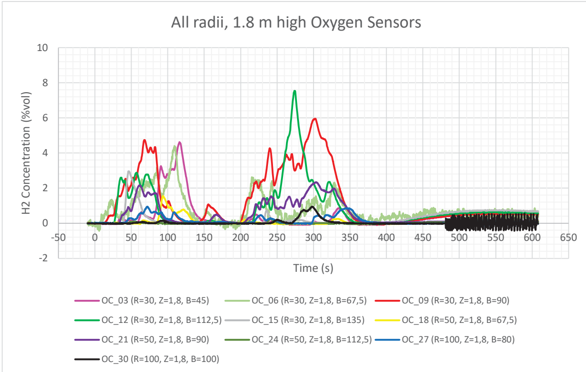
FOR AVERAGING
Start: 200 sec
End: 325 sec

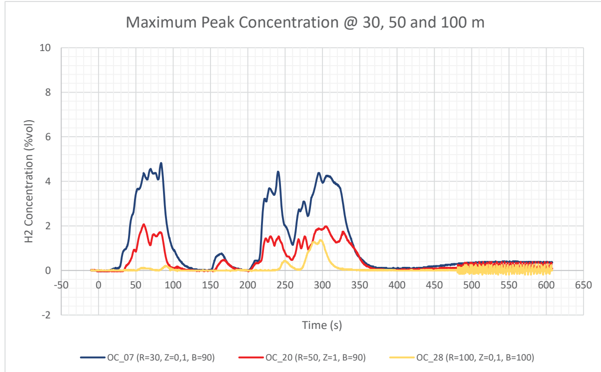
Notes:
Higher H2 concentration at low level. Peak concentrations observed @ 30m
Max. ~7%vol detected at 30m west

Sensor	Average	Max	Min	STDEV	units
OC_01 (R=30, Z=0,1, B=45)	0,0	0,1	0,0	0,0	%vol
OC_02 (R=30, Z=1, B=45)	0,1	0,3	0,0	0,1	%vol
OC_03 (R=30, Z=1,8, B=45)	0,1	0,5	-0,1	0,1	%vol
OC_04 (R=30, Z=0,1, B=67,5)	0,9	3,1	-0,1	0,9	%vol
OC_05 (R=30, Z=1, B=67,5)	1,1	3,1	0,1	0,8	%vol
OC_06 (R=30, Z=1,8, B=67,5)	1,0	2,6	-0,1	0,7	%vol
OC_07 (R=30, Z=0,1, B=90)	2,8	4,4	0,0	1,3	%vol
OC_08 (R=30, Z=1, B=90)	3,6	5,7	0,1	1,5	%vol
OC_09 (R=30, Z=1,8, B=90)	3,4	6,0	0,0	1,4	%vol
OC_10 (R=30, Z=0,1, B=112,5)	2,4	6,2	0,0	1,9	%vol
OC_11 (R=30, Z=1, B=112,5)	2,3	7,7	0,0	2,0	%vol
OC_12 (R=30, Z=1,8, B=112,5)	2,3	7,5	0,0	1,9	%vol
OC_13 (R=30, Z=0,1, B=135)	0,4	1,0	0,0	0,3	%vol
OC_14 (R=30, Z=1, B=135)	0,1	0,6	-0,1	0,2	%vol
OC_15 (R=30, Z=1,8, B=135)	0,1	0,7	0,0	0,1	%vol
OC_16 (R=50, Z=0,1, B=67,5)	0,0	0,1	0,0	0,0	%vol
OC_17 (R=50, Z=1, B=67,5)	0,0	0,2	-0,1	0,1	%vol
OC_18 (R=50, Z=1,8, B=67,5)	0,0	0,2	0,0	0,1	%vol
OC_19 (R=50, Z=0,1, B=90)	0,9	1,6	0,0	0,5	%vol
OC_20 (R=50, Z=1, B=90)	1,1	2,0	0,0	0,5	%vol
OC_21 (R=50, Z=1,8, B=90)	1,3	2,3	0,0	0,6	%vol
OC_22 (R=50, Z=0,1, B=112,5)	0,0	0,1	0,0	0,0	%vol
OC_23 (R=50, Z=1, B=112,5)	0,0	0,2	0,0	0,0	%vol
OC_24 (R=50, Z=1,8, B=112,5)	0,0	0,3	0,0	0,1	%vol
OC_25 (R=100, Z=0,1, B=80)	0,1	0,6	0,0	0,2	%vol
OC_26 (R=100, Z=1, B=80)	0,2	0,6	0,0	0,2	%vol
OC_27 (R=100, Z=1,8, B=80)	0,2	0,5	0,0	0,2	%vol
OC_28 (R=100, Z=0,1, B=100)	0,3	1,4	0,0	0,4	%vol
OC_29 (R=100, Z=1, B=100)	0,3	1,2	0,0	0,4	%vol
OC_30 (R=100, Z=1,8, B=100)	0,2	0,9	0,0	0,3	%vol

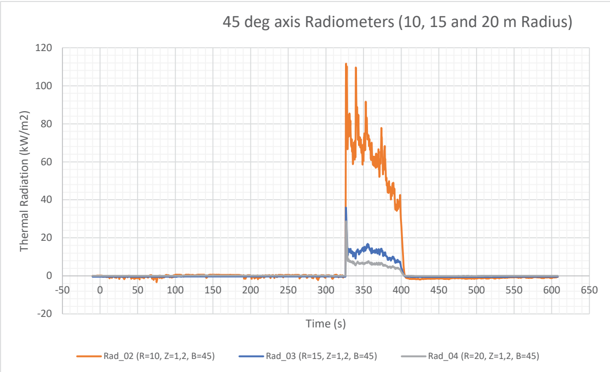


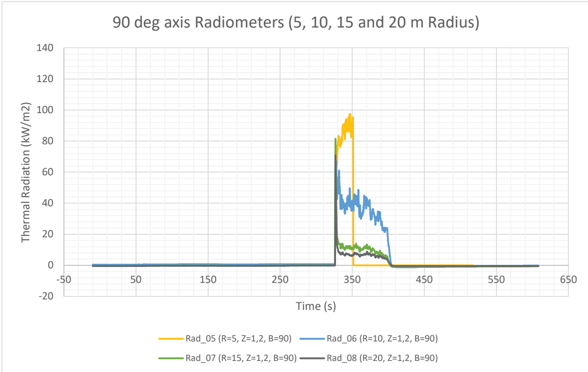


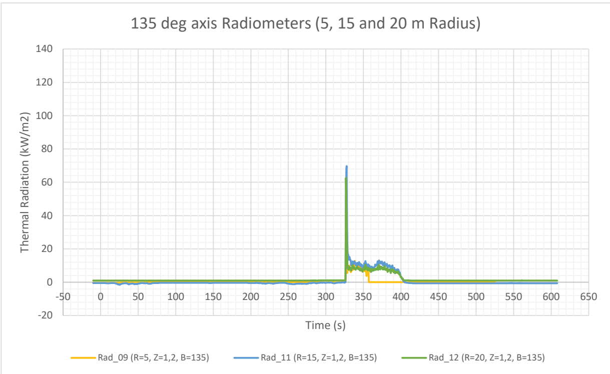


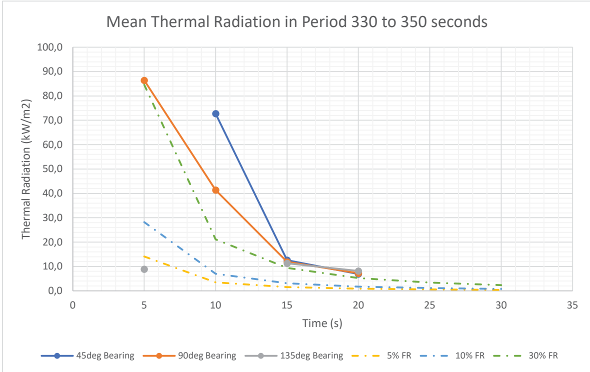


DNV·GL









Thermal Radiation

Test Name: Test05
Hole Size: 25,4 mm
Orientation: Downwards

FOR AVERAGING
Start: 330 sec
End: 350 sec

Notes: Rad_01 and Rad_10 suffered cabling damage prior to ignition. Maximum thermal radiation level of ca. 120kW/m2 measured at 45deg bearing and 10 m radius.

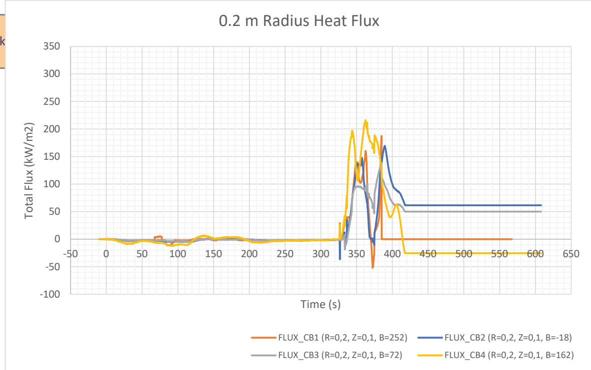
Sensor	Average	Max	Min	STDEV	units	Radius	Bearing
Rad_01 (R=5, Z=1,2, B=45)					kW/m2	5	45
Rad_02 (R=10, Z=1,2, B=45)	72,7	109,6	58,5	10,4	kW/m2	10	45
Rad_03 (R=15, Z=1,2, B=45)	12,6	15,0	9,1	1,2	kW/m2	15	45
Rad_04 (R=20, Z=1,2, B=45)	6,9	8,9	5,5	0,6	kW/m2	20	45
Rad_05 (R=5, Z=1,2, B=90)	86,4	97,5	76,3	5,9	kW/m2	5	90
Rad_06 (R=10, Z=1,2, B=90)	41,4	61,1	33,3	6,0	kW/m2	10	90
Rad_07 (R=15, Z=1,2, B=90)	11,9	15,7	9,9	1,2	kW/m2	15	90
Rad_08 (R=20, Z=1,2, B=90)	7,2	10,3	6,0	0,8	kW/m2	20	90
Rad_09 (R=5, Z=1,2, B=135)	8,9	12,7	6,0	1,5	kW/m2	5	135
Rad_10 (R=10, Z=1,2, B=135)					kW/m2	10	135
Rad_11 (R=15, Z=1,2, B=135)	11,3	15,2	8,8	1,4	kW/m2	15	135
Rad_12 (R=20, Z=1,2, B=135)	8,2	10,2	6,3	0,7	kW/m2	20	135

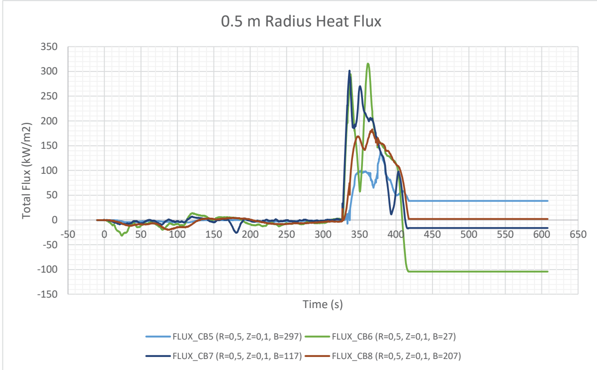
Heat Flux

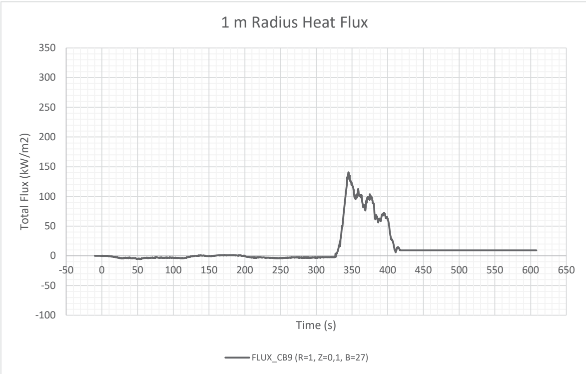
Test Name	Test05		FOR AVERAGING		
Hole Size	25,4	mm	Start	325	sec
Orientation	Downwards		End	400	sec

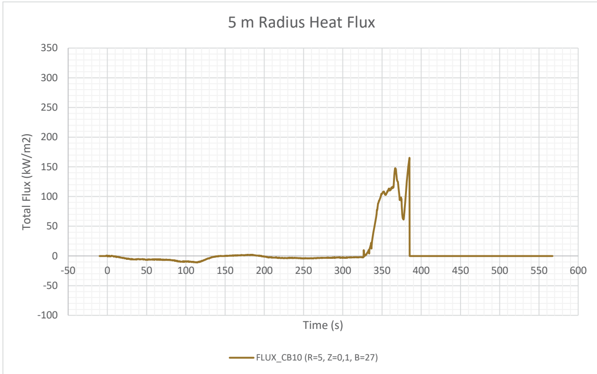
Notes: Peak heat flux during ignition reached ca. 300kW/m2. Average values around 150k during jet fire.

Sensor	Average	Max	Min	STDEV	units
FLUX_CB1 (R=0,2, Z=0,1, B=252)	59,8	139,9	5,9	39,4	kW/m2
FLUX_CB2 (R=0,2, Z=0,1, B=-18)	47,8	130,3	-6,3	42,3	kW/m2
FLUX_CB3 (R=0,2, Z=0,1, B=72)	37,1	95,9	-18,9	39,9	kW/m2
FLUX_CB4 (R=0,2, Z=0,1, B=162)	120,1	196,8	12,0	63,1	kW/m2
FLUX_CB5 (R=0,5, Z=0,1, B=297)	50,3	98,8	-7,5	37,1	kW/m2
FLUX_CB6 (R=0,5, Z=0,1, B=27)	189,2	294,3	62,7	64,2	kW/m2
FLUX_CB7 (R=0,5, Z=0,1, B=117)	221,7	301,6	135,7	40,4	kW/m2
FLUX_CB8 (R=0,5, Z=0,1, B=207)	109,1	169,2	8,3	55,7	kW/m2
FLUX_CB9 (R=1, Z=0,1, B=27)	82,6	140,6	8,0	45,6	kW/m2
FLUX_CB10 (R=5, Z=0,1, B=27)	50,7	104,7	2,6	35,9	kW/m2









FFI: LH2 Releases

Notes

Second ignited release. Flow established for couple of minutes. Ignition achieved ca.140s (firework @30 m from release). Ignited release continued for a further 60 s. Maybe offset in temperature - no measurements reach liquid temp, need to investigate

Test Name	Test06	
Hole Size	25,4	mm
Orientation	Horizontal	

FOR PLOTS

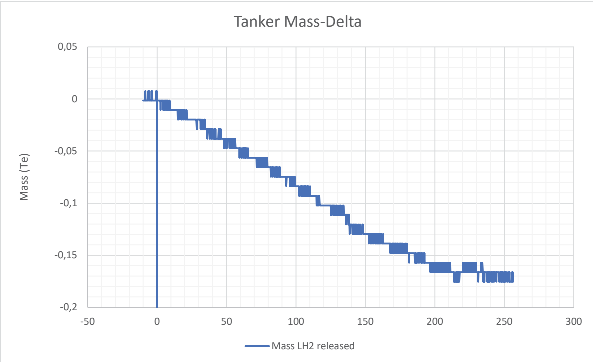
Start Time	-10	sec
End Time	300	sec

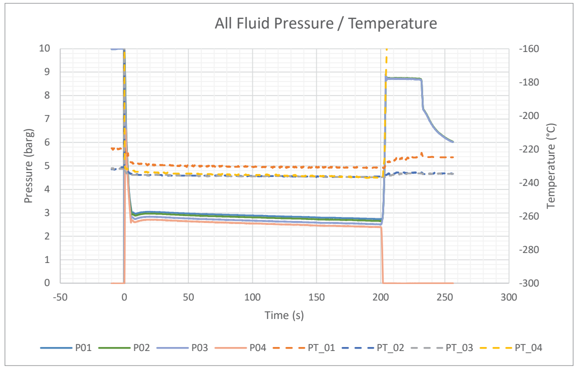
Date 13.12.2019

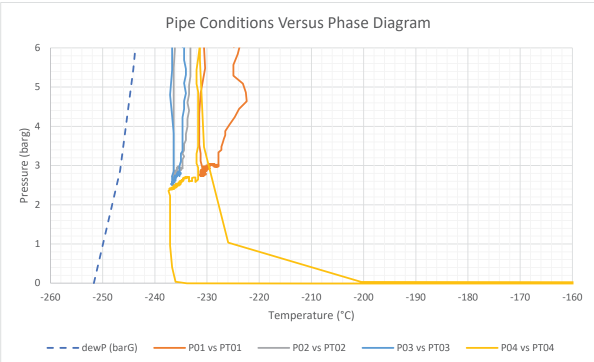
FOR AVERAGING

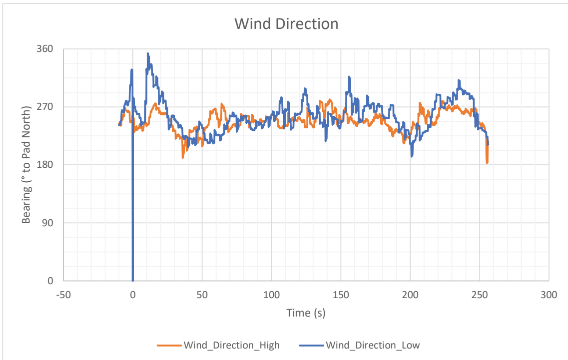
Start	25	sec
End	200	sec

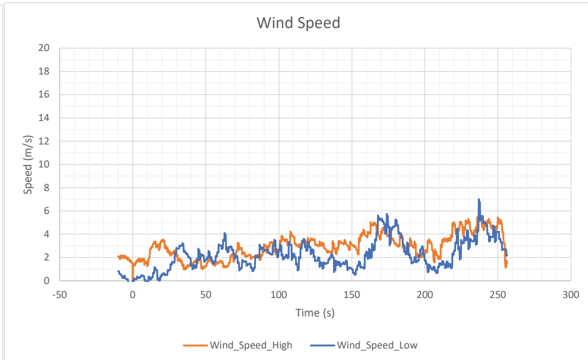
Sensor	Average	Max	Min	STDEV	units
Mass LH2 released	-	-0,020	-0,166	-	Te
P01	2,87	3,04	2,73	0,08	Barg
P02	2,79	2,96	2,65	0,09	Barg
P03	2,65	2,83	2,51	0,09	Barg
P04	2,53	2,70	2,39	0,09	Barg
PT_01	-230,5	-229,0	-231,4	0,5	°C
PT_02	-236,1	-235,4	-236,8	0,3	°C
PT_03	-236,2	-235,1	-236,9	0,4	°C
PT_04	-235,5	-233,9	-237,2	0,8	°C
MassFlow	0,833				kg/s
Wind_Direction_High	245,4	281,9	190,7	14,6	Deg
Wind_Direction_Low	250,0	317,4	207,8	18,9	Deg
Wind_Speed_High	2,7	5,0	1,0	0,9	m/s
Wind_Speed_Low	2,3	5,8	0,5	1,0	m/s











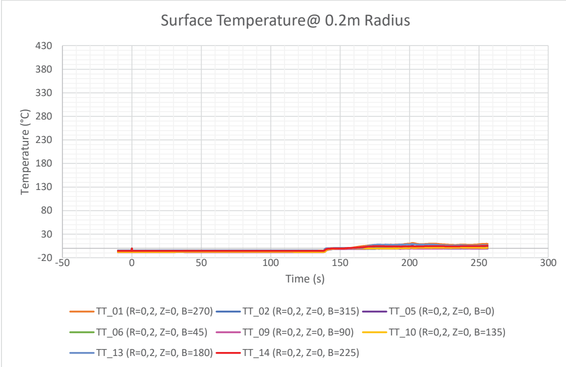
DNV·GL

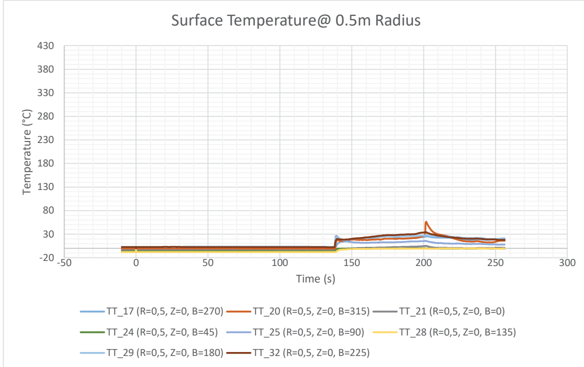
Pad Temperature

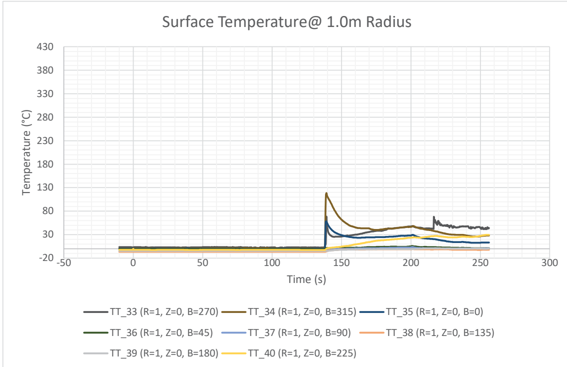
Test Name	Test06		FOR AVERAGING		
Hole Size	25,4	mm	Start	25	sec
Orientation	Horizontal		End	140	sec

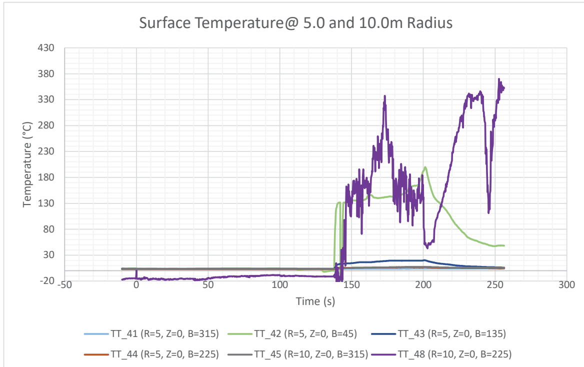
Notes: Liquid temperatures not observed.
Note centre and bearing of array needs to be clarified (300mm to east)

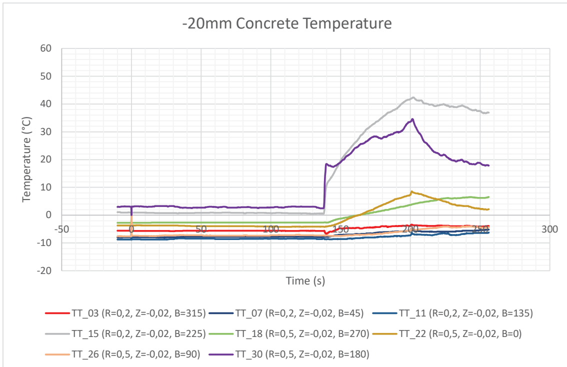
Sensor	Average	Max	Min	STDEV	units
TT_01 (R=0,2, Z=0, B=270)	-4,4	-0,3	-4,6	0,4	°C
TT_02 (R=0,2, Z=0, B=315)	-5,2	-3,9	-5,4	0,1	°C
TT_03 (R=0,2, Z=-0,02, B=315)	-5,6	-5,6	-6,7	0,1	°C
TT_04 (R=0,2, Z=-0,03, B=315)	-6,3	-5,9	-6,4	0,0	°C
TT_05 (R=0,2, Z=0, B=0)	-6,4	-1,4	-6,7	0,5	°C
TT_06 (R=0,2, Z=0, B=45)	-7,3	-3,1	-7,4	0,3	°C
TT_07 (R=0,2, Z=-0,02, B=45)	-7,8	-7,7	-8,0	0,1	°C
TT_08 (R=0,2, Z=-0,03, B=45)	-8,2	-8,1	-8,3	0,1	°C
TT_09 (R=0,2, Z=0, B=90)	-8,2	-5,3	-8,3	0,2	°C
TT_10 (R=0,2, Z=0, B=135)	-7,6	-4,9	-8,0	0,2	°C
TT_11 (R=0,2, Z=-0,02, B=135)	-8,5	-8,4	-8,8	0,1	°C
TT_12 (R=0,2, Z=-0,03, B=135)	-9,2	-9,1	-9,5	0,1	°C
TT_13 (R=0,2, Z=0, B=180)	-4,7	0,1	-4,9	0,4	°C
TT_14 (R=0,2, Z=0, B=225)	-5,3	-1,9	-5,5	0,3	°C
TT_15 (R=0,2, Z=-0,02, B=225)	0,9	10,8	0,5	0,9	°C
TT_16 (R=0,2, Z=-0,03, B=225)	2,3	52,8	1,3	5,8	°C
TT_17 (R=0,5, Z=0, B=270)	-1,1	9,1	-1,6	0,8	°C
TT_18 (R=0,5, Z=-0,02, B=270)	-2,6	-2,6	-2,7	0,0	°C
TT_19 (R=0,5, Z=-0,03, B=270)	-3,5	-3,1	-3,6	0,1	°C
TT_20 (R=0,5, Z=0, B=315)	-0,6	17,0	-1,3	1,7	°C
TT_21 (R=0,5, Z=0, B=0)	-4,4	-2,0	-4,7	0,3	°C
TT_22 (R=0,5, Z=-0,02, B=0)	-4,0	-3,8	-4,2	0,1	°C
TT_23 (R=0,5, Z=-0,03, B=0)	0,3	30,3	-0,3	3,3	°C
TT_24 (R=0,5, Z=0, B=45)	-6,2	-1,1	-6,6	0,4	°C
TT_25 (R=0,5, Z=0, B=90)	3,3	26,5	2,8	2,6	°C
TT_26 (R=0,5, Z=-0,02, B=90)	-7,3	-7,1	-7,4	0,1	°C
TT_27 (R=0,5, Z=-0,03, B=90)	-8,8	-8,7	-9,2	0,0	°C
TT_28 (R=0,5, Z=0, B=135)	-7,8	-5,4	-7,9	0,2	°C
TT_29 (R=0,5, Z=0, B=180)	3,8	24,3	3,1	2,2	°C
TT_30 (R=0,5, Z=-0,02, B=180)	3,0	18,4	2,4	1,5	°C
TT_31 (R=0,5, Z=-0,03, B=180)	-4,6	-0,9	-4,6	0,3	°C
TT_32 (R=0,5, Z=0, B=225)	2,8	19,7	2,1	1,8	°C
TT_33 (R=1, Z=0, B=270)	3,4	68,8	0,8	5,0	°C
TT_34 (R=1, Z=0, B=315)	2,8	118,8	0,4	12,9	°C
TT_35 (R=1, Z=0, B=0)	1,0	58,7	-0,4	6,6	°C
TT_36 (R=1, Z=0, B=45)	-0,8	1,8	-1,1	0,3	°C
TT_37 (R=1, Z=0, B=90)	-4,1	-0,6	-4,3	0,3	°C
TT_38 (R=1, Z=0, B=135)	-6,5	-4,6	-6,6	0,1	°C
TT_39 (R=1, Z=0, B=180)	-4,5	-4,4	-4,6	0,1	°C
TT_40 (R=1, Z=0, B=225)	-2,4	1,2	-2,9	0,3	°C
TT_41 (R=5, Z=0, B=315)	3,5	3,7	3,5	0,0	°C
TT_42 (R=5, Z=0, B=45)	5,3	126,6	-2,2	13,2	°C
TT_43 (R=5, Z=0, B=135)	3,9	11,4	3,8	0,6	°C
TT_44 (R=5, Z=0, B=225)	3,0	4,9	2,9	0,2	°C
TT_45 (R=10, Z=0, B=315)	3,4	3,8	3,3	0,0	°C
TT_46 (R=10, Z=0, B=45)	-2000,0	-2000,0	-2000,0	0,0	°C
TT_47 (R=10, Z=0, B=135)	-44,3	32,8	-2000,0	84,1	°C
TT_48 (R=10, Z=0, B=225)	-12,0	14,8	-63,4	3,8	°C

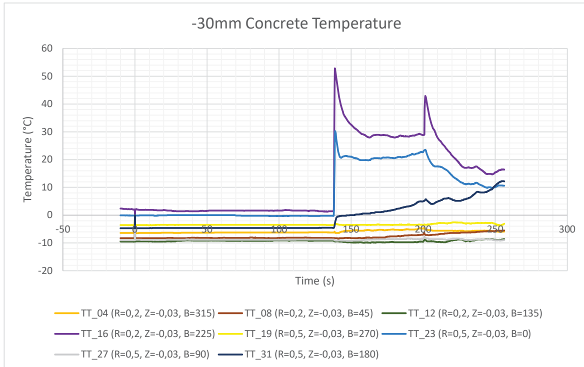










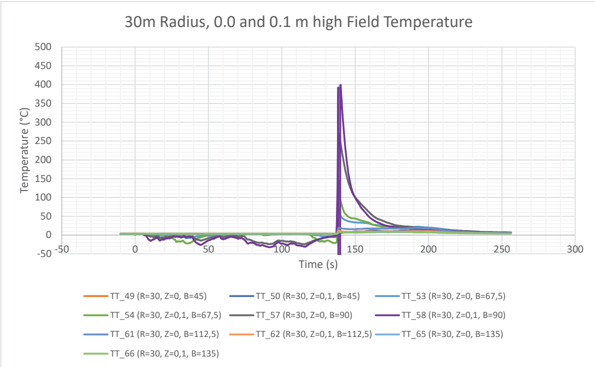


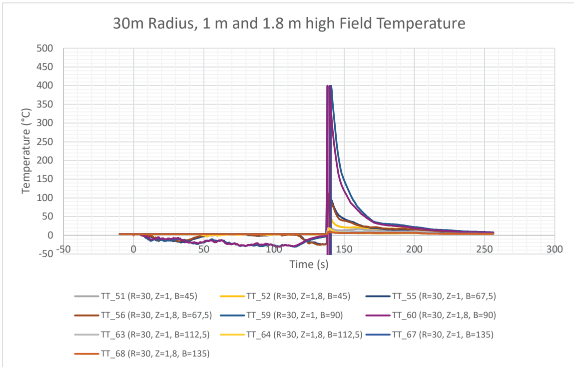
Notes: Greater temperature drop during release observed at 30 m, both at low and high level. No significant temperature drop at 50 m (low or high level). 30 m radius thermocouples reached high temperatures during the ignited release at both low and high level.

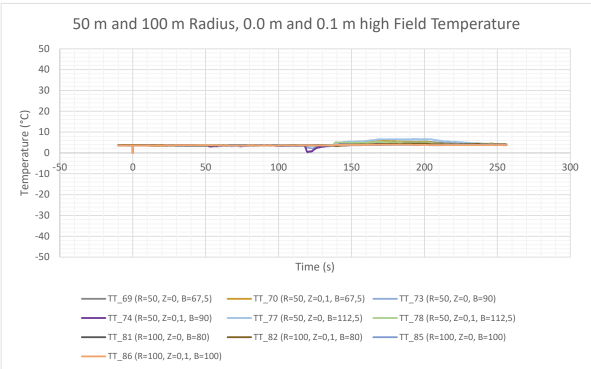
Field Temperature

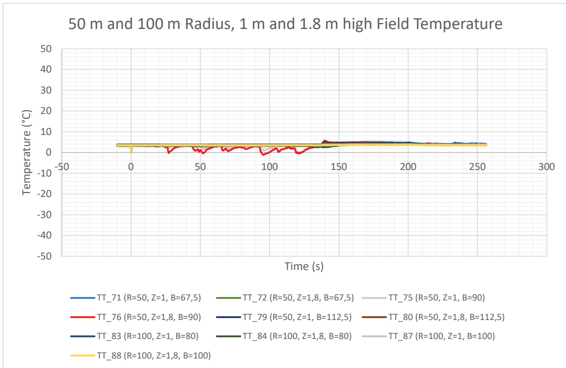
Test Name: Test06
Hole Size: 25,4 mm
Orientation: Horizontal

FOR AVERAGING
Start: 25 sec
End: 140 sec









Sensor	Average	Max	Min	STDEV	units
TT_49 (R=30, Z=0, B=45)	3,4	6,2	3,4	0,2	°C
TT_50 (R=30, Z=0,1, B=45)	3,6	7,6	3,0	0,4	°C
TT_51 (R=30, Z=1, B=45)	3,9	35,2	2,8	2,5	°C
TT_52 (R=30, Z=1,8, B=45)	3,8	73,9	2,1	6,1	°C
TT_53 (R=30, Z=0, B=67,5)	1,1	74,6	-7,8	9,2	°C
TT_54 (R=30, Z=0,1, B=67,5)	-1,4	145,9	-22,3	18,5	°C
TT_55 (R=30, Z=1, B=67,5)	-3,5	102,6	-24,4	15,1	°C
TT_56 (R=30, Z=1,8, B=67,5)	-2,9	114,1	-25,7	16,1	°C
TT_57 (R=30, Z=0, B=90)	-6,6	269,3	-24,3	33,0	°C
TT_58 (R=30, Z=0,1, B=90)	-33,6	399,6	-2000,0	204,4	°C
TT_59 (R=30, Z=1, B=90)	-49,4	399,6	-2000,0	247,0	°C
TT_60 (R=30, Z=1,8, B=90)	-40,2	399,6	-2000,0	220,1	°C
TT_61 (R=30, Z=0, B=112,5)	3,1	19,3	-2,5	2,3	°C
TT_62 (R=30, Z=0,1, B=112,5)	3,8	11,9	3,2	1,0	°C
TT_63 (R=30, Z=1, B=112,5)	3,0	19,6	-3,6	2,4	°C
TT_64 (R=30, Z=1,8, B=112,5)	2,5	18,8	-3,3	2,1	°C
TT_65 (R=30, Z=0, B=135)	3,3	7,8	3,2	0,5	°C
TT_66 (R=30, Z=0,1, B=135)	3,8	8,8	3,6	0,6	°C
TT_67 (R=30, Z=1, B=135)	3,8	9,2	3,6	0,6	°C
TT_68 (R=30, Z=1,8, B=135)	3,4	8,9	3,3	0,6	°C
TT_69 (R=50, Z=0, B=67,5)	3,5	4,3	3,4	0,1	°C
TT_70 (R=50, Z=0,1, B=67,5)	3,7	4,8	3,5	0,1	°C
TT_71 (R=50, Z=1, B=67,5)	3,6	4,6	3,1	0,1	°C
TT_72 (R=50, Z=1,8, B=67,5)	3,1	4,0	2,4	0,1	°C
TT_73 (R=50, Z=0, B=90)	3,3	4,0	2,2	0,3	°C
TT_74 (R=50, Z=0,1, B=90)	3,4	5,1	0,3	0,7	°C
TT_75 (R=50, Z=1, B=90)	2,7	5,9	-0,5	1,0	°C
TT_76 (R=50, Z=1,8, B=90)	1,8	5,6	-1,1	1,2	°C
TT_77 (R=50, Z=0, B=112,5)	3,5	4,8	3,4	0,1	°C
TT_78 (R=50, Z=0,1, B=112,5)	3,8	5,2	3,8	0,1	°C
TT_79 (R=50, Z=1, B=112,5)	3,8	5,1	3,8	0,1	°C
TT_80 (R=50, Z=1,8, B=112,5)	3,5	4,8	3,4	0,1	°C
TT_81 (R=100, Z=0, B=80)	3,6	3,6	3,5	0,1	°C
TT_82 (R=100, Z=0,1, B=80)	3,7	3,8	3,3	0,1	°C
TT_83 (R=100, Z=1, B=80)	3,6	3,7	2,9	0,2	°C
TT_84 (R=100, Z=1,8, B=80)	3,1	3,3	2,6	0,2	°C
TT_85 (R=100, Z=0, B=100)	3,7	3,8	3,7	0,0	°C
TT_86 (R=100, Z=0,1, B=100)	3,6	3,8	3,6	0,1	°C
TT_87 (R=100, Z=1, B=100)	3,7	3,9	3,6	0,0	°C
TT_88 (R=100, Z=1,8, B=100)	3,3	3,6	3,3	0,0	°C

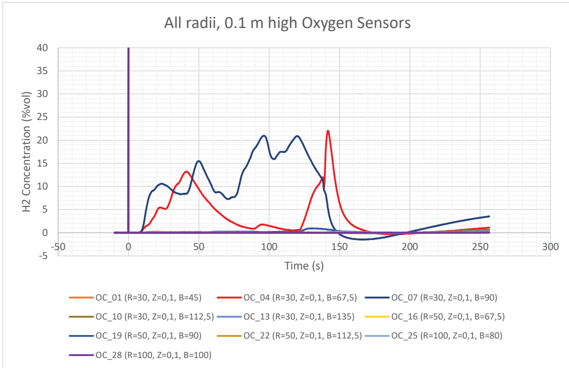
Gas Concentrations

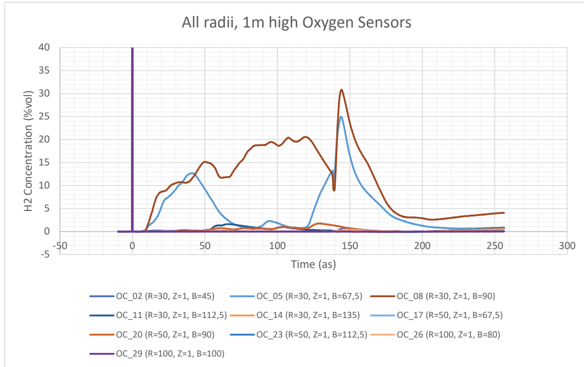
Test Name	Test06		FOR AVERAGING		
Hole Size	25,4	mm	Start	20	sec
Orientation	Horizontal		End	140	sec

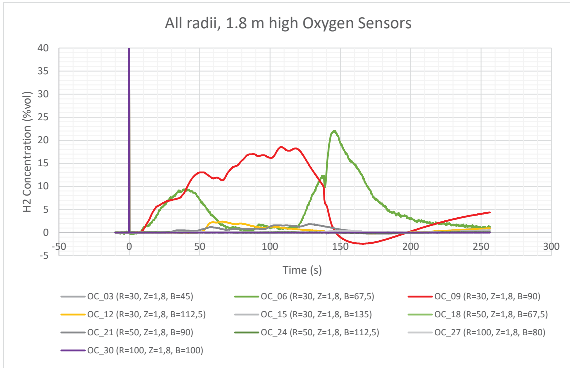
Notes:

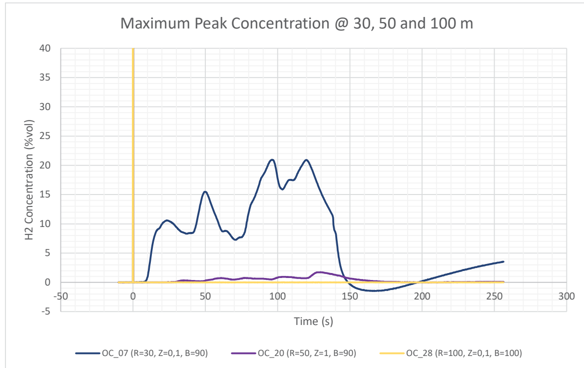
Peak concentrations observed @ 30m
Max. ~15%vol detected at 30m west

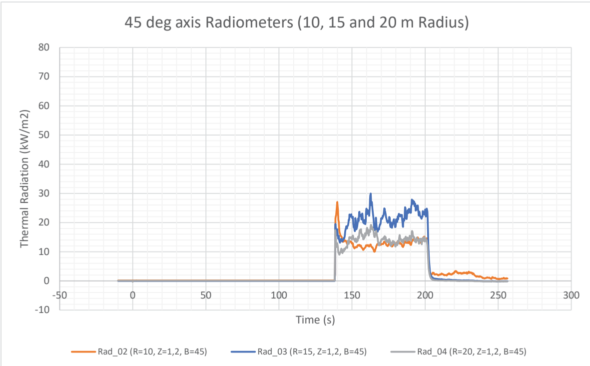
Sensor	Average	Max	Min	STDEV	units
OC_01 (R=30, Z=0,1, B=45)	0,1	0,2	0,0	0,1	%vol
OC_02 (R=30, Z=1, B=45)	0,1	0,2	0,0	0,1	%vol
OC_03 (R=30, Z=1,8, B=45)	0,1	0,3	-0,2	0,1	%vol
OC_04 (R=30, Z=0,1, B=67,5)	4,9	15,6	0,5	4,0	%vol
OC_05 (R=30, Z=1, B=67,5)	5,1	14,4	0,5	4,3	%vol
OC_06 (R=30, Z=1,8, B=67,5)	4,2	12,4	0,2	3,5	%vol
OC_07 (R=30, Z=0,1, B=90)	13,5	21,0	7,3	4,3	%vol
OC_08 (R=30, Z=1, B=90)	15,4	20,6	8,7	3,7	%vol
OC_09 (R=30, Z=1,8, B=90)	13,3	18,6	5,7	3,8	%vol
OC_10 (R=30, Z=0,1, B=112,5)	0,0	0,1	0,0	0,0	%vol
OC_11 (R=30, Z=1, B=112,5)	0,6	1,6	0,0	0,5	%vol
OC_12 (R=30, Z=1,8, B=112,5)	0,9	2,4	0,0	0,8	%vol
OC_13 (R=30, Z=0,1, B=135)	0,0	0,0	0,0	0,0	%vol
OC_14 (R=30, Z=1, B=135)	0,0	0,0	0,0	0,0	%vol
OC_15 (R=30, Z=1,8, B=135)	0,0	0,0	0,0	0,0	%vol
OC_16 (R=50, Z=0,1, B=67,5)	0,0	0,1	0,0	0,0	%vol
OC_17 (R=50, Z=1, B=67,5)	0,0	0,2	0,0	0,1	%vol
OC_18 (R=50, Z=1,8, B=67,5)	0,0	0,2	0,0	0,0	%vol
OC_19 (R=50, Z=0,1, B=90)	0,2	1,0	0,0	0,3	%vol
OC_20 (R=50, Z=1, B=90)	0,7	1,8	0,0	0,4	%vol
OC_21 (R=50, Z=1,8, B=90)	0,9	1,8	0,0	0,5	%vol
OC_22 (R=50, Z=0,1, B=112,5)	0,0	0,0	0,0	0,0	%vol
OC_23 (R=50, Z=1, B=112,5)	0,0	0,0	0,0	0,0	%vol
OC_24 (R=50, Z=1,8, B=112,5)	0,0	0,0	0,0	0,0	%vol
OC_25 (R=100, Z=0,1, B=80)	0,0	0,1	0,0	0,0	%vol
OC_26 (R=100, Z=1, B=80)	0,0	0,1	0,0	0,0	%vol
OC_27 (R=100, Z=1,8, B=80)	0,1	0,2	0,0	0,1	%vol
OC_28 (R=100, Z=0,1, B=100)	0,0	0,0	0,0	0,0	%vol
OC_29 (R=100, Z=1, B=100)	0,0	0,0	0,0	0,0	%vol
OC_30 (R=100, Z=1,8, B=100)	0,0	0,0	0,0	0,0	%vol

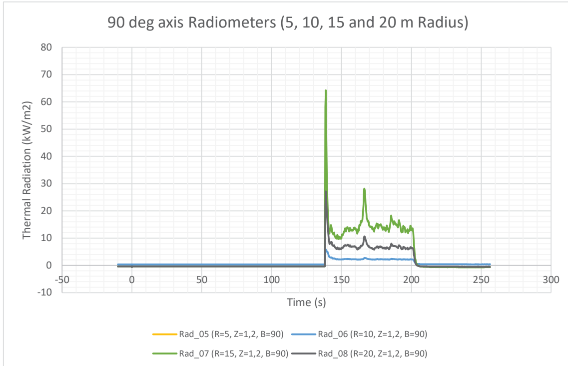










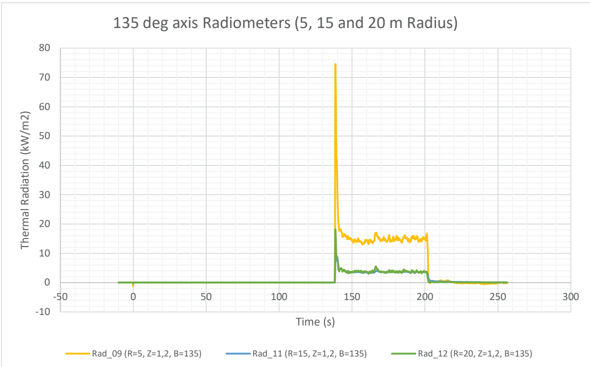


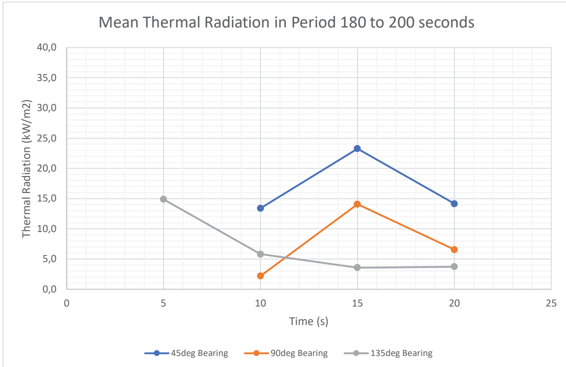
Thermal Radiation

Test Name	Test06		FOR AVERAGING		
Hole Size	25,4	mm	Start	180	sec
Orientation	Horizontal		End	200	sec

Notes: Rad_01 and Rad_05 suffered cabling damage prior to ignition. Maximum thermal radiation level of ca. 21kW/m2 measured at 45deg bearing and 15 m radius.

Sensor	Average	Max	Min	STDEV	units	Radius	Bearing
Rad_01 (R=5, Z=1,2, B=45)					kW/m2	5	45
Rad_02 (R=10, Z=1,2, B=45)	13,4	15,2	11,6	0,8	kW/m2	10	45
Rad_03 (R=15, Z=1,2, B=45)	23,3	27,9	18,5	2,1	kW/m2	15	45
Rad_04 (R=20, Z=1,2, B=45)	14,2	17,1	12,2	0,9	kW/m2	20	45
Rad_05 (R=5, Z=1,2, B=90)					kW/m2	5	90
Rad_06 (R=10, Z=1,2, B=90)	2,2	2,4	2,1	0,1	kW/m2	10	90
Rad_07 (R=15, Z=1,2, B=90)	14,1	18,3	11,8	1,4	kW/m2	15	90
Rad_08 (R=20, Z=1,2, B=90)	6,6	7,9	5,8	0,5	kW/m2	20	90
Rad_09 (R=5, Z=1,2, B=135)	14,9	16,2	13,6	0,6	kW/m2	5	135
Rad_10 (R=10, Z=1,2, B=135)	5,8	6,1	5,4	0,2	kW/m2	10	135
Rad_11 (R=15, Z=1,2, B=135)	3,6	3,8	3,3	0,1	kW/m2	15	135
Rad_12 (R=20, Z=1,2, B=135)	3,7	4,4	3,2	0,3	kW/m2	20	135



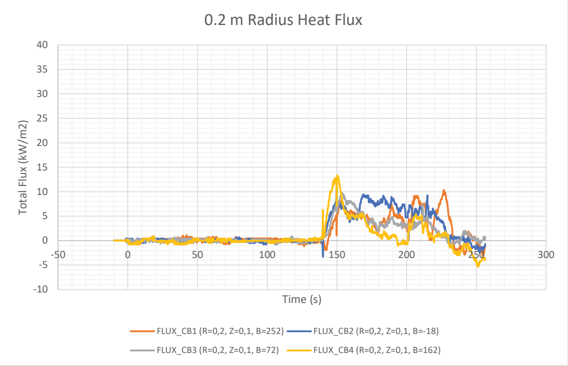


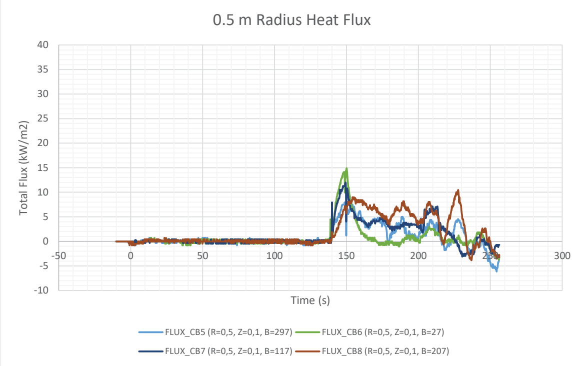
Heat Flux

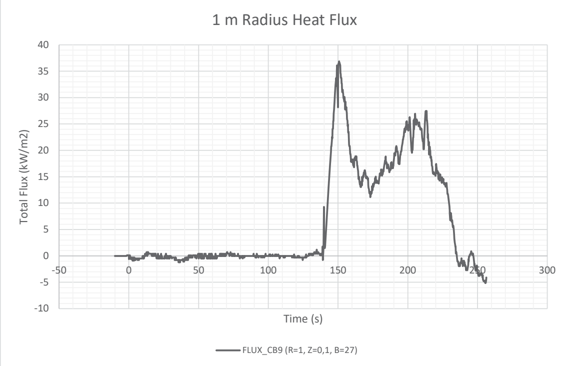
Test Name	Test06			FOR AVERAGING	
Hole Size	25,4	mm	Start	325	sec
Orientation	Horizontal		End	400	sec

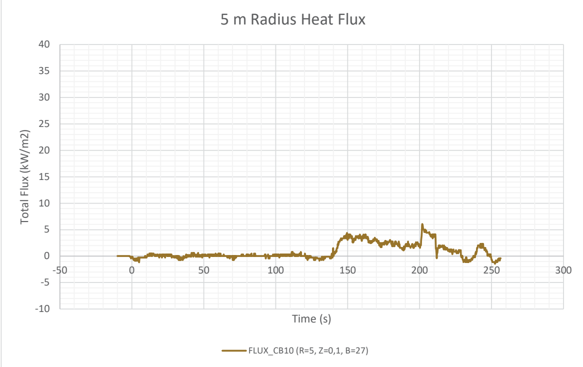
Notes: Peak heat flux during ignition reached ca. 35kW/m2. Average values around 10kW/m2 during jet fire.

Sensor	Average	Max	Min	STDEV	units
FLUX_CB1 (R=0,2, Z=0,1, B=252)	4,5	7,6	1,9	1,2	kW/m2
FLUX_CB2 (R=0,2, Z=0,1, B=-18)	7,4	9,2	4,7	1,0	kW/m2
FLUX_CB3 (R=0,2, Z=0,1, B=72)	3,4	4,8	2,3	0,5	kW/m2
FLUX_CB4 (R=0,2, Z=0,1, B=162)	0,4	2,0	-1,0	0,8	kW/m2
FLUX_CB5 (R=0,5, Z=0,1, B=297)	2,0	5,0	0,0	1,3	kW/m2
FLUX_CB6 (R=0,5, Z=0,1, B=27)	0,1	1,2	-1,0	0,6	kW/m2
FLUX_CB7 (R=0,5, Z=0,1, B=117)	3,2	3,8	2,1	0,4	kW/m2
FLUX_CB8 (R=0,5, Z=0,1, B=207)	5,9	8,2	3,3	1,1	kW/m2
FLUX_CB9 (R=1, Z=0,1, B=27)	18,8	25,5	15,2	2,8	kW/m2
FLUX_CB10 (R=5, Z=0,1, B=27)	2,0	2,8	1,1	0,4	kW/m2









DNV·GL

FFI: LH2 Releases

Notes

Maybe offset in temperature - no measurements reaach liquid temp, need to investigate

Test Name	Test07	
Hole Size	25,4	mm
Orientation	Downwards	

FOR PLOTS

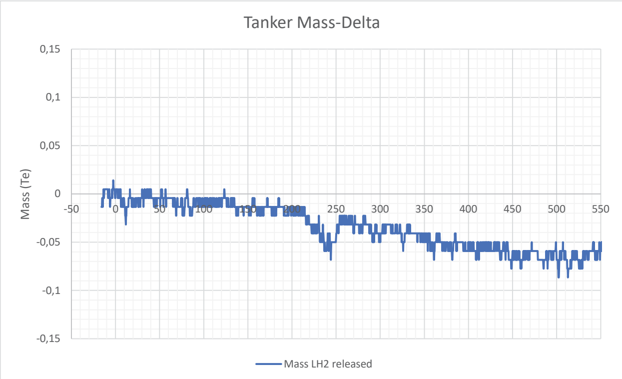
Start Time	-16	sec
End Time	620	sec

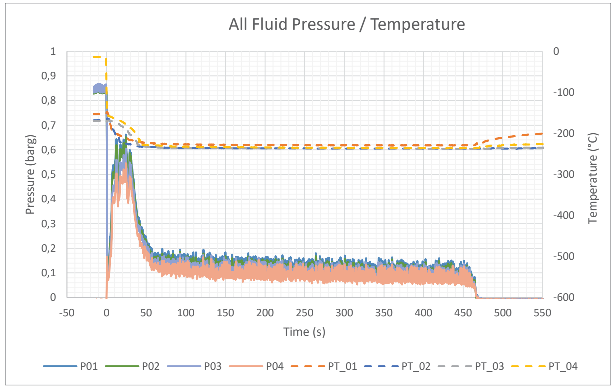
Date 13.12.2019

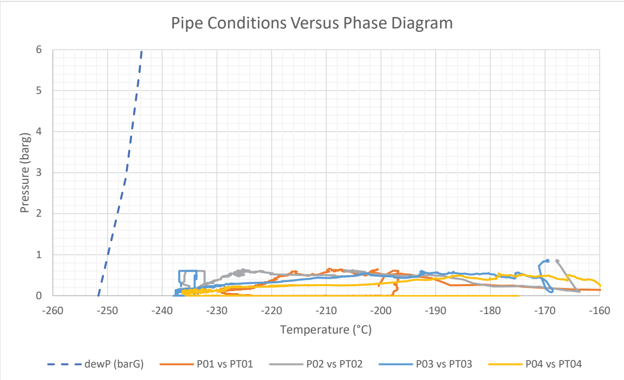
FOR AVERAGING

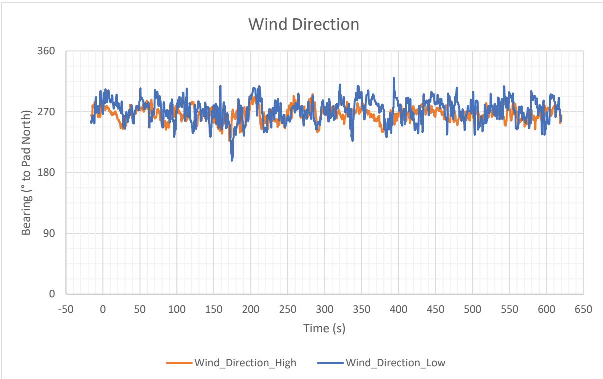
Start	100	sec
End	425	sec

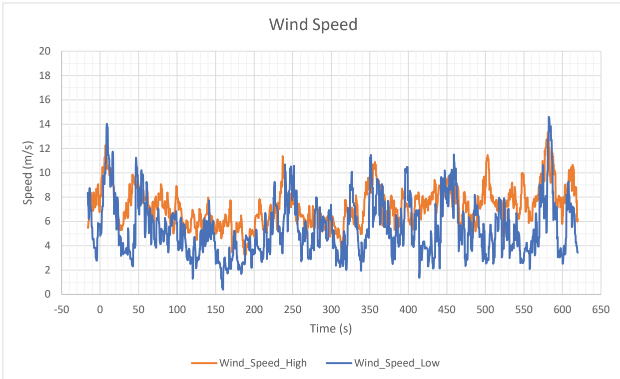
Sensor	Average	Max	Min	STDEV	units
Mass LH2 released	-	0,005	-0,068	-	Te
P01	0,14	0,19	0,11	0,01	Barg
P02	0,12	0,18	0,09	0,01	Barg
P03	0,11	0,17	0,07	0,02	Barg
P04	0,09	0,16	0,05	0,02	Barg
PT_01	-228,4	-226,3	-229,8	0,7	°C
PT_02	-236,6	-235,1	-237,2	0,5	°C
PT_03	-236,6	-235,1	-237,5	0,6	°C
PT_04	-234,5	-232,1	-236,3	0,9	°C
MassFlow	0,162				kg/s
Wind_Direction_High	265,2	296,0	226,9	11,5	0,0
Wind_Direction_Low	269,7	320,3	197,4	18,3	Deg
Wind_Speed_High	6,5	11,4	3,3	1,4	m/s
Wind_Speed_Low	5,0	11,5	0,4	2,1	m/s









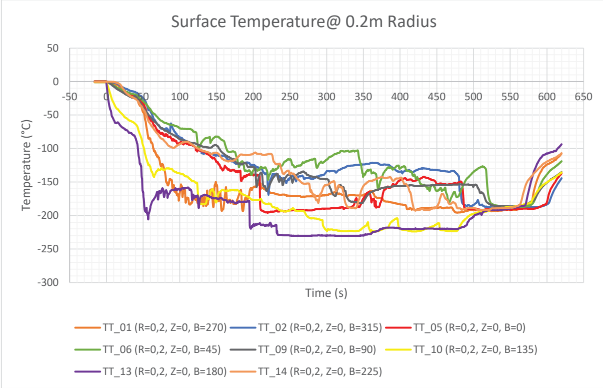


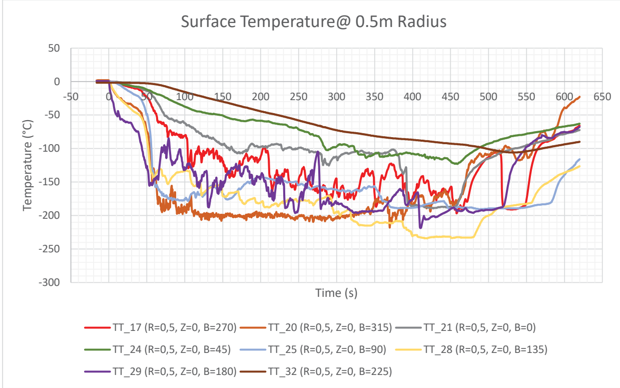
Pad Temperature

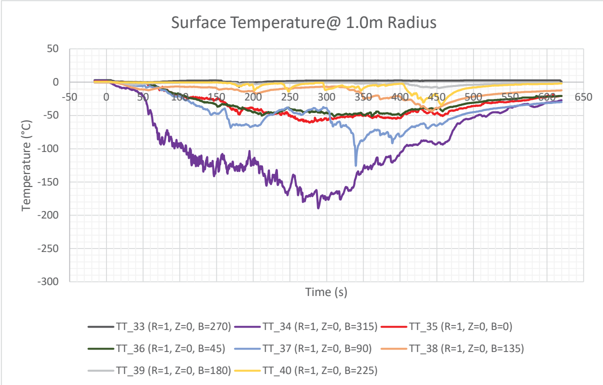
Test Name	Test07		FOR AVERAGING		
Hole Size	25,4	mm	Start	100	sec
Orientation	Downwards		End	450	sec

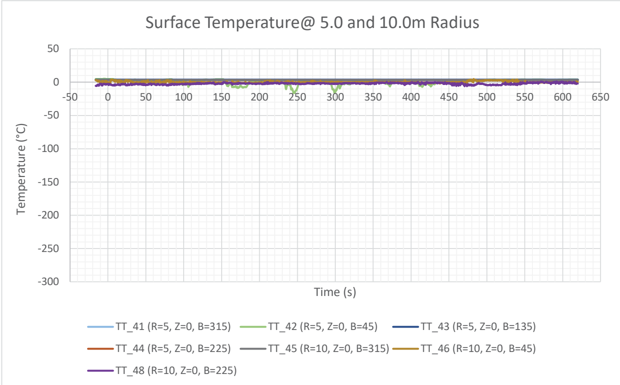
Notes: Looks like Liquid observed on surface @0.5m but not 1m.
LH2 not observed further than 0.5m
Note centre and bearing of array needs to be clarified (300mm to east)

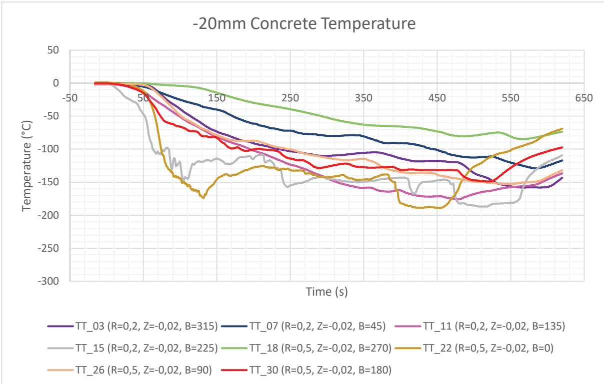
Sensor	Average	Max	Min	STDEV	units
TT_01 (R=0,2, Z=0, B=270)	-173,5	-149,6	-193,3	9,3	°C
TT_02 (R=0,2, Z=0, B=315)	-126,6	-83,5	-169,0	14,6	°C
TT_03 (R=0,2, Z=-0,02, B=315)	-96,9	-39,3	-118,6	19,5	°C
TT_04 (R=0,2, Z=-0,03, B=315)	-53,5	-6,4	-86,5	23,4	°C
TT_05 (R=0,2, Z=0, B=0)	-158,6	-90,0	-195,6	32,2	°C
TT_06 (R=0,2, Z=0, B=45)	-118,8	-69,8	-163,4	22,3	°C
TT_07 (R=0,2, Z=-0,02, B=45)	-70,2	-25,3	-101,4	20,4	°C
TT_08 (R=0,2, Z=-0,03, B=45)	-58,2	-14,9	-90,1	20,8	°C
TT_09 (R=0,2, Z=0, B=90)	-140,3	-86,1	-181,6	25,7	°C
TT_10 (R=0,2, Z=0, B=135)	-196,0	-137,2	-225,2	25,4	°C
TT_11 (R=0,2, Z=-0,02, B=135)	-126,9	-51,1	-171,9	35,9	°C
TT_12 (R=0,2, Z=-0,03, B=135)	-68,0	-12,1	-113,6	30,3	°C
TT_13 (R=0,2, Z=0, B=180)	-210,3	-158,2	-230,1	23,5	°C
TT_14 (R=0,2, Z=0, B=225)	-140,0	-89,6	-192,4	30,3	°C
TT_15 (R=0,2, Z=-0,02, B=225)	-137,2	-108,3	-167,9	15,6	°C
TT_16 (R=0,2, Z=-0,03, B=225)	-206,0	-178,4	-238,3	8,2	°C
TT_17 (R=0,5, Z=0, B=270)	-141,5	-79,9	-187,0	22,8	°C
TT_18 (R=0,5, Z=-0,02, B=270)	-43,2	-4,1	-73,3	21,2	°C
TT_19 (R=0,5, Z=-0,03, B=270)	-19,4	-0,3	-43,9	14,8	°C
TT_20 (R=0,5, Z=0, B=315)	-194,5	-160,9	-217,9	10,7	°C
TT_21 (R=0,5, Z=0, B=0)	-114,8	-62,2	-189,4	34,2	°C
TT_22 (R=0,5, Z=-0,02, B=0)	-148,3	-125,3	-188,6	19,0	°C
TT_23 (R=0,5, Z=-0,03, B=0)	-202,4	-170,3	-228,4	9,9	°C
TT_24 (R=0,5, Z=0, B=45)	-82,4	-37,5	-118,7	25,7	°C
TT_25 (R=0,5, Z=0, B=90)	-165,4	-142,3	-190,0	13,8	°C
TT_26 (R=0,5, Z=-0,02, B=90)	-104,2	-48,6	-138,9	23,2	°C
TT_27 (R=0,5, Z=-0,03, B=90)	-28,6	-3,1	-58,9	16,9	°C
TT_28 (R=0,5, Z=0, B=135)	-191,2	-132,7	-234,2	25,7	°C
TT_29 (R=0,5, Z=0, B=180)	-168,5	-104,4	-218,7	25,1	°C
TT_30 (R=0,5, Z=-0,02, B=180)	-111,7	-66,0	-131,8	19,3	°C
TT_31 (R=0,5, Z=-0,03, B=180)	-101,9	-37,4	-174,4	32,5	°C
TT_32 (R=0,5, Z=0, B=225)	-61,2	-15,6	-92,6	23,5	°C
TT_33 (R=1, Z=0, B=270)	1,8	2,6	-7,1	1,1	°C
TT_34 (R=1, Z=0, B=315)	-131,9	-87,4	-189,8	26,1	°C
TT_35 (R=1, Z=0, B=0)	-44,8	-19,7	-60,8	10,9	°C
TT_36 (R=1, Z=0, B=45)	-41,5	-17,9	-51,3	7,4	°C
TT_37 (R=1, Z=0, B=90)	-58,1	-21,3	-125,6	17,3	°C
TT_38 (R=1, Z=0, B=135)	-15,2	-6,4	-43,5	9,5	°C
TT_39 (R=1, Z=0, B=180)	-2,0	-0,5	-8,1	1,8	°C
TT_40 (R=1, Z=0, B=225)	-6,2	-0,3	-30,8	6,4	°C
TT_41 (R=5, Z=0, B=315)	3,4	3,5	3,4	0,0	°C
TT_42 (R=5, Z=0, B=45)	-1,1	4,5	-16,3	3,9	°C
TT_43 (R=5, Z=0, B=135)	3,7	3,7	3,6	0,0	°C
TT_44 (R=5, Z=0, B=225)	2,9	2,9	2,9	0,0	°C
TT_45 (R=10, Z=0, B=315)	3,2	3,2	3,1	0,0	°C
TT_46 (R=10, Z=0, B=45)	-0,3	2,8	-2,1	0,7	°C
TT_47 (R=10, Z=0, B=135)	1,3	19,3	-31,4	8,2	°C
TT_48 (R=10, Z=0, B=225)	-1,8	0,4	-4,3	0,7	°C

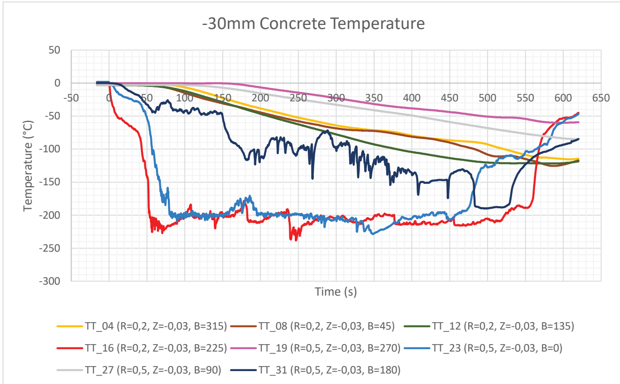








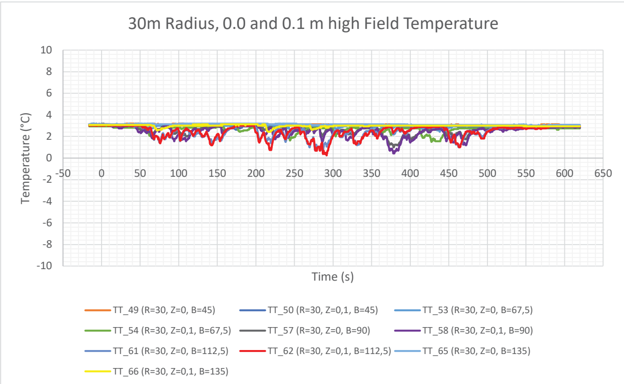


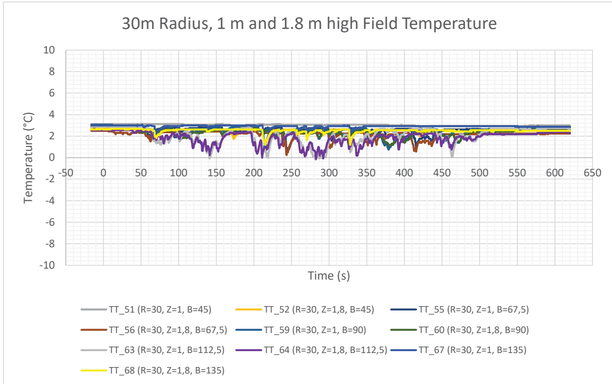


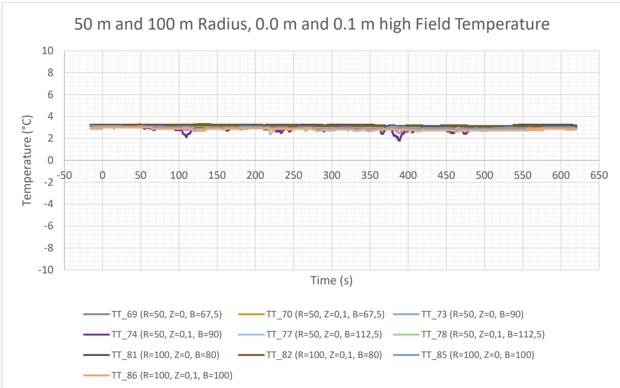
Field Temperature

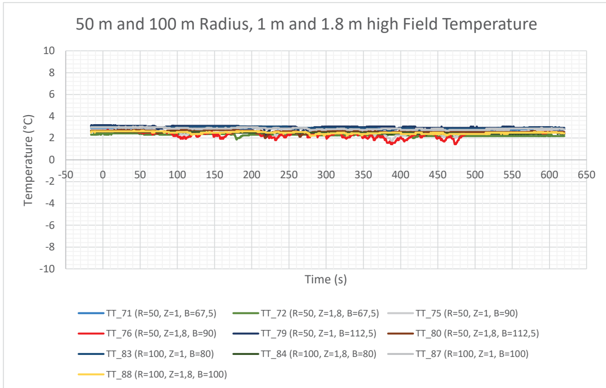
Notes: Greater temperature drop observed at 30 m, 1 and 1.8 m high

Test Name	Test07		FOR AVERAGING	
Hole Size	25,4 mm		Start	100 sec
Orientation	Downwards		End	450 sec









Sensor	Average	Max	Min	STDEV	units
TT_49 (R=30, Z=0, B=45)	3,1	3,2	2,9	0,1	°C
TT_50 (R=30, Z=0,1, B=45)	3,0	3,0	2,6	0,1	°C
TT_51 (R=30, Z=1, B=45)	3,0	3,1	2,7	0,1	°C
TT_52 (R=30, Z=1,8, B=45)	2,6	2,6	1,8	0,1	°C
TT_53 (R=30, Z=0, B=67,5)	2,9	3,1	2,4	0,1	°C
TT_54 (R=30, Z=0,1, B=67,5)	2,6	2,9	1,5	0,3	°C
TT_55 (R=30, Z=1, B=67,5)	2,5	2,8	0,7	0,4	°C
TT_56 (R=30, Z=1,8, B=67,5)	2,1	2,4	0,3	0,4	°C
TT_57 (R=30, Z=0, B=90)	2,5	3,0	1,0	0,4	°C
TT_58 (R=30, Z=0,1, B=90)	2,3	3,0	0,4	0,5	°C
TT_59 (R=30, Z=1, B=90)	2,4	2,9	0,8	0,4	°C
TT_60 (R=30, Z=1,8, B=90)	2,3	2,8	1,1	0,3	°C
TT_61 (R=30, Z=0, B=112,5)	2,3	3,1	0,6	0,5	°C
TT_62 (R=30, Z=0,1, B=112,5)	2,3	3,0	0,3	0,6	°C
TT_63 (R=30, Z=1, B=112,5)	1,8	2,9	-0,2	0,8	°C
TT_64 (R=30, Z=1,8, B=112,5)	1,6	2,4	-0,1	0,6	°C
TT_65 (R=30, Z=0, B=135)	3,1	3,2	3,1	0,1	°C
TT_66 (R=30, Z=0,1, B=135)	3,0	3,1	2,4	0,1	°C
TT_67 (R=30, Z=1, B=135)	2,9	3,0	1,1	0,2	°C
TT_68 (R=30, Z=1,8, B=135)	2,5	2,6	1,2	0,2	°C
TT_69 (R=50, Z=0, B=67,5)	3,1	3,2	3,1	0,0	°C
TT_70 (R=50, Z=0,1, B=67,5)	2,9	3,1	2,8	0,1	°C
TT_71 (R=50, Z=1, B=67,5)	2,9	3,0	2,6	0,1	°C
TT_72 (R=50, Z=1,8, B=67,5)	2,3	2,4	1,9	0,1	°C
TT_73 (R=50, Z=0, B=90)	3,0	3,2	2,5	0,1	°C
TT_74 (R=50, Z=0,1, B=90)	2,9	3,2	1,8	0,2	°C
TT_75 (R=50, Z=1, B=90)	2,7	3,0	1,7	0,2	°C
TT_76 (R=50, Z=1,8, B=90)	2,2	2,7	1,4	0,2	°C
TT_77 (R=50, Z=0, B=112,5)	3,1	3,2	2,8	0,1	°C
TT_78 (R=50, Z=0,1, B=112,5)	3,0	3,1	2,4	0,1	°C
TT_79 (R=50, Z=1, B=112,5)	3,0	3,1	2,3	0,1	°C
TT_80 (R=50, Z=1,8, B=112,5)	2,6	2,8	2,0	0,1	°C
TT_81 (R=100, Z=0, B=80)	3,2	3,3	3,1	0,0	°C
TT_82 (R=100, Z=0,1, B=80)	3,1	3,3	2,8	0,1	°C
TT_83 (R=100, Z=1, B=80)	2,9	3,1	2,6	0,1	°C
TT_84 (R=100, Z=1,8, B=80)	2,5	2,6	2,3	0,0	°C
TT_85 (R=100, Z=0, B=100)	2,9	3,1	2,8	0,1	°C
TT_86 (R=100, Z=0,1, B=100)	2,8	2,9	2,6	0,1	°C
TT_87 (R=100, Z=1, B=100)	2,9	3,0	2,7	0,1	°C
TT_88 (R=100, Z=1,8, B=100)	2,5	2,6	2,2	0,1	°C

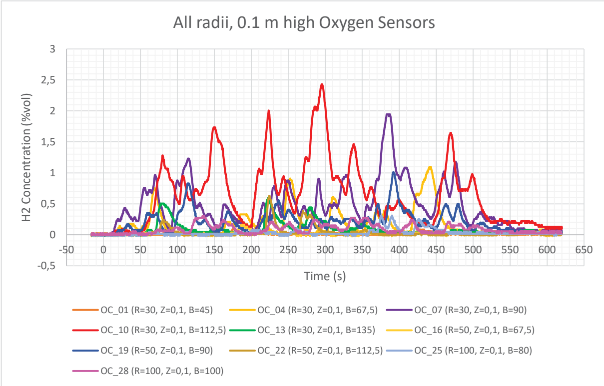
Gas Concentrations

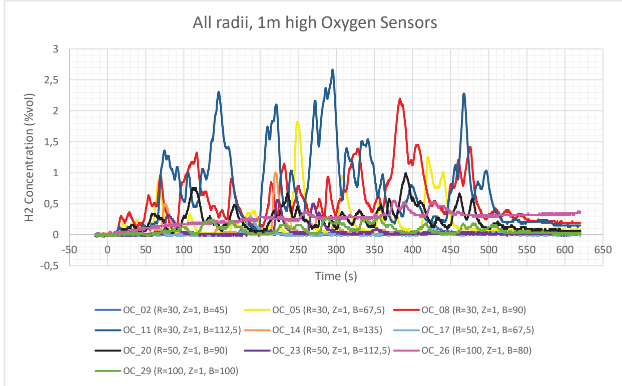
Test Name	Test07		FOR AVERAGING		
Hole Size	25,4	mm	Start	100	sec
Orientation	Downwards		End	450	sec

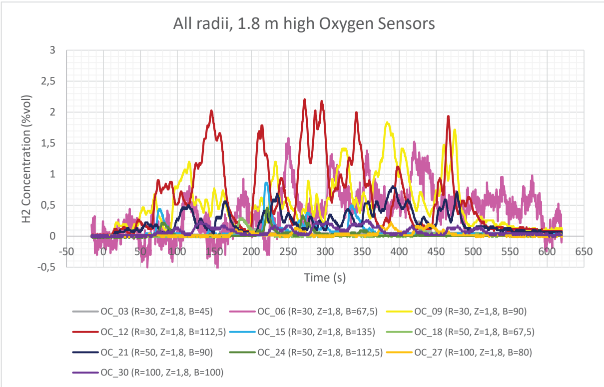
Notes:

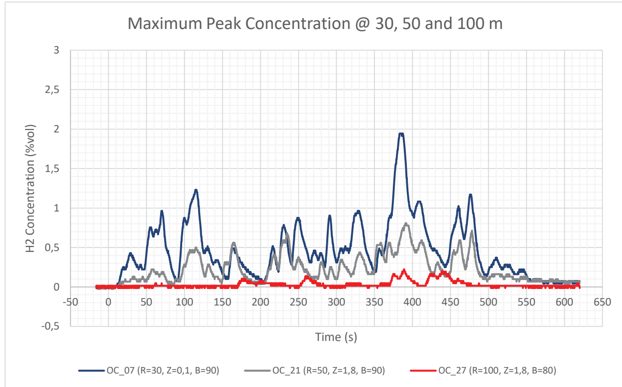
Peak concentrations observed @ 30 m
Max. ~3%vol detected at 30m west

Sensor	Average	Max	Min	STDEV	units
OC_01 (R=30, Z=0,1, B=45)	0,0	0,2	0,0	0,0	%vol
OC_02 (R=30, Z=1, B=45)	0,0	0,2	0,0	0,0	%vol
OC_03 (R=30, Z=1,8, B=45)	0,1	0,3	0,0	0,1	%vol
OC_04 (R=30, Z=0,1, B=67,5)	0,2	1,1	0,0	0,3	%vol
OC_05 (R=30, Z=1, B=67,5)	0,3	1,8	0,0	0,4	%vol
OC_06 (R=30, Z=1,8, B=67,5)	0,5	1,6	-0,6	0,4	%vol
OC_07 (R=30, Z=0,1, B=90)	0,6	1,9	0,0	0,4	%vol
OC_08 (R=30, Z=1, B=90)	0,7	2,2	0,1	0,4	%vol
OC_09 (R=30, Z=1,8, B=90)	0,7	1,8	0,1	0,4	%vol
OC_10 (R=30, Z=0,1, B=112,5)	0,8	2,4	0,1	0,5	%vol
OC_11 (R=30, Z=1, B=112,5)	0,9	2,7	0,1	0,6	%vol
OC_12 (R=30, Z=1,8, B=112,5)	0,9	2,2	0,1	0,6	%vol
OC_13 (R=30, Z=0,1, B=135)	0,1	0,6	0,0	0,1	%vol
OC_14 (R=30, Z=1, B=135)	0,1	1,0	0,0	0,1	%vol
OC_15 (R=30, Z=1,8, B=135)	0,1	0,9	0,0	0,1	%vol
OC_16 (R=50, Z=0,1, B=67,5)	0,0	0,2	0,0	0,0	%vol
OC_17 (R=50, Z=1, B=67,5)	0,0	0,3	0,0	0,0	%vol
OC_18 (R=50, Z=1,8, B=67,5)	0,0	0,3	0,0	0,1	%vol
OC_19 (R=50, Z=0,1, B=90)	0,3	1,0	0,0	0,2	%vol
OC_20 (R=50, Z=1, B=90)	0,3	1,0	0,0	0,2	%vol
OC_21 (R=50, Z=1,8, B=90)	0,3	0,8	0,0	0,2	%vol
OC_22 (R=50, Z=0,1, B=112,5)	0,1	0,6	0,0	0,1	%vol
OC_23 (R=50, Z=1, B=112,5)	0,1	0,6	0,0	0,1	%vol
OC_24 (R=50, Z=1,8, B=112,5)	0,0	0,5	0,0	0,1	%vol
OC_25 (R=100, Z=0,1, B=80)	0,0	0,3	0,0	0,1	%vol
OC_26 (R=100, Z=1, B=80)	0,3	0,6	0,2	0,1	%vol
OC_27 (R=100, Z=1,8, B=80)	0,0	0,2	0,0	0,1	%vol
OC_28 (R=100, Z=0,1, B=100)	0,1	0,3	0,0	0,1	%vol
OC_29 (R=100, Z=1, B=100)	0,1	0,3	0,0	0,1	%vol
OC_30 (R=100, Z=1,8, B=100)	0,1	0,3	0,0	0,1	%vol









B Results closed room and ventilation mast leakage tests

The results for Test 8 to Test 15 are given in this appendix.

DNV·GL

FFI: LH2 Releases

Notes

P04 was damaged by cold temperature around 210s
Maybe offset in temperature - no measurements reach liquid temp, need to investigate

Test Name	Test08	
Hole Size	25,4	mm
Orientation	Downwards	

FOR PLOTS

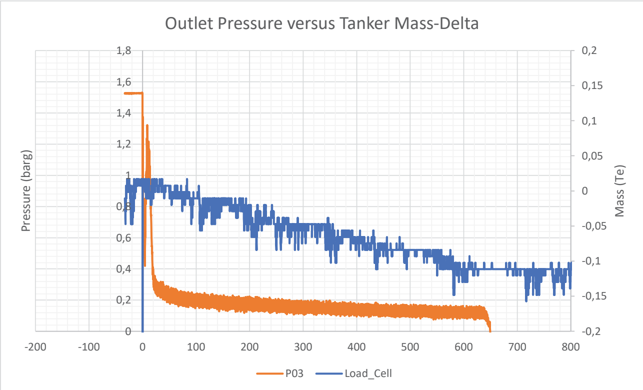
Start Time	-33	sec
End Time	1600	sec

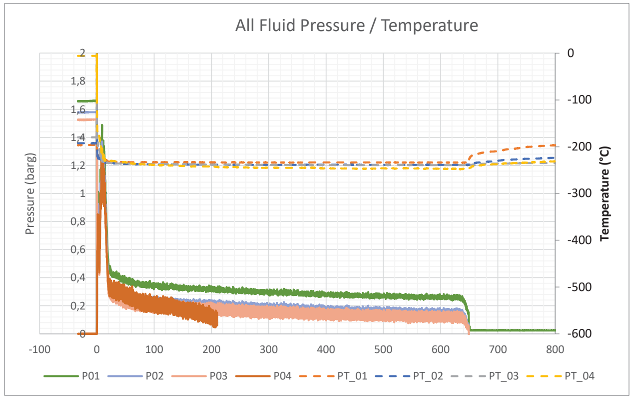
Date 13.01.2020

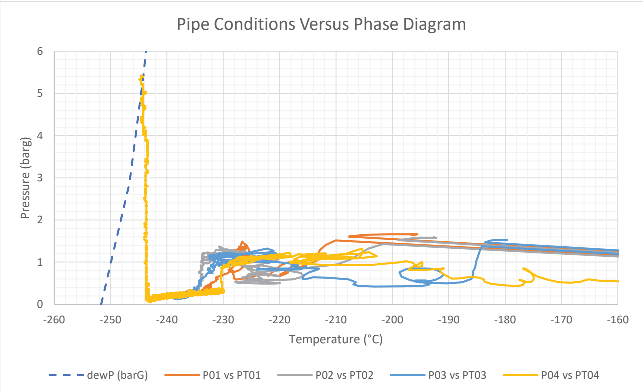
FOR AVERAGING

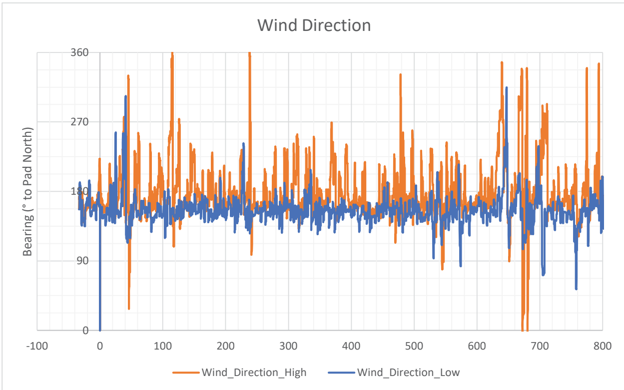
Start	100	sec
End	600	sec

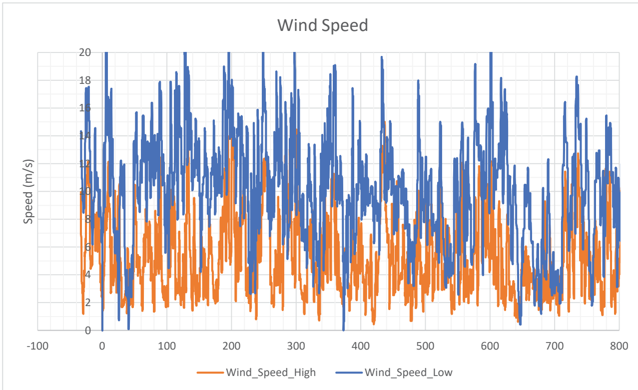
Sensor	Average	Max	Min	STDEV	units
Load_Cell	-0,062	0,008	-0,148	0,028	Te
P01	0,29	0,37	0,24	0,02	Barg
P02	0,19	0,26	0,14	0,03	Barg
P03	0,14	0,25	0,08	0,03	Barg
P04	1,64	20,37	-2,31	4,74	Barg
PT_01	-233,7	-232,9	-234,2	0,2	°C
PT_02	-238,6	-237,8	-239,0	0,3	°C
PT_03	-238,6	-237,1	-239,4	0,7	°C
PT_04	-244,7	-238,9	-247,7	2,2	°C
MassFlow	0,183				kg/s
Wind_Direction_High	176,3	363,1	78,9	30,8	0,0
Wind_Direction_Low	154,5	242,2	83,0	14,3	Deg
Wind_Speed_High	5,6	15,0	0,4	3,0	m/s
Wind_Speed_Low	10,6	26,0	0,0	3,7	m/s









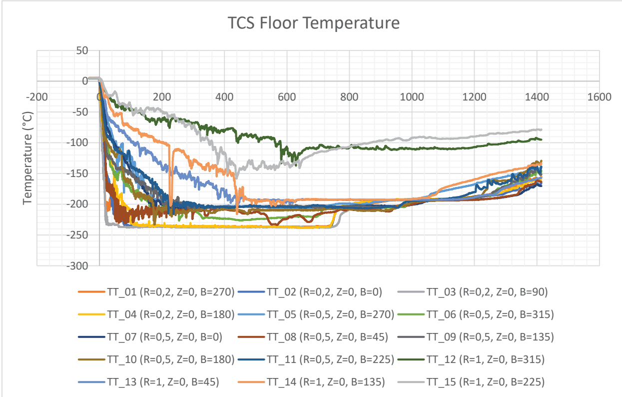


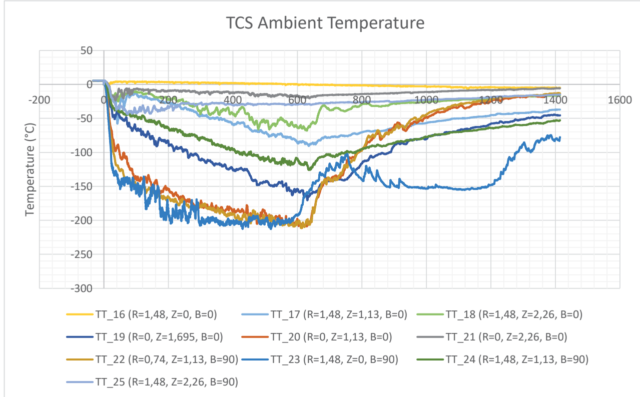
TCS Temperature

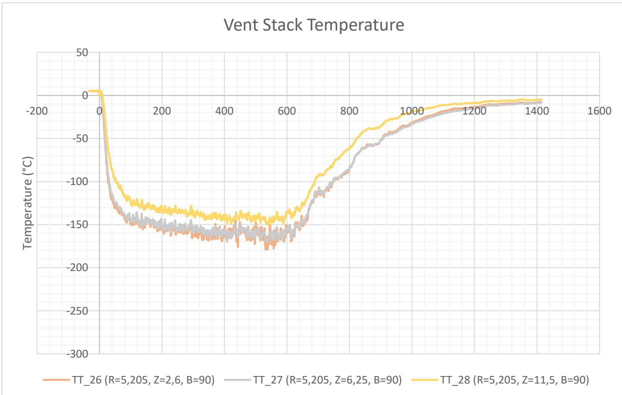
Test Name	Test08		FOR AVERAGING	
Hole Size	25,4 mm		Start	100 sec
Orientation	Downwards		End	500 sec

Notes: Liquid H2 observed on TCS floor surface @0.2m. Around 100s after end of release most floor temperatures register ca. -200°C for over 2.5 minutes. Floor temps rised after that. Ambient temperature within chamber reached -200°C, these quickly increased as soon as the release stopped. Temperature sensors show low temps in stack. The closest temperature sensor to the end of the stack registered a higher temperature than the other two, as expected.

Sensor	Average	Max	Min	STDEV	units
TT_01 (R=0,2, Z=0, B=270)	-235,4	-230,4	-236,7	1,0	°C
TT_02 (R=0,2, Z=0, B=0)	-236,2	-230,4	-237,0	0,5	°C
TT_03 (R=0,2, Z=0, B=90)	-237,3	-236,2	-237,7	0,3	°C
TT_04 (R=0,2, Z=0, B=180)	-235,8	-227,3	-237,3	1,3	°C
TT_05 (R=0,5, Z=0, B=270)	-194,7	-123,1	-207,2	17,6	°C
TT_06 (R=0,5, Z=0, B=315)	-212,6	-176,6	-226,7	13,6	°C
TT_07 (R=0,5, Z=0, B=0)	-198,3	-148,6	-208,6	14,2	°C
TT_08 (R=0,5, Z=0, B=45)	-211,3	-202,6	-229,4	3,3	°C
TT_09 (R=0,5, Z=0, B=135)	-195,1	-148,6	-210,8	15,4	°C
TT_10 (R=0,5, Z=0, B=180)	-206,2	-165,1	-232,9	10,5	°C
TT_11 (R=0,5, Z=0, B=225)	-190,5	-136,2	-215,7	20,8	°C
TT_12 (R=1, Z=0, B=315)	-70,7	-44,1	-100,3	12,2	°C
TT_13 (R=1, Z=0, B=45)	-156,5	-96,6	-202,2	29,1	°C
TT_14 (R=1, Z=0, B=135)	-131,5	-74,7	-216,1	35,6	°C
TT_15 (R=1, Z=0, B=225)	-86,8	-40,7	-158,3	36,3	°C
TT_16 (R=1,48, Z=0, B=0)	2,5	4,1	0,3	0,9	°C
TT_17 (R=1,48, Z=1,13, B=0)	-42,8	-13,4	-72,2	16,5	°C
TT_18 (R=1,48, Z=2,26, B=0)	-32,6	-10,4	-66,3	13,2	°C
TT_19 (R=0, Z=1,695, B=0)	-106,9	-65,2	-148,3	22,1	°C
TT_20 (R=0, Z=1,13, B=0)	-171,7	-133,4	-205,1	17,8	°C
TT_21 (R=0, Z=2,26, B=0)	-11,0	-6,2	-17,4	2,2	°C
TT_22 (R=0,74, Z=1,13, B=90)	-178,6	-147,8	-205,6	14,8	°C
TT_23 (R=1,48, Z=0, B=90)	-190,3	-135,6	-212,5	17,0	°C
TT_24 (R=1,48, Z=1,13, B=90)	-79,4	-45,7	-112,9	18,7	°C
TT_25 (R=1,48, Z=2,26, B=90)	-31,3	-26,8	-42,9	4,1	°C
TT_26 (R=5,205, Z=2,6, B=90)	-156,1	-136,0	-175,6	6,6	°C
TT_27 (R=5,205, Z=6,25, B=90)	-154,0	-135,9	-168,3	6,0	°C
TT_28 (R=5,205, Z=11,5, B=90)	-136,1	-120,1	-148,8	5,9	°C





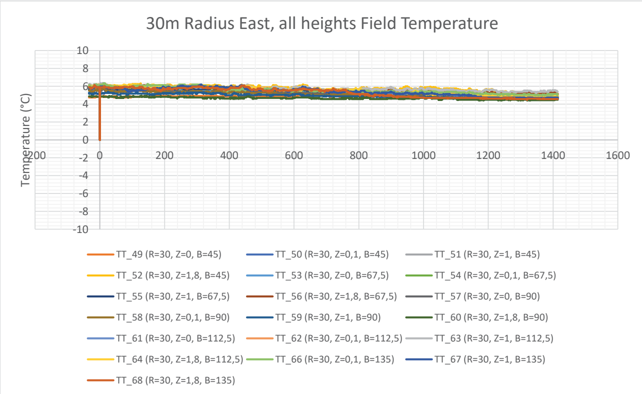


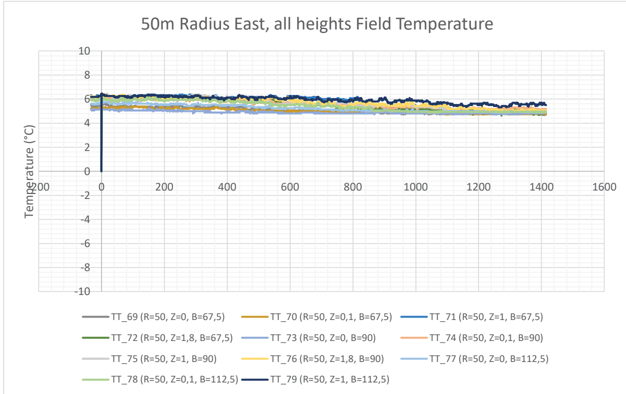
DNV·GL

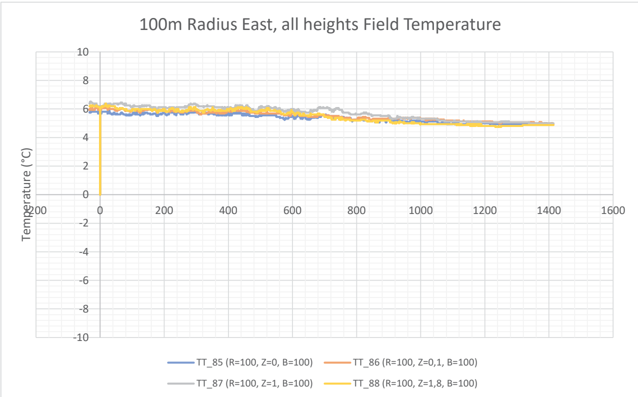
Notes: No significant temperature drop in the field. TT_65 and TT_80 faulty after start of release. Low temps intermittently registered near low level vent

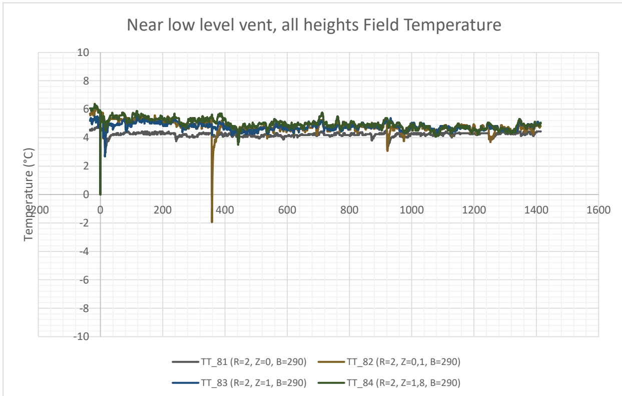
Field Temperature

Test Name	Test08		FOR AVERAGING		
Hole Size	25,4	mm	Start	100	sec
Orientation	Downwards		End	500	sec









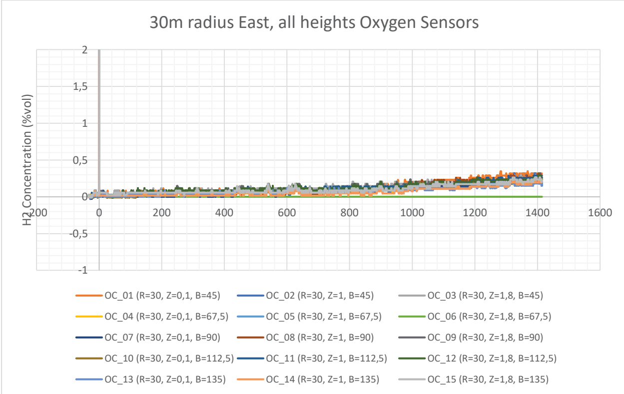
Sensor	Average	Max	Min	STDEV	units
TT_49 (R=30, Z=0, B=45)	4,9	4,9	4,8	0,0	°C
TT_50 (R=30, Z=0,1, B=45)	5,7	5,9	5,4	0,1	°C
TT_51 (R=30, Z=1, B=45)	5,7	6,0	5,6	0,1	°C
TT_52 (R=30, Z=1,8, B=45)	6,1	6,3	5,8	0,1	°C
TT_53 (R=30, Z=0, B=67,5)	5,5	5,8	5,3	0,1	°C
TT_54 (R=30, Z=0,1, B=67,5)	5,7	6,0	5,5	0,1	°C
TT_55 (R=30, Z=1, B=67,5)	5,7	5,9	5,4	0,1	°C
TT_56 (R=30, Z=1,8, B=67,5)	5,9	6,1	5,5	0,1	°C
TT_57 (R=30, Z=0, B=90)	5,4	5,6	5,3	0,1	°C
TT_58 (R=30, Z=0,1, B=90)	5,4	5,7	5,1	0,1	°C
TT_59 (R=30, Z=1, B=90)	5,2	5,3	5,0	0,1	°C
TT_60 (R=30, Z=1,8, B=90)	4,8	4,9	4,6	0,1	°C
TT_61 (R=30, Z=0, B=112,5)	5,9	6,1	5,6	0,1	°C
TT_62 (R=30, Z=0,1, B=112,5)	5,9	6,1	5,6	0,1	°C
TT_63 (R=30, Z=1, B=112,5)	6,0	6,2	5,7	0,1	°C
TT_64 (R=30, Z=1,8, B=112,5)	5,9	6,2	5,7	0,1	°C
TT_65 (R=30, Z=0, B=135)	3,2	5,7	-2,8	0,6	°C
TT_66 (R=30, Z=0,1, B=135)	5,9	6,3	5,4	0,2	°C
TT_67 (R=30, Z=1, B=135)	5,8	6,2	5,5	0,2	°C
TT_68 (R=30, Z=1,8, B=135)	5,8	6,1	5,4	0,1	°C
TT_69 (R=50, Z=0, B=67,5)	5,3	5,5	5,1	0,1	°C
TT_70 (R=50, Z=0,1, B=67,5)	5,2	5,4	5,0	0,1	°C
TT_71 (R=50, Z=1, B=67,5)	6,2	6,4	6,0	0,1	°C
TT_72 (R=50, Z=1,8, B=67,5)	6,0	6,2	5,8	0,1	°C
TT_73 (R=50, Z=0, B=90)	5,0	5,3	4,8	0,1	°C
TT_74 (R=50, Z=0,1, B=90)	5,9	6,2	5,6	0,1	°C
TT_75 (R=50, Z=1, B=90)	6,1	6,4	5,8	0,1	°C
TT_76 (R=50, Z=1,8, B=90)	6,1	6,3	5,8	0,1	°C
TT_77 (R=50, Z=0, B=112,5)	5,5	5,7	5,3	0,1	°C
TT_78 (R=50, Z=0,1, B=112,5)	5,9	6,2	5,6	0,1	°C
TT_79 (R=50, Z=1, B=112,5)	6,2	6,4	5,9	0,1	°C
TT_80 (R=50, Z=1,8, B=112,5)	5,6	6,4	-1,3	0,9	°C
TT_81 (R=2, Z=0, B=290)	4,2	4,4	3,8	0,1	°C
TT_82 (R=2, Z=0,1, B=290)	4,8	5,6	-1,9	0,6	°C
TT_83 (R=2, Z=1, B=290)	4,8	5,5	3,7	0,3	°C
TT_84 (R=2, Z=1,8, B=290)	5,2	5,9	3,5	0,3	°C
TT_85 (R=100, Z=0, B=100)	5,7	5,9	5,4	0,1	°C
TT_86 (R=100, Z=0,1, B=100)	5,8	6,0	5,6	0,1	°C
TT_87 (R=100, Z=1, B=100)	6,1	6,4	5,9	0,1	°C
TT_88 (R=100, Z=1,8, B=100)	5,9	6,1	5,8	0,1	°C

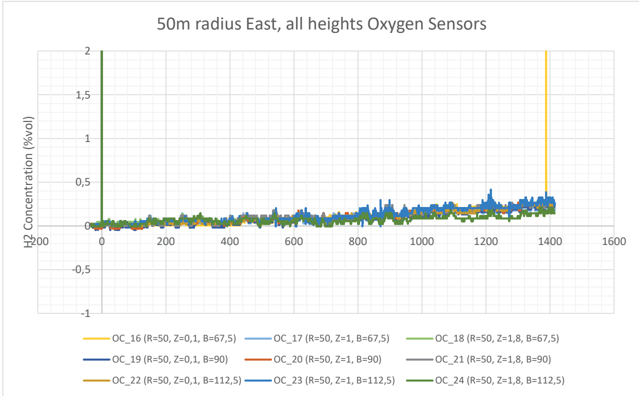
Gas Concentrations

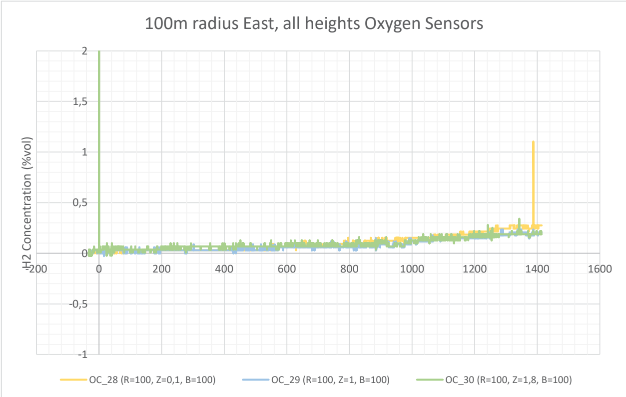
Test Name	Test08		FOR AVERAGING		
Hole Size	25,4	mm	Start	100	sec
Orientation	Downwards		End	500	sec

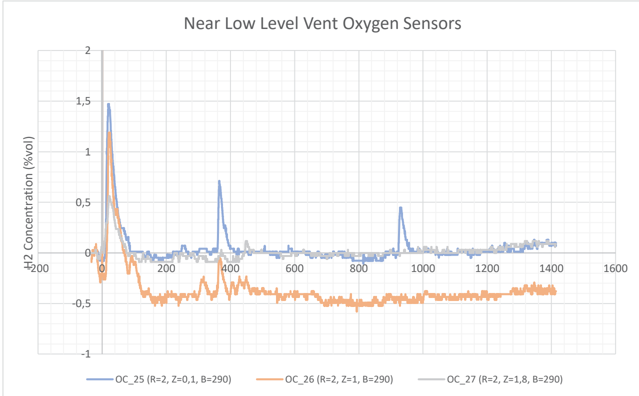
Notes: No H2 detected in the field. Small amounts detected near low level vent at the beginning of the release. Very high concentrations within the TCS. Sensors were likely affected by cold temperatures, so decay measurements are likely affected. Correction to be applied if possible.

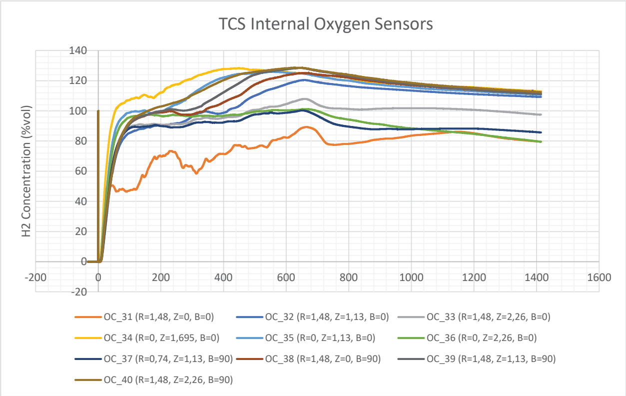
Sensor	Average	Max	Min	STDEV	units
OC_01 (R=30, Z=0,1, B=45)	0,1	0,1	0,0	0,0	%vol
OC_02 (R=30, Z=1, B=45)	0,0	0,1	0,0	0,0	%vol
OC_03 (R=30, Z=1,8, B=45)	0,1	0,1	0,0	0,0	%vol
OC_04 (R=30, Z=0,1, B=67,5)	0,1	0,1	0,0	0,0	%vol
OC_05 (R=30, Z=1, B=67,5)	0,1	0,1	0,0	0,0	%vol
OC_06 (R=30, Z=1,8, B=67,5)	0,0	0,0	0,0	0,0	%vol
OC_07 (R=30, Z=0,1, B=90)	0,0	0,1	0,0	0,0	%vol
OC_08 (R=30, Z=1, B=90)	0,0	0,1	0,0	0,0	%vol
OC_09 (R=30, Z=1,8, B=90)	0,1	0,1	0,0	0,0	%vol
OC_10 (R=30, Z=0,1, B=112,5)	0,1	0,1	0,0	0,0	%vol
OC_11 (R=30, Z=1, B=112,5)	0,1	0,1	0,0	0,0	%vol
OC_12 (R=30, Z=1,8, B=112,5)	0,1	0,1	0,0	0,0	%vol
OC_13 (R=30, Z=0,1, B=135)	0,0	0,1	0,0	0,0	%vol
OC_14 (R=30, Z=1, B=135)	0,0	0,1	0,0	0,0	%vol
OC_15 (R=30, Z=1,8, B=135)	0,1	0,1	0,0	0,0	%vol
OC_16 (R=50, Z=0,1, B=67,5)	0,0	0,1	0,0	0,0	%vol
OC_17 (R=50, Z=1, B=67,5)	0,0	0,1	0,0	0,0	%vol
OC_18 (R=50, Z=1,8, B=67,5)	0,1	0,1	0,0	0,0	%vol
OC_19 (R=50, Z=0,1, B=90)	0,0	0,1	0,0	0,0	%vol
OC_20 (R=50, Z=1, B=90)	0,0	0,1	0,0	0,0	%vol
OC_21 (R=50, Z=1,8, B=90)	0,1	0,1	0,0	0,0	%vol
OC_22 (R=50, Z=0,1, B=112,5)	0,0	0,1	0,0	0,0	%vol
OC_23 (R=50, Z=1, B=112,5)	0,1	0,1	0,0	0,0	%vol
OC_24 (R=50, Z=1,8, B=112,5)	0,1	0,1	0,0	0,0	%vol
OC_25 (R=2, Z=0,1, B=290)	0,0	0,7	-0,1	0,1	%vol
OC_26 (R=2, Z=1, B=290)	-0,4	0,0	-0,5	0,1	%vol
OC_27 (R=2, Z=1,8, B=290)	0,0	0,1	-0,1	0,0	%vol
OC_28 (R=100, Z=0,1, B=100)	0,0	0,1	0,0	0,0	%vol
OC_29 (R=100, Z=1, B=100)	0,0	0,1	0,0	0,0	%vol
OC_30 (R=100, Z=1,8, B=100)	0,1	0,1	0,0	0,0	%vol
OC_31 (R=1,48, Z=0, B=0)	67,0	77,3	47,2	7,9	%vol
OC_32 (R=1,48, Z=1,13, B=0)	95,8	110,0	85,3	6,3	%vol
OC_33 (R=1,48, Z=2,26, B=0)	93,6	100,7	89,1	2,9	%vol
OC_34 (R=0, Z=1,695, B=0)	120,0	128,4	107,1	7,4	%vol
OC_35 (R=0, Z=1,13, B=0)	111,3	125,0	97,9	10,2	%vol
OC_36 (R=0, Z=2,26, B=0)	97,0	99,5	95,7	0,7	%vol
OC_37 (R=0,74, Z=1,13, B=90)	91,5	97,6	88,5	2,2	%vol
OC_38 (R=1,48, Z=0, B=90)	101,8	117,4	91,3	6,0	%vol
OC_39 (R=1,48, Z=1,13, B=90)	105,5	123,9	91,2	8,6	%vol
OC_40 (R=1,48, Z=2,26, B=90)	111,0	125,9	92,4	9,7	%vol











FFI: LH2 Releases

Notes

Maybe offset in temperature - no measurements reach liquid temp, need to investigate

Test Name	Test09	
Hole Size	25,4	mm
Orientation	Downwards	

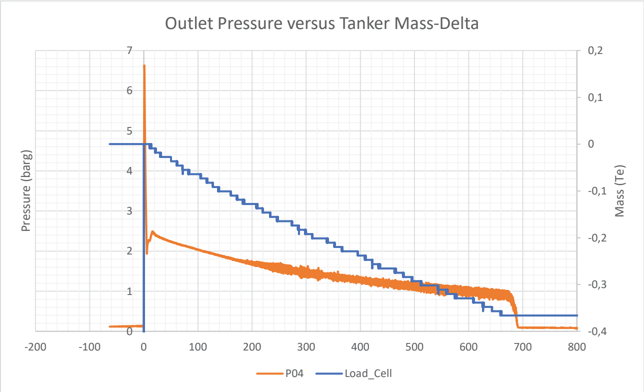
FOR PLOTS

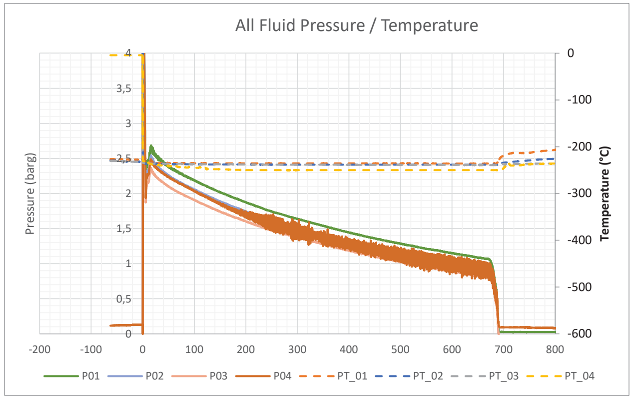
Start Time	-66	sec
End Time	1600	sec

Date 15.01.2020

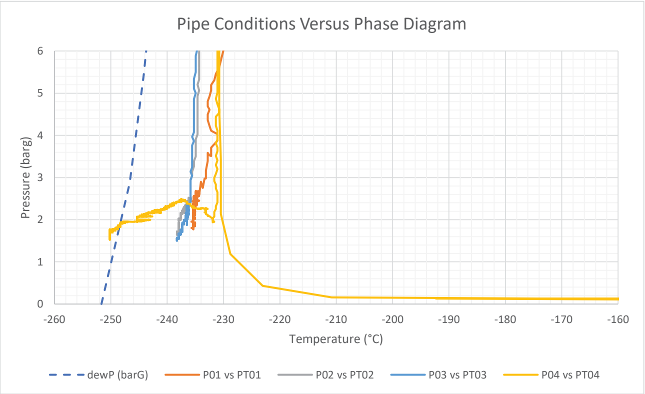
FOR AVERAGING

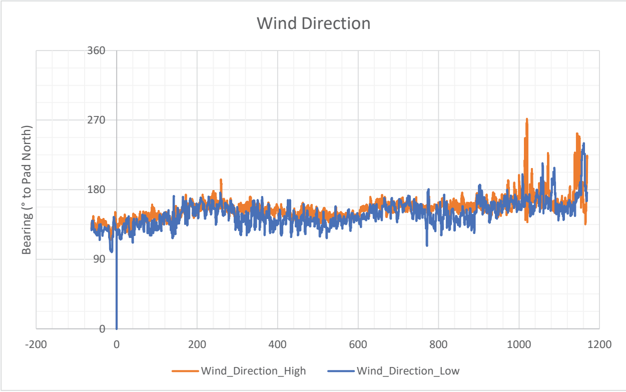
Start	100	sec
End	600	sec

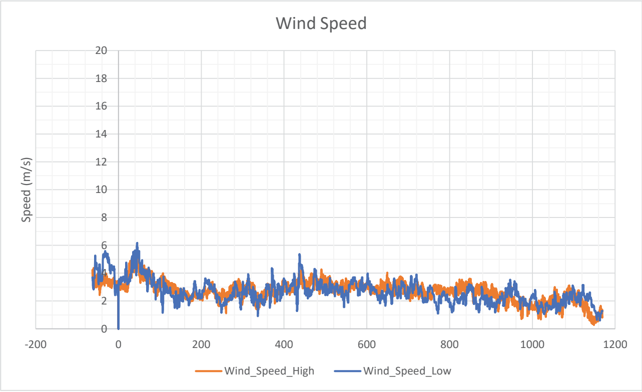




Sensor	Average	Max	Min	STDEV	units
Load_Cell	-0,210	-0,064	-0,330	0,077	Te
P01	1,58	2,19	1,15	0,29	Barg
P02	1,45	2,06	1,02	0,29	Barg
P03	1,32	1,91	0,89	0,28	Barg
P04	1,41	2,04	0,85	0,30	Barg
PT_01	-235,5	-235,1	-236,2	0,2	°C
PT_02	-238,2	-237,6	-238,6	0,2	°C
PT_03	-238,5	-237,0	-239,3	0,6	°C
PT_04	-249,7	-243,0	-250,7	1,2	°C
MassFlow	0,530				kg/s
Wind_Direction_High	150,7	193,3	130,2	7,6	0,0
Wind_Direction_Low	144,4	176,0	117,3	11,7	Deg
Wind_Speed_High	2,8	4,4	1,1	0,4	m/s
Wind_Speed_Low	2,7	5,4	0,9	0,6	m/s







DNV·GL

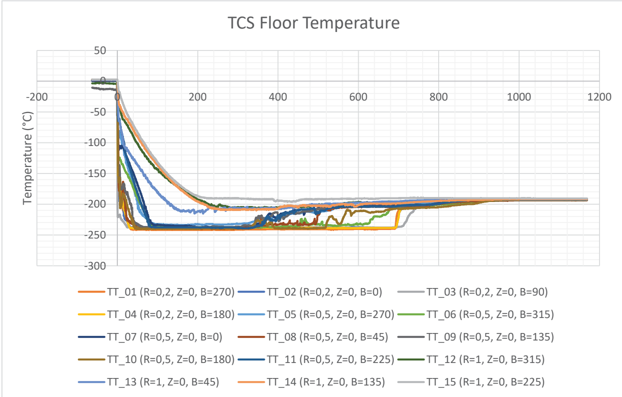
TCS Temperature

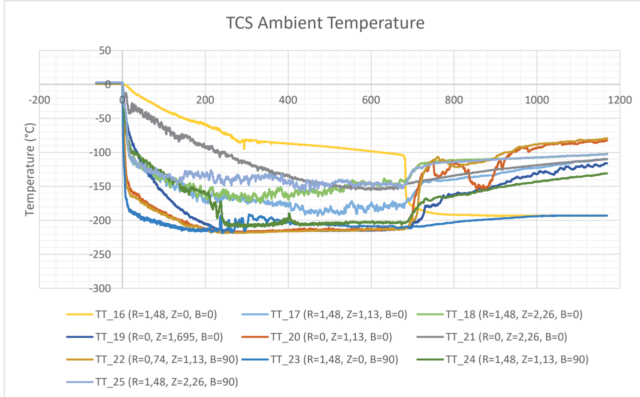
Test Name	Test09		FOR AVERAGING		
Hole Size	25,4	mm	Start	100	sec
Orientation	Downwards		End	500	sec

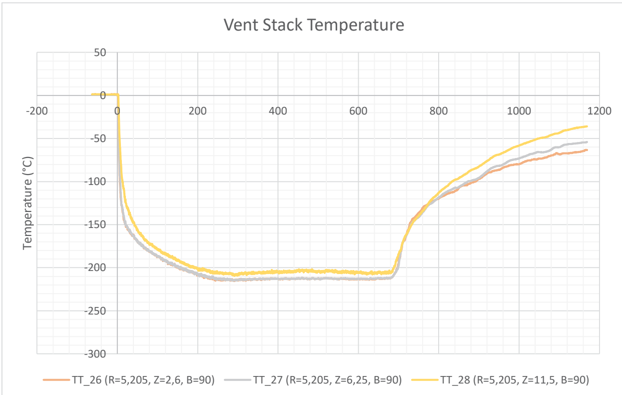
Notes:

Liquid H2 observed on TCS floor surface @0.2m. Around 100s after end of release most floor temperatures register ca. -200°C for over 2.5 minutes. Ambient temperature within chamber reached -200°C, these quickly increased as soon as the release stopped. Temperature sensors show low temps in stack. The closest temperature sensor to the end of the stack registered a higher temperature than the other two, as expected.

Sensor	Average	Max	Min	STDEV	units
TT_01 (R=0,2, Z=0, B=270)	-241,2	-240,8	-241,8	0,4	°C
TT_02 (R=0,2, Z=0, B=0)	-237,5	-237,1	-238,1	0,3	°C
TT_03 (R=0,2, Z=0, B=90)	-237,3	-237,0	-237,8	0,2	°C
TT_04 (R=0,2, Z=0, B=180)	-238,1	-237,4	-238,6	0,2	°C
TT_05 (R=0,5, Z=0, B=270)	-226,8	-212,0	-233,9	7,8	°C
TT_06 (R=0,5, Z=0, B=315)	-236,5	-223,1	-238,1	2,3	°C
TT_07 (R=0,5, Z=0, B=0)	-228,8	-206,1	-238,7	11,0	°C
TT_08 (R=0,5, Z=0, B=45)	-236,7	-214,7	-240,1	4,0	°C
TT_09 (R=0,5, Z=0, B=135)	-229,0	-206,9	-237,9	10,4	°C
TT_10 (R=0,5, Z=0, B=180)	-238,2	-225,9	-240,0	3,4	°C
TT_11 (R=0,5, Z=0, B=225)	-230,1	-205,4	-239,1	11,5	°C
TT_12 (R=1, Z=0, B=315)	-195,2	-143,3	-207,2	16,3	°C
TT_13 (R=1, Z=0, B=45)	-205,5	-180,0	-215,3	5,5	°C
TT_14 (R=1, Z=0, B=135)	-196,8	-136,5	-209,9	18,0	°C
TT_15 (R=1, Z=0, B=225)	-184,9	-132,3	-196,4	14,6	°C
TT_16 (R=1,48, Z=0, B=0)	-74,1	-37,2	-95,4	16,4	°C
TT_17 (R=1,48, Z=1,13, B=0)	-170,0	-137,6	-193,4	12,3	°C
TT_18 (R=1,48, Z=2,26, B=0)	-158,6	-133,5	-174,8	7,6	°C
TT_19 (R=0, Z=1,695, B=0)	-207,9	-159,9	-217,4	14,2	°C
TT_20 (R=0, Z=1,13, B=0)	-212,1	-187,8	-218,3	6,8	°C
TT_21 (R=0, Z=2,26, B=0)	-112,7	-62,0	-149,8	24,9	°C
TT_22 (R=0,74, Z=1,13, B=90)	-213,5	-191,1	-218,8	6,5	°C
TT_23 (R=1,48, Z=0, B=90)	-206,8	-191,4	-218,6	6,5	°C
TT_24 (R=1,48, Z=1,13, B=90)	-188,2	-130,9	-209,6	24,8	°C
TT_25 (R=1,48, Z=2,26, B=90)	-140,0	-126,5	-157,3	6,3	°C
TT_26 (R=5,205, Z=2,6, B=90)	-209,3	-186,4	-215,5	7,1	°C
TT_27 (R=5,205, Z=6,25, B=90)	-209,0	-186,6	-215,1	7,1	°C
TT_28 (R=5,205, Z=11,5, B=90)	-201,6	-178,5	-209,4	7,1	°C



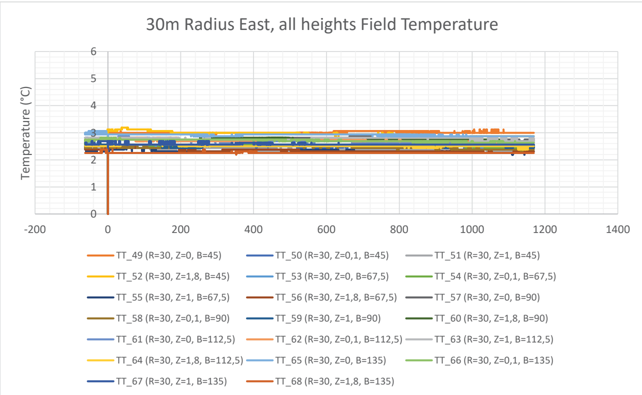


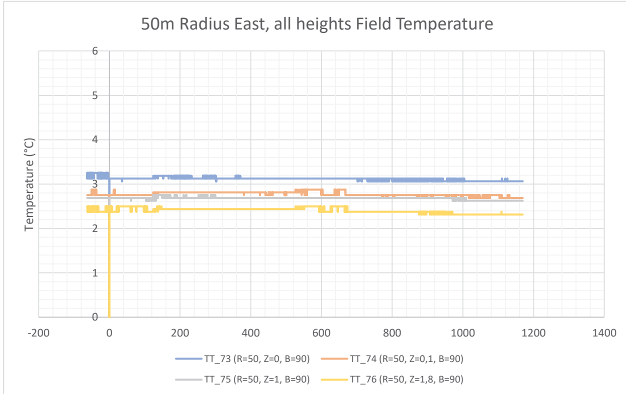


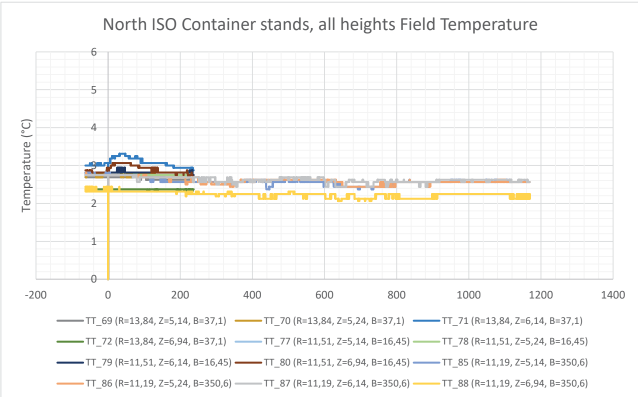
Field Temperature

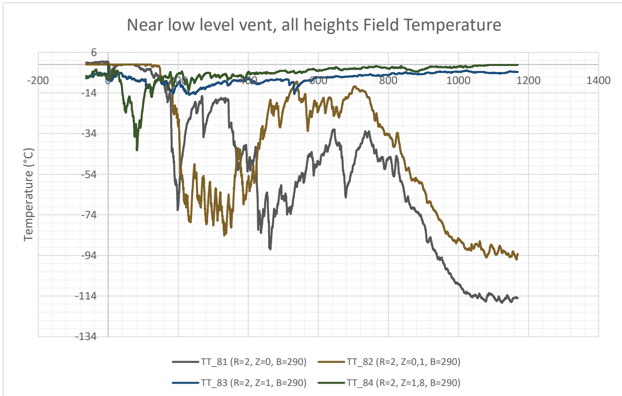
Notes: No significant temperature drop in the field or on top of ISO containers.Low temps registered near low level vent

Test Name	Test09		FOR AVERAGING		
Hole Size	25,4	mm	Start	100	sec
Orientation	Downwards		End	500	sec









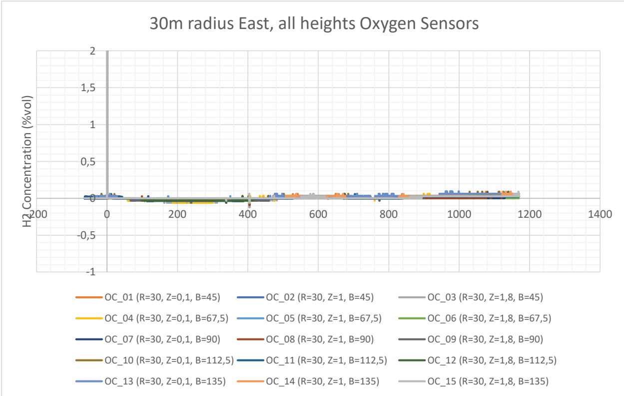
Sensor	Average	Max	Min	STDEV	units
TT_49 (R=30, Z=0, B=45)	3,0	3,0	2,9	0,0	°C
TT_50 (R=30, Z=0,1, B=45)	2,5	2,6	2,4	0,0	°C
TT_51 (R=30, Z=1, B=45)	2,4	2,4	2,3	0,0	°C
TT_52 (R=30, Z=1,8, B=45)	3,0	3,1	2,9	0,0	°C
TT_53 (R=30, Z=0, B=67,5)	2,5	2,6	2,5	0,0	°C
TT_54 (R=30, Z=0,1, B=67,5)	2,5	2,6	2,5	0,0	°C
TT_55 (R=30, Z=1, B=67,5)	2,3	2,4	2,3	0,0	°C
TT_56 (R=30, Z=1,8, B=67,5)	2,4	2,4	2,3	0,0	°C
TT_57 (R=30, Z=0, B=90)	2,8	2,8	2,8	0,0	°C
TT_58 (R=30, Z=0,1, B=90)	2,5	2,6	2,4	0,0	°C
TT_59 (R=30, Z=1, B=90)	2,5	2,6	2,4	0,0	°C
TT_60 (R=30, Z=1,8, B=90)	2,8	2,8	2,8	0,0	°C
TT_61 (R=30, Z=0, B=112,5)	2,7	2,8	2,6	0,1	°C
TT_62 (R=30, Z=0,1, B=112,5)	2,7	2,8	2,7	0,0	°C
TT_63 (R=30, Z=1, B=112,5)	2,8	2,8	2,7	0,0	°C
TT_64 (R=30, Z=1,8, B=112,5)	2,5	2,6	2,5	0,0	°C
TT_65 (R=30, Z=0, B=135)	2,9	2,9	2,9	0,0	°C
TT_66 (R=30, Z=0,1, B=135)	2,7	2,8	2,7	0,0	°C
TT_67 (R=30, Z=1, B=135)	2,6	2,7	2,6	0,0	°C
TT_68 (R=30, Z=1,8, B=135)	2,3	2,4	2,2	0,0	°C
TT_69 (R=13,84, Z=5,14, B=37,1)	2,6	2,7	2,6	0,0	°C
TT_70 (R=13,84, Z=5,24, B=37,1)	2,7	2,8	2,6	0,0	°C
TT_71 (R=13,84, Z=6,14, B=37,1)	2,9	3,1	2,8	0,1	°C
TT_72 (R=13,84, Z=6,94, B=37,1)	2,4	2,4	2,3	0,0	°C
TT_73 (R=50, Z=0, B=90)	3,1	3,2	3,1	0,0	°C
TT_74 (R=50, Z=0,1, B=90)	2,8	2,8	2,8	0,0	°C
TT_75 (R=50, Z=1, B=90)	2,7	2,8	2,6	0,0	°C
TT_76 (R=50, Z=1,8, B=90)	2,4	2,5	2,4	0,0	°C
TT_77 (R=11,51, Z=5,14, B=16,45)	2,6	2,8	2,6	0,0	°C
TT_78 (R=11,51, Z=5,24, B=16,45)	2,7	2,8	2,6	0,1	°C
TT_79 (R=11,51, Z=6,14, B=16,45)	2,8	2,9	2,6	0,1	°C
TT_80 (R=11,51, Z=6,94, B=16,45)	2,7	2,9	2,3	0,1	°C
TT_81 (R=2, Z=0, B=290)	-35,8	-2,1	-90,9	23,6	°C
TT_82 (R=2, Z=0,1, B=290)	-42,6	0,1	-84,1	26,2	°C
TT_83 (R=2, Z=1, B=290)	-9,7	-6,9	-14,9	2,1	°C
TT_84 (R=2, Z=1,8, B=290)	-6,2	-3,1	-19,4	2,6	°C
TT_85 (R=11,19, Z=5,14, B=350,6)	2,6	2,7	2,4	0,1	°C
TT_86 (R=11,19, Z=5,24, B=350,6)	2,6	2,8	2,4	0,1	°C
TT_87 (R=11,19, Z=6,14, B=350,6)	2,6	2,7	2,4	0,1	°C
TT_88 (R=11,19, Z=6,94, B=350,6)	2,3	2,3	2,1	0,1	°C

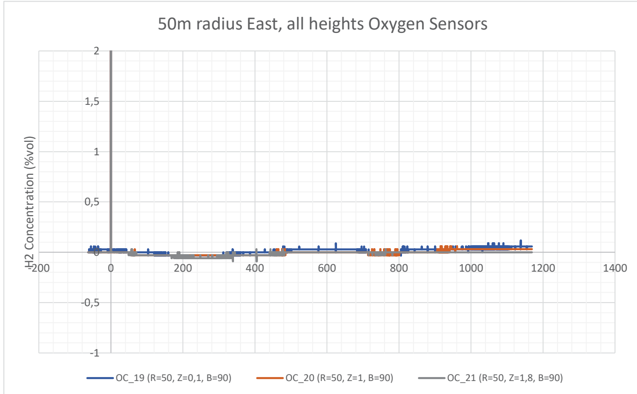
Gas Concentrations

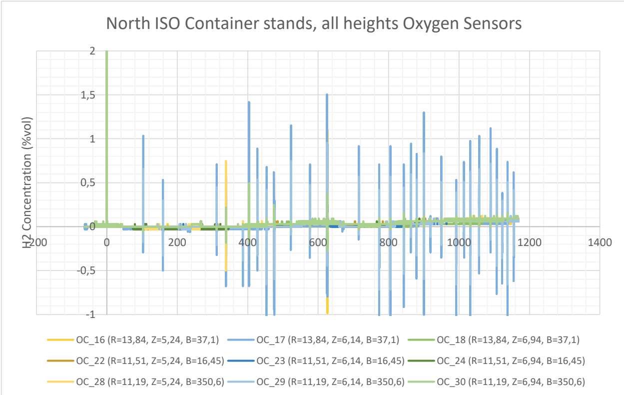
Test Name	Test09		FOR AVERAGING		
Hole Size	25,4	mm	Start	100	sec
Orientation	Downwards		End	500	sec

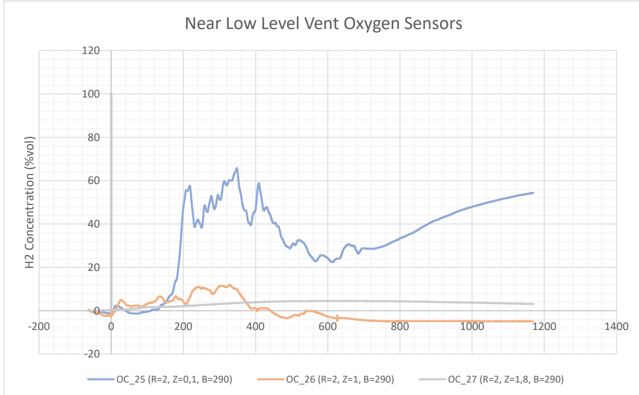
Notes: No H2 detected in the field. H2 detected near low level vent at the beginning of the release. Very high concentrations within the TCS. Sensors were likely affected by cold temperatures, so decay measurements are likely affected. Correction to be applied if possible.

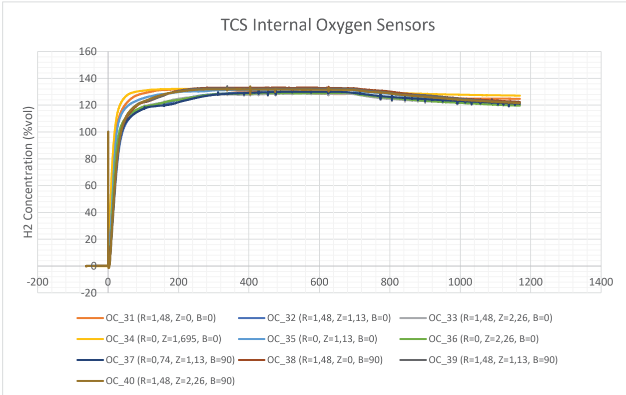
Sensor	Average	Max	Min	STDEV	units
OC_01 (R=30, Z=0,1, B=45)	0,0	0,1	-0,1	0,0	%vol
OC_02 (R=30, Z=1, B=45)	0,0	0,0	0,0	0,0	%vol
OC_03 (R=30, Z=1,8, B=45)	0,0	0,0	-0,1	0,0	%vol
OC_04 (R=30, Z=0,1, B=67,5)	0,0	0,0	-0,1	0,0	%vol
OC_05 (R=30, Z=1, B=67,5)	0,0	0,0	0,0	0,0	%vol
OC_06 (R=30, Z=1,8, B=67,5)	0,0	0,0	0,0	0,0	%vol
OC_07 (R=30, Z=0,1, B=90)	0,0	0,0	-0,1	0,0	%vol
OC_08 (R=30, Z=1, B=90)	0,0	0,0	-0,1	0,0	%vol
OC_09 (R=30, Z=1,8, B=90)	0,0	0,0	-0,1	0,0	%vol
OC_10 (R=30, Z=0,1, B=112,5)	0,0	0,1	-0,1	0,0	%vol
OC_11 (R=30, Z=1, B=112,5)	0,0	0,0	0,0	0,0	%vol
OC_12 (R=30, Z=1,8, B=112,5)	0,0	0,1	-0,1	0,0	%vol
OC_13 (R=30, Z=0,1, B=135)	0,0	0,1	0,0	0,0	%vol
OC_14 (R=30, Z=1, B=135)	0,0	0,1	-0,1	0,0	%vol
OC_15 (R=30, Z=1,8, B=135)	0,0	0,1	-0,1	0,0	%vol
OC_16 (R=13,84, Z=5,24, B=37,1)	0,0	1,2	-0,7	0,0	%vol
OC_17 (R=13,84, Z=6,14, B=37,1)	0,0	1,4	-1,1	0,1	%vol
OC_18 (R=13,84, Z=6,94, B=37,1)	0,0	0,1	-0,1	0,0	%vol
OC_19 (R=50, Z=0,1, B=90)	0,0	0,1	0,0	0,0	%vol
OC_20 (R=50, Z=1, B=90)	0,0	0,0	0,0	0,0	%vol
OC_21 (R=50, Z=1,8, B=90)	0,0	0,0	-0,1	0,0	%vol
OC_22 (R=11,51, Z=5,24, B=16,45)	0,0	0,1	-0,1	0,0	%vol
OC_23 (R=11,51, Z=6,14, B=16,45)	0,0	0,3	-0,3	0,0	%vol
OC_24 (R=11,51, Z=6,94, B=16,45)	0,0	0,1	-0,1	0,0	%vol
OC_25 (R=2, Z=0,1, B=290)	37,7	65,8	-0,4	19,4	%vol
OC_26 (R=2, Z=1, B=290)	5,0	11,9	-3,4	4,5	%vol
OC_27 (R=2, Z=1,8, B=290)	3,0	4,3	1,6	0,9	%vol
OC_28 (R=11,19, Z=5,24, B=350,6)	0,0	0,7	-0,5	0,0	%vol
OC_29 (R=11,19, Z=6,14, B=350,6)	0,0	0,7	-0,7	0,0	%vol
OC_30 (R=11,19, Z=6,94, B=350,6)	0,0	0,5	-0,2	0,0	%vol
OC_31 (R=1,48, Z=0, B=0)	131,0	132,0	128,8	1,0	%vol
OC_32 (R=1,48, Z=1,13, B=0)	126,5	130,7	117,9	3,4	%vol
OC_33 (R=1,48, Z=2,26, B=0)	126,1	129,2	118,8	2,7	%vol
OC_34 (R=0, Z=1,695, B=0)	131,8	132,2	130,8	0,3	%vol
OC_35 (R=0, Z=1,13, B=0)	130,2	131,7	125,2	1,5	%vol
OC_36 (R=0, Z=2,26, B=0)	126,2	129,1	118,8	3,1	%vol
OC_37 (R=0,74, Z=1,13, B=90)	125,8	131,2	117,2	4,0	%vol
OC_38 (R=1,48, Z=0, B=90)	131,1	133,6	122,0	3,1	%vol
OC_39 (R=1,48, Z=1,13, B=90)	130,8	134,1	122,4	2,8	%vol
OC_40 (R=1,48, Z=2,26, B=90)	130,4	134,0	122,7	2,3	%vol











DNV·GL

FFI: LH2 Releases

Notes

Maybe offset in temperature - no measurements reach liquid temp, need to investigate

Test Name	Test10	
Hole Size	13	mm
Orientation	Downwards	

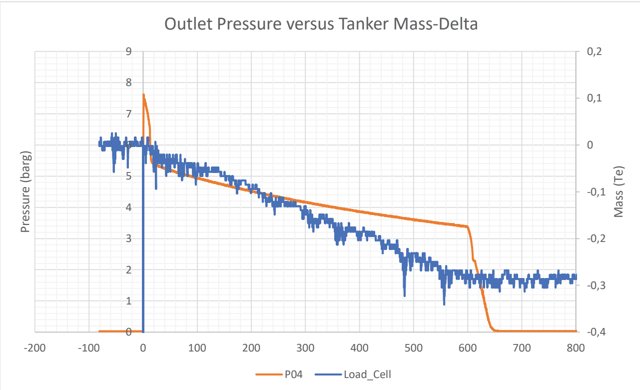
FOR PLOTS

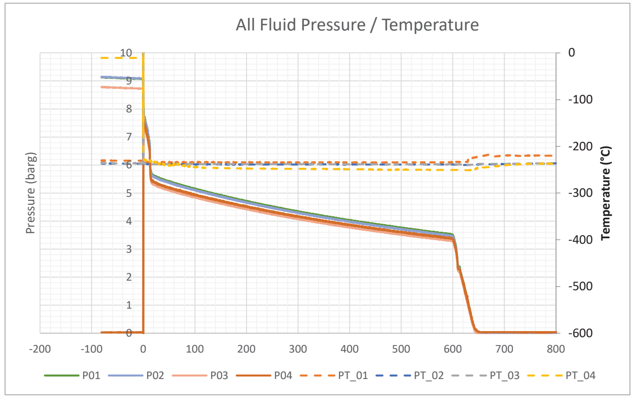
Start Time	-80	sec
End Time	1200	sec

Date 16.01.2020

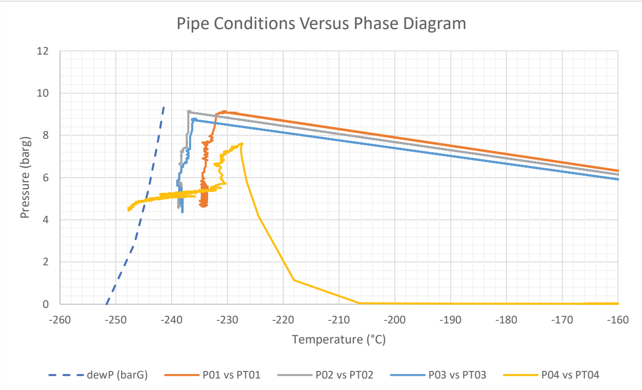
FOR AVERAGING

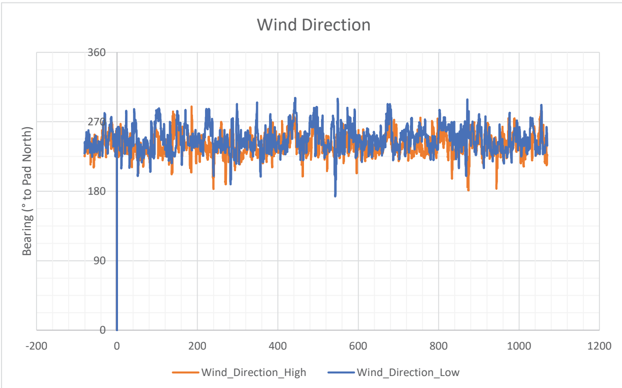
Start	50	sec
End	550	sec

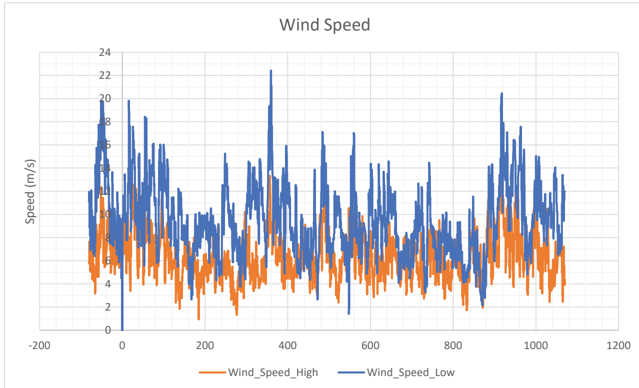




Sensor	Average	Max	Min	STDEV	units
Load_Cell	-0,145	-0,021	-0,323	0,070	Te
P01	4,40	5,43	3,64	0,50	Barg
P02	4,35	5,37	3,58	0,51	Barg
P03	4,13	5,12	3,40	0,48	Barg
P04	4,22	5,20	3,48	0,48	Barg
PT_01	-234,3	-233,2	-234,9	0,3	°C
PT_02	-238,8	-238,4	-239,1	0,2	°C
PT_03	-238,3	-237,9	-238,8	0,2	°C
PT_04	-247,6	-235,9	-250,7	2,7	°C
MassFlow	0,477				kg/s
Wind_Direction_High	238,8	289,8	183,0	13,6	0,0
Wind_Direction_Low	247,1	300,6	173,0	18,8	Deg
Wind_Speed_High	5,9	13,3	0,9	1,9	m/s
Wind_Speed_Low	9,4	22,4	1,4	3,1	m/s







DNV·GL

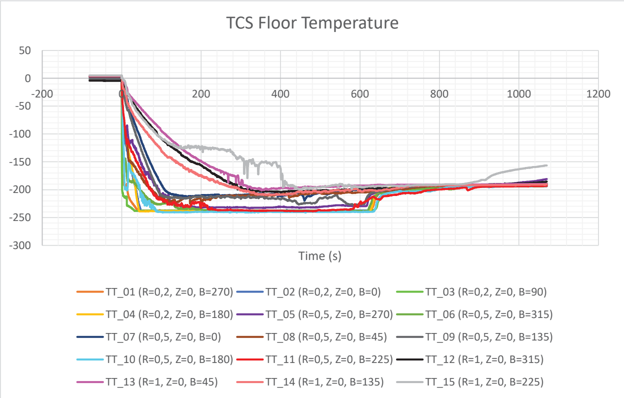
TCS Temperature

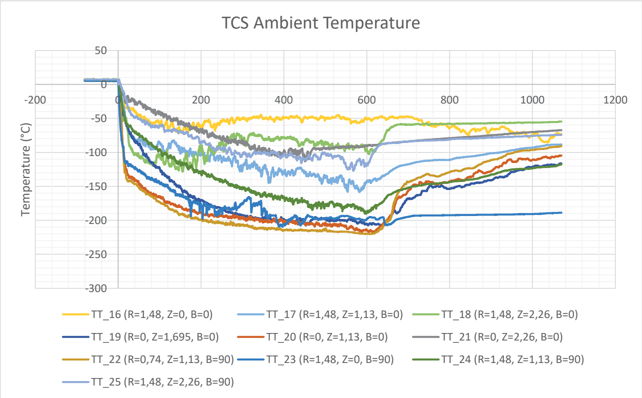
Test Name	Test10	FOR AVERAGING	
Hole Size	13 mm	Start	50 sec
Orientation	Downwards	End	550 sec

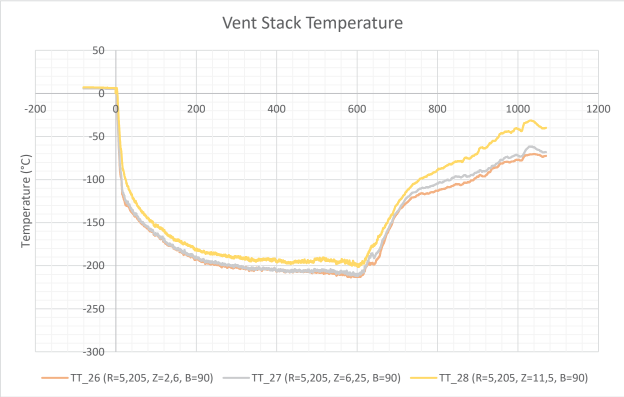
Notes:

Liquid H2 observed on TCS floor surface @0.2m. Around 100s after end of release most floor temperatures register ca. -200°C for over 2.5 minutes. Ambient temperature within chamber reached -200°C, these quickly increased as soon as the release stopped. Temperature sensors show low temps in stack. The closest temperature sensor to the end of the stack registered a higher temperature than the other two, as expected.

Sensor	Average	Max	Min	STDEV	units
TT_01 (R=0,2, Z=0, B=270)	-237,4	-236,9	-237,8	0,1	°C
TT_02 (R=0,2, Z=0, B=0)	-237,5	-236,9	-238,1	0,2	°C
TT_03 (R=0,2, Z=0, B=90)	-237,9	-237,3	-238,6	0,2	°C
TT_04 (R=0,2, Z=0, B=180)	-238,4	-237,9	-238,9	0,2	°C
TT_05 (R=0,5, Z=0, B=270)	-225,3	-153,0	-233,2	15,8	°C
TT_06 (R=0,5, Z=0, B=315)	-234,4	-203,9	-238,8	6,5	°C
TT_07 (R=0,5, Z=0, B=0)	-203,3	-113,8	-219,7	17,9	°C
TT_08 (R=0,5, Z=0, B=45)	-210,7	-179,0	-228,4	6,8	°C
TT_09 (R=0,5, Z=0, B=135)	-211,3	-129,8	-226,3	15,2	°C
TT_10 (R=0,5, Z=0, B=180)	-239,1	-208,6	-240,6	4,2	°C
TT_11 (R=0,5, Z=0, B=225)	-230,8	-166,6	-238,8	13,0	°C
TT_12 (R=1, Z=0, B=315)	-172,5	-66,3	-205,0	39,2	°C
TT_13 (R=1, Z=0, B=45)	-163,7	-55,6	-201,2	41,5	°C
TT_14 (R=1, Z=0, B=135)	-182,2	-85,5	-209,5	32,2	°C
TT_15 (R=1, Z=0, B=225)	-147,9	-70,6	-199,9	34,9	°C
TT_16 (R=1,48, Z=0, B=0)	-53,5	-44,5	-71,6	6,0	°C
TT_17 (R=1,48, Z=1,13, B=0)	-115,4	-78,9	-152,4	18,0	°C
TT_18 (R=1,48, Z=2,26, B=0)	-93,4	-71,4	-128,2	15,1	°C
TT_19 (R=0, Z=1,695, B=0)	-177,2	-86,9	-206,6	29,9	°C
TT_20 (R=0, Z=1,13, B=0)	-192,0	-145,4	-209,6	15,1	°C
TT_21 (R=0, Z=2,26, B=0)	-78,8	-24,6	-113,4	22,1	°C
TT_22 (R=0,74, Z=1,13, B=90)	-201,6	-151,3	-217,3	16,7	°C
TT_23 (R=1,48, Z=0, B=90)	-179,2	-125,6	-209,4	20,4	°C
TT_24 (R=1,48, Z=1,13, B=90)	-144,6	-72,5	-186,7	30,0	°C
TT_25 (R=1,48, Z=2,26, B=90)	-91,6	-50,1	-120,6	17,6	°C
TT_26 (R=5,205, Z=2,6, B=90)	-193,9	-142,0	-211,8	16,9	°C
TT_27 (R=5,205, Z=6,25, B=90)	-192,7	-139,4	-209,4	17,1	°C
TT_28 (R=5,205, Z=11,5, B=90)	-182,1	-126,1	-198,1	17,1	°C





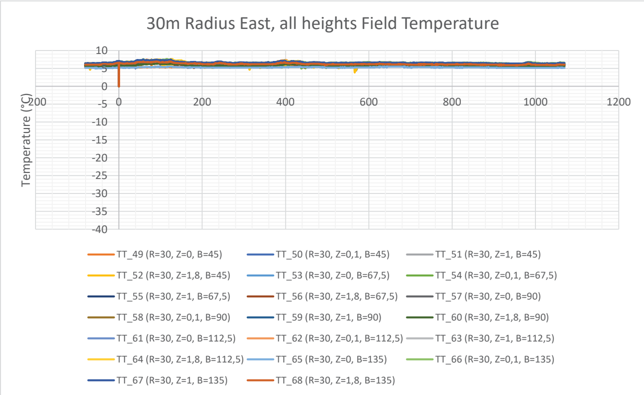


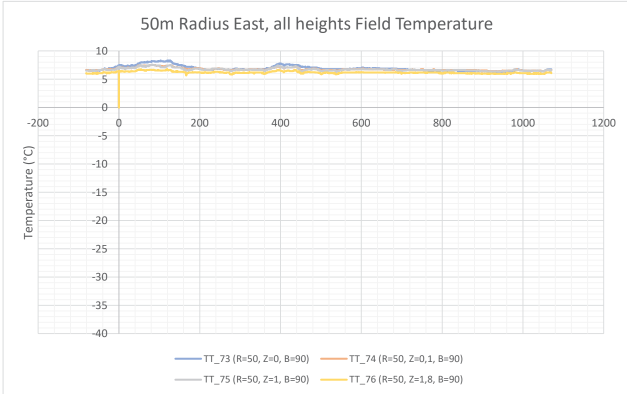
DNV·GL

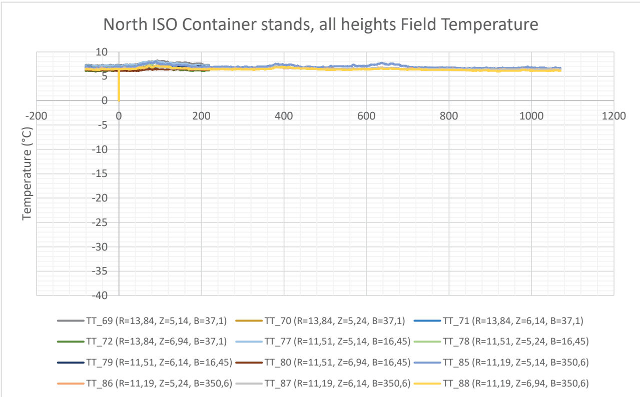
Notes: No significant temperature drop in the field.Low temps registered near low level vent

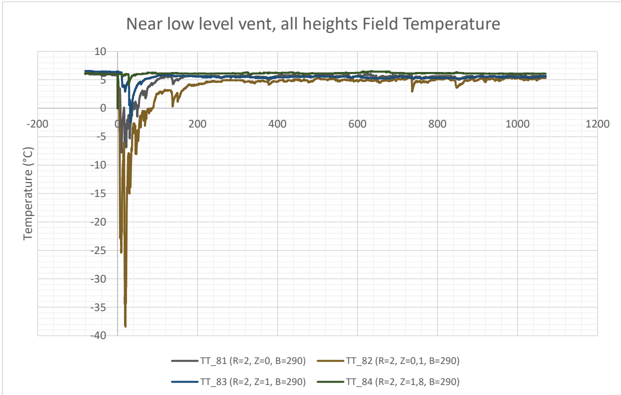
Field Temperature

Test Name	Test10		FOR AVERAGING		
Hole Size	13	mm	Start	50	sec
Orientation	Downwards		End	550	sec









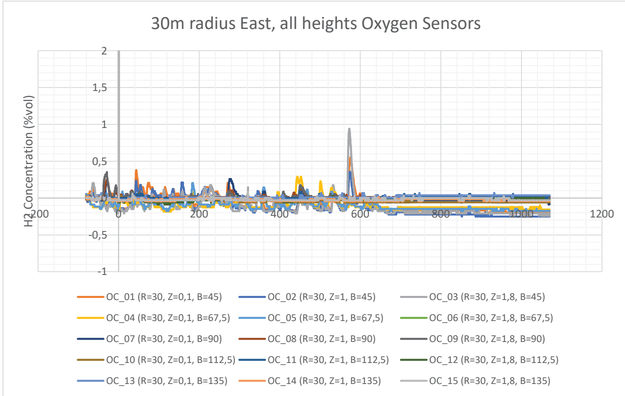
Sensor	Average	Max	Min	STDEV	units
TT_49 (R=30, Z=0, B=45)	5,5	5,8	5,3	0,1	°C
TT_50 (R=30, Z=0,1, B=45)	6,3	7,4	5,3	0,4	°C
TT_51 (R=30, Z=1, B=45)	6,2	6,9	5,3	0,2	°C
TT_52 (R=30, Z=1,8, B=45)	6,0	6,8	4,6	0,3	°C
TT_53 (R=30, Z=0, B=67,5)	6,1	6,8	5,2	0,3	°C
TT_54 (R=30, Z=0,1, B=67,5)	6,1	6,8	4,9	0,4	°C
TT_55 (R=30, Z=1, B=67,5)	6,1	6,9	5,2	0,3	°C
TT_56 (R=30, Z=1,8, B=67,5)	6,0	6,6	5,2	0,3	°C
TT_57 (R=30, Z=0, B=90)	6,5	7,1	5,9	0,2	°C
TT_58 (R=30, Z=0,1, B=90)	6,5	7,4	5,8	0,4	°C
TT_59 (R=30, Z=1, B=90)	6,3	6,6	5,8	0,1	°C
TT_60 (R=30, Z=1,8, B=90)	5,9	6,4	5,6	0,2	°C
TT_61 (R=30, Z=0, B=112,5)	6,5	7,2	6,1	0,3	°C
TT_62 (R=30, Z=0,1, B=112,5)	6,7	7,5	6,1	0,3	°C
TT_63 (R=30, Z=1, B=112,5)	6,8	7,5	6,3	0,3	°C
TT_64 (R=30, Z=1,8, B=112,5)	6,8	7,6	6,3	0,3	°C
TT_65 (R=30, Z=0, B=135)	5,3	5,6	5,2	0,1	°C
TT_66 (R=30, Z=0,1, B=135)	6,8	7,6	6,4	0,3	°C
TT_67 (R=30, Z=1, B=135)	6,8	7,5	6,4	0,3	°C
TT_68 (R=30, Z=1,8, B=135)	6,4	6,9	5,9	0,2	°C
TT_69 (R=13,84, Z=5,14, B=37,1)	7,6	8,2	7,1	0,2	°C
TT_70 (R=13,84, Z=5,24, B=37,1)	6,8	7,2	6,6	0,1	°C
TT_71 (R=13,84, Z=6,14, B=37,1)	6,6	7,2	6,3	0,2	°C
TT_72 (R=13,84, Z=6,94, B=37,1)	6,3	7,1	6,1	0,2	°C
TT_73 (R=50, Z=0, B=90)	7,2	8,3	6,6	0,5	°C
TT_74 (R=50, Z=0,1, B=90)	6,9	7,5	6,4	0,3	°C
TT_75 (R=50, Z=1, B=90)	6,9	7,6	6,3	0,3	°C
TT_76 (R=50, Z=1,8, B=90)	6,3	6,8	5,7	0,2	°C
TT_77 (R=11,51, Z=5,14, B=16,45)	7,4	8,1	6,9	0,3	°C
TT_78 (R=11,51, Z=5,24, B=16,45)	6,9	7,9	6,5	0,3	°C
TT_79 (R=11,51, Z=6,14, B=16,45)	6,9	7,1	6,7	0,1	°C
TT_80 (R=11,51, Z=6,94, B=16,45)	6,4	6,6	6,1	0,1	°C
TT_81 (R=2, Z=0, B=290)	5,4	5,9	-0,7	0,9	°C
TT_82 (R=2, Z=0,1, B=290)	3,9	5,3	-5,8	1,8	°C
TT_83 (R=2, Z=1, B=290)	5,5	5,9	4,1	0,2	°C
TT_84 (R=2, Z=1,8, B=290)	6,1	6,3	5,9	0,1	°C
TT_85 (R=11,19, Z=5,14, B=350,6)	7,1	7,9	6,6	0,3	°C
TT_86 (R=11,19, Z=5,24, B=350,6)	6,6	7,2	6,4	0,2	°C
TT_87 (R=11,19, Z=6,14, B=350,6)	6,6	7,2	6,4	0,2	°C
TT_88 (R=11,19, Z=6,94, B=350,6)	6,6	7,1	6,3	0,2	°C

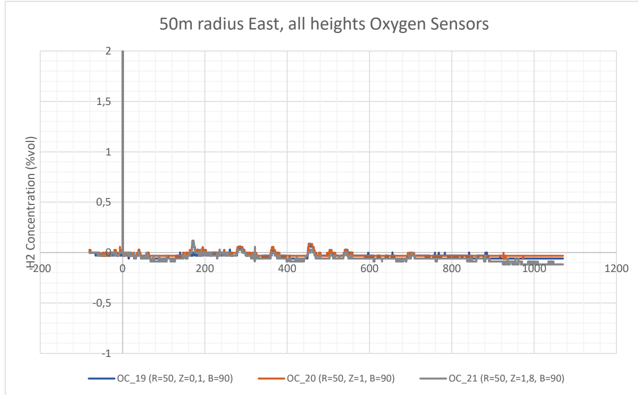
Gas Concentrations

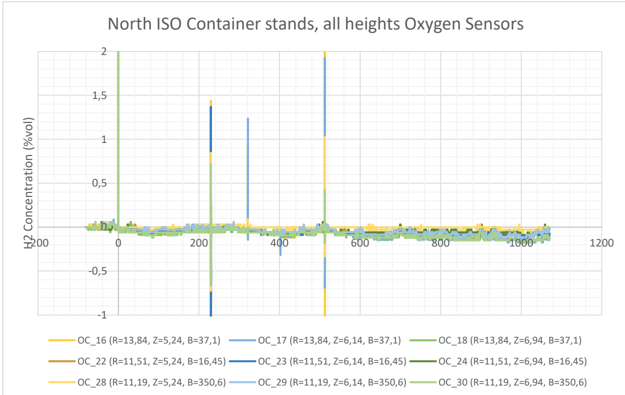
Test Name	Test10		FOR AVERAGING		
Hole Size	13	mm	Start	50	sec
Orientation	Downwards		End	550	sec

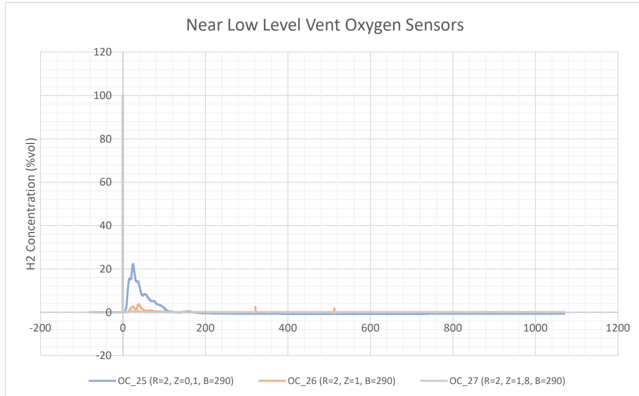
Notes: No H2 detected in the field. Small amounts detected near low level vent at the beginning of the release. Very high concentrations within the TCS. Sensors were likely affected by cold temperatures, so decay measurements are likely affected. Correction to be applied if possible.

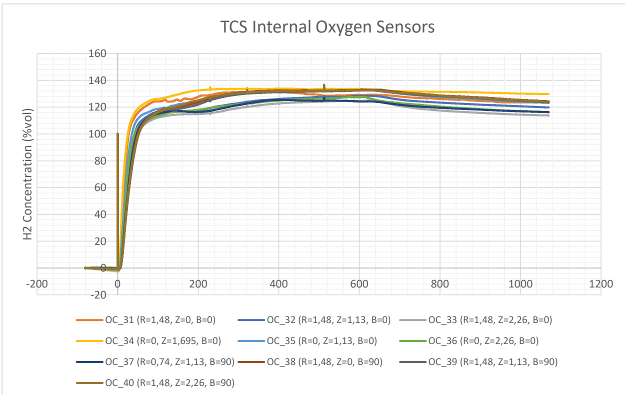
Sensor	Average	Max	Min	STDEV	units
OC_01 (R=30, Z=0,1, B=45)	0,0	0,2	-0,2	0,1	%vol
OC_02 (R=30, Z=1, B=45)	-0,1	0,2	-0,2	0,1	%vol
OC_03 (R=30, Z=1,8, B=45)	-0,1	0,2	-0,2	0,1	%vol
OC_04 (R=30, Z=0,1, B=67,5)	-0,1	0,3	-0,2	0,1	%vol
OC_05 (R=30, Z=1, B=67,5)	-0,1	0,2	-0,2	0,1	%vol
OC_06 (R=30, Z=1,8, B=67,5)	0,0	0,0	0,0	0,0	%vol
OC_07 (R=30, Z=0,1, B=90)	0,0	0,3	-0,1	0,0	%vol
OC_08 (R=30, Z=1, B=90)	0,0	0,1	0,0	0,0	%vol
OC_09 (R=30, Z=1,8, B=90)	0,0	0,2	0,0	0,0	%vol
OC_10 (R=30, Z=0,1, B=112,5)	0,0	0,1	-0,1	0,0	%vol
OC_11 (R=30, Z=1, B=112,5)	0,0	0,1	0,0	0,0	%vol
OC_12 (R=30, Z=1,8, B=112,5)	0,0	0,1	-0,1	0,0	%vol
OC_13 (R=30, Z=0,1, B=135)	0,0	0,1	-0,1	0,0	%vol
OC_14 (R=30, Z=1, B=135)	0,0	0,1	0,0	0,0	%vol
OC_15 (R=30, Z=1,8, B=135)	0,0	0,1	0,0	0,0	%vol
OC_16 (R=13,84, Z=5,24, B=37,1)	0,0	3,9	-1,5	0,1	%vol
OC_17 (R=13,84, Z=6,14, B=37,1)	-0,1	1,9	-1,4	0,1	%vol
OC_18 (R=13,84, Z=6,94, B=37,1)	-0,1	0,6	-0,5	0,0	%vol
OC_19 (R=50, Z=0,1, B=90)	0,0	0,1	-0,1	0,0	%vol
OC_20 (R=50, Z=1, B=90)	0,0	0,1	0,0	0,0	%vol
OC_21 (R=50, Z=1,8, B=90)	0,0	0,1	-0,1	0,0	%vol
OC_22 (R=11,51, Z=5,24, B=16,45)	0,0	0,1	-0,1	0,0	%vol
OC_23 (R=11,51, Z=6,14, B=16,45)	0,0	1,4	-1,5	0,0	%vol
OC_24 (R=11,51, Z=6,94, B=16,45)	0,0	0,4	-0,4	0,0	%vol
OC_25 (R=2, Z=0,1, B=290)	0,0	8,4	-0,8	1,8	%vol
OC_26 (R=2, Z=1, B=290)	0,1	2,5	-0,6	0,2	%vol
OC_27 (R=2, Z=1,8, B=290)	0,0	0,1	-0,1	0,0	%vol
OC_28 (R=11,19, Z=5,24, B=350,6)	0,0	1,0	-0,7	0,0	%vol
OC_29 (R=11,19, Z=6,14, B=350,6)	0,0	0,2	-0,1	0,0	%vol
OC_30 (R=11,19, Z=6,94, B=350,6)	-0,1	0,7	-0,7	0,0	%vol
OC_31 (R=1,48, Z=0, B=0)	128,4	131,5	115,8	3,3	%vol
OC_32 (R=1,48, Z=1,13, B=0)	121,9	128,3	106,4	5,0	%vol
OC_33 (R=1,48, Z=2,26, B=0)	118,4	125,8	100,7	5,1	%vol
OC_34 (R=0, Z=1,695, B=0)	131,7	134,9	118,7	3,4	%vol
OC_35 (R=0, Z=1,13, B=0)	127,4	132,7	111,2	5,5	%vol
OC_36 (R=0, Z=2,26, B=0)	120,8	126,8	104,9	5,1	%vol
OC_37 (R=0,74, Z=1,13, B=90)	120,4	126,9	102,2	4,8	%vol
OC_38 (R=1,48, Z=0, B=90)	126,8	134,5	99,6	7,3	%vol
OC_39 (R=1,48, Z=1,13, B=90)	125,7	132,2	97,4	7,3	%vol
OC_40 (R=1,48, Z=2,26, B=90)	126,8	136,7	98,0	7,3	%vol











FFI: LH2 Releases

Notes

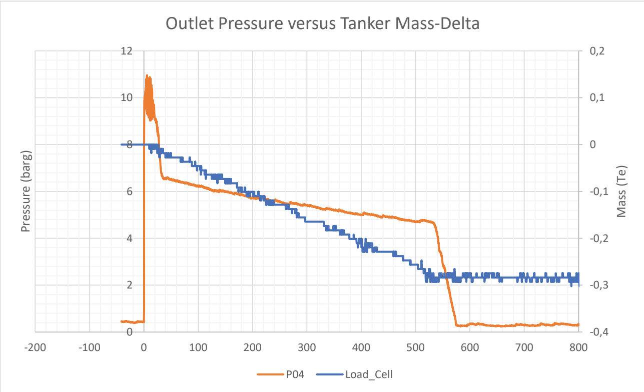
Release and by-pass valves (V1 and V2) re-located to outside the box to avoid freezing of actuators and allow shut-off near release point. Evidence of plastic sheet tear during release. Test started with an attempted nitrogen purge, however sealing of the enclosure wasn't enough to achieve full purge in reasonable time, modifications needed. Decided to carry on as a air purge release.
Polythene sheet teared 370 s into release. Maybe offset in temperature - no measurements reach liquid temp, need to investigate

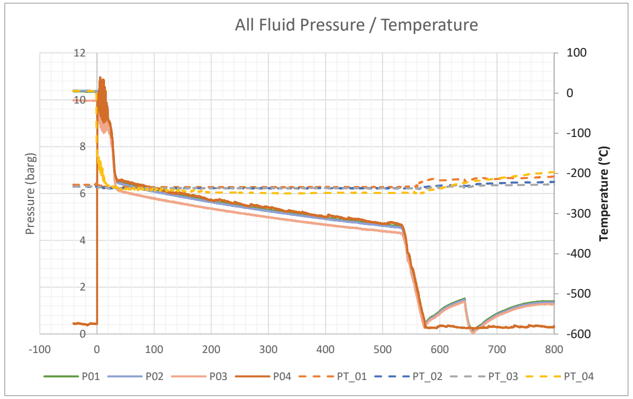
Test Name	Test11	
Hole Size	13	mm
Orientation	Downwards	

FOR PLOTS

Start Time	-80	sec
End Time	1200	sec

Date 16.01.2020

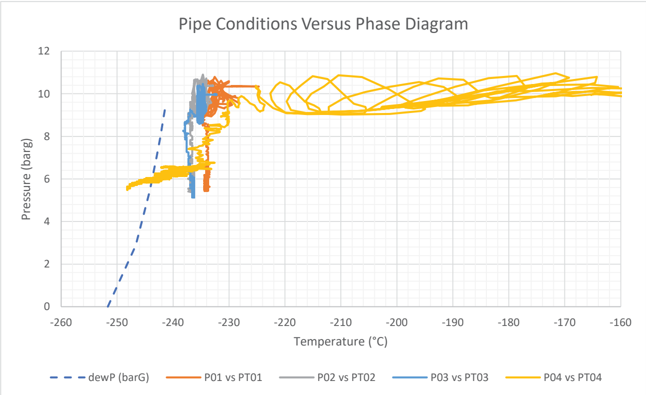


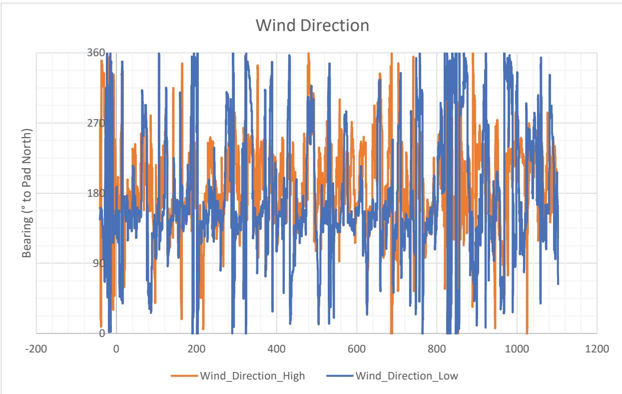


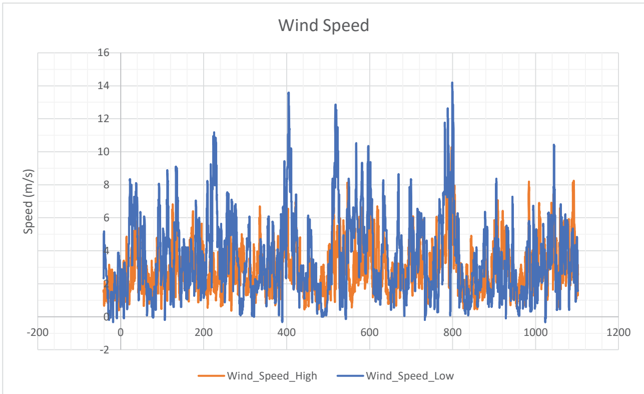
FOR AVERAGING

Start	50	sec
End	500	sec

Sensor	Average	Max	Min	STDEV	units
Load_Cell	-0,142	-0,018	-0,256	0,068	Te
P01	5,43	6,41	4,67	0,49	Barg
P02	5,39	6,37	4,62	0,49	Barg
P03	5,12	6,07	4,39	0,47	Barg
P04	5,52	6,54	4,71	0,50	Barg
PT_01	-234,0	-233,5	-234,7	0,2	°C
PT_02	-236,9	-236,3	-237,4	0,3	°C
PT_03	-236,5	-235,9	-236,9	0,2	°C
PT_04	-246,3	-233,2	-250,1	3,6	°C
MassFlow		0,522			kg/s
Wind_Direction_High	186,9	362,6	5,5	52,5	0,0
Wind_Direction_Low	174,8	420,6	-35,0	77,2	Deg
Wind_Speed_High	2,6	7,0	0,4	1,2	m/s
Wind_Speed_Low	3,5	13,6	-0,3	2,4	m/s







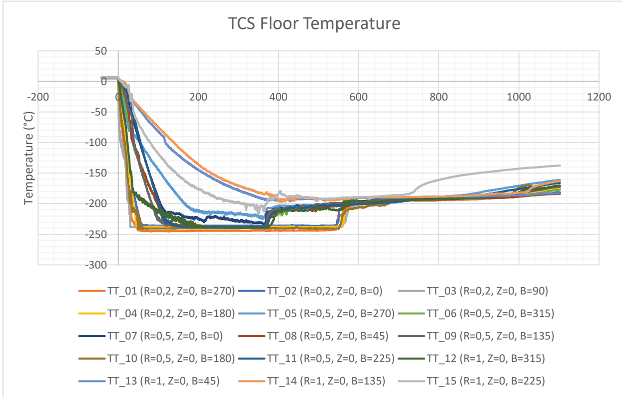
TCS Temperature

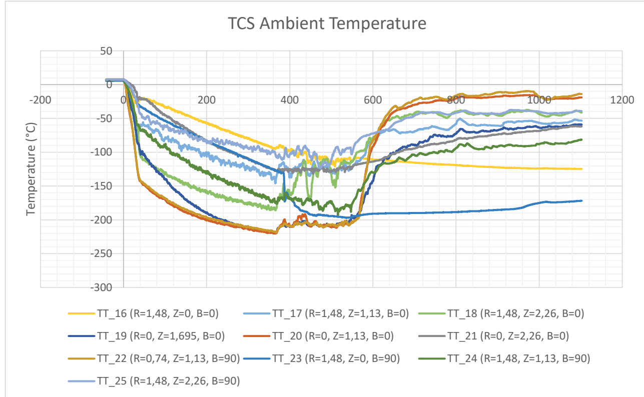
Test Name	Test11		FOR AVERAGING	
Hole Size	13 mm		Start	50 sec
Orientation	Downwards		End	550 sec

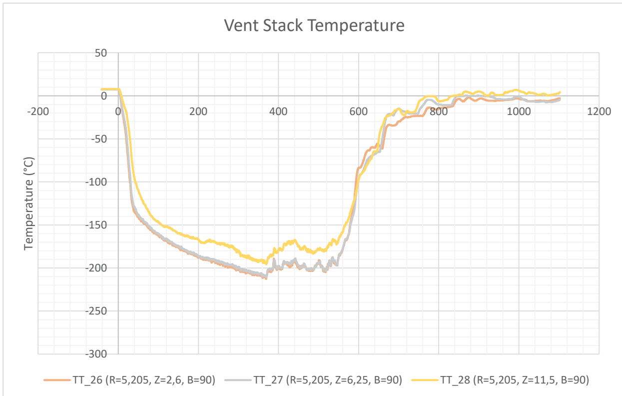
Notes:

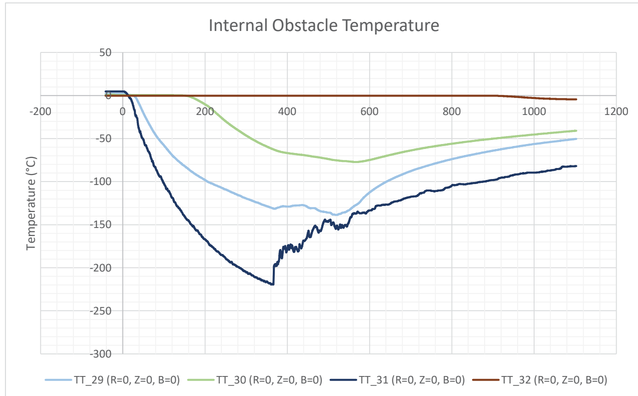
Liquid H2 observed on TCS floor surface @0.2m. Around 100s after end of release most floor temperatures register ca. -200°C for over 2.5 minutes. Ambient temperature within chamber reached -200°C, these quickly increased as soon as the release stopped. Temperature sensors show low temps in stack. The closest temperature sensor to the end of the stack registered a higher temperature than the other two, as expected.

Sensor	Average	Max	Min	STDEV	units
TT_01 (R=0,2, Z=0, B=270)	-243,9	-218,4	-245,1	2,0	°C
TT_02 (R=0,2, Z=0, B=0)	-235,7	-215,7	-236,4	1,5	°C
TT_03 (R=0,2, Z=0, B=90)	-237,9	-237,1	-238,3	0,2	°C
TT_04 (R=0,2, Z=0, B=180)	-238,2	-237,6	-238,4	0,3	°C
TT_05 (R=0,5, Z=0, B=270)	-195,8	-96,3	-224,8	29,2	°C
TT_06 (R=0,5, Z=0, B=315)	-219,8	-127,9	-238,4	23,6	°C
TT_07 (R=0,5, Z=0, B=0)	-209,1	-91,7	-234,0	25,6	°C
TT_08 (R=0,5, Z=0, B=45)	-218,9	-120,6	-238,8	23,6	°C
TT_09 (R=0,5, Z=0, B=135)	-220,0	-129,2	-237,8	21,8	°C
TT_10 (R=0,5, Z=0, B=180)	-240,2	-216,9	-240,9	1,2	°C
TT_11 (R=0,5, Z=0, B=225)	-216,4	-84,9	-238,1	29,9	°C
TT_12 (R=1, Z=0, B=315)	-223,1	-186,1	-239,2	14,5	°C
TT_13 (R=1, Z=0, B=45)	-158,2	-43,9	-196,3	43,2	°C
TT_14 (R=1, Z=0, B=135)	-152,1	-40,5	-197,6	45,3	°C
TT_15 (R=1, Z=0, B=225)	-174,6	-68,4	-216,6	32,8	°C
TT_16 (R=1,48, Z=0, B=0)	-75,7	-20,8	-121,4	28,9	°C
TT_17 (R=1,48, Z=1,13, B=0)	-111,0	-59,6	-145,9	20,1	°C
TT_18 (R=1,48, Z=2,26, B=0)	-149,0	-109,3	-185,9	22,6	°C
TT_19 (R=0, Z=1,695, B=0)	-191,1	-102,8	-219,5	28,8	°C
TT_20 (R=0, Z=1,13, B=0)	-199,6	-148,0	-220,2	16,7	°C
TT_21 (R=0, Z=2,26, B=0)	-97,7	-21,2	-131,7	32,1	°C
TT_22 (R=0,74, Z=1,13, B=90)	-198,1	-146,8	-218,9	17,2	°C
TT_23 (R=1,48, Z=0, B=90)	-120,2	-35,4	-197,1	52,9	°C
TT_24 (R=1,48, Z=1,13, B=90)	-145,7	-67,4	-193,0	32,3	°C
TT_25 (R=1,48, Z=2,26, B=90)	-88,5	-46,3	-123,2	17,0	°C
TT_26 (R=5,205, Z=2,6, B=90)	-189,2	-140,3	-212,4	16,5	°C
TT_27 (R=5,205, Z=6,25, B=90)	-188,1	-137,8	-210,9	16,7	°C
TT_28 (R=5,205, Z=11,5, B=90)	-169,4	-109,8	-195,7	16,5	°C
TT_29 (R=0, Z=0, B=0)	-107,2	-20,1	-138,7	30,1	°C
TT_30 (R=0, Z=0, B=0)	-39,3	0,6	-76,5	29,8	°C
TT_31 (R=0, Z=0, B=0)	-161,7	-51,0	-219,5	38,8	°C
TT_32 (R=0, Z=0, B=0)	-0,2	-0,1	-0,2	0,0	°C





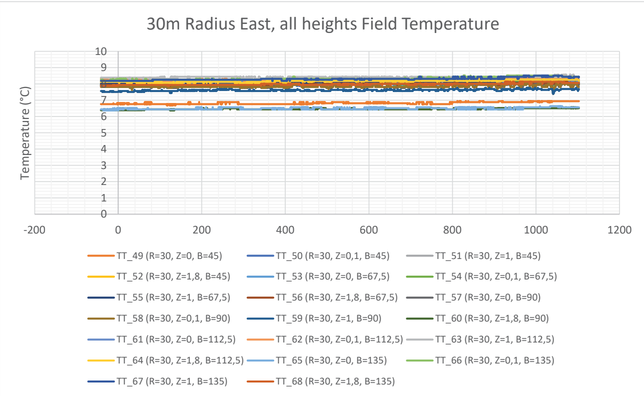


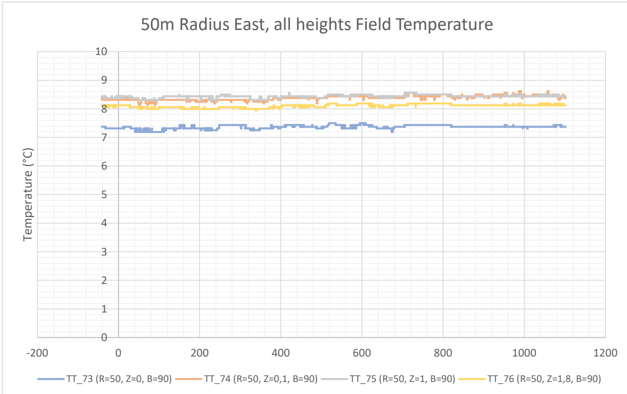


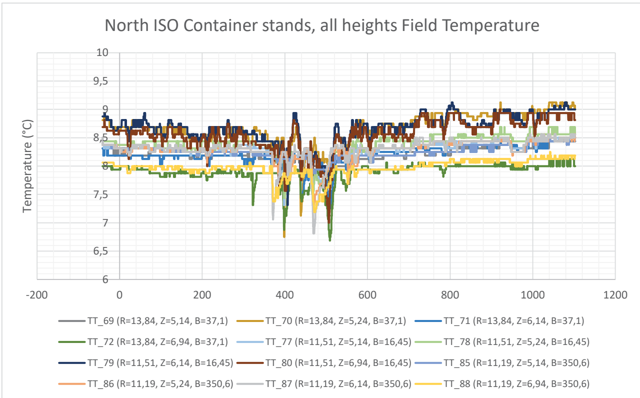
Field Temperature

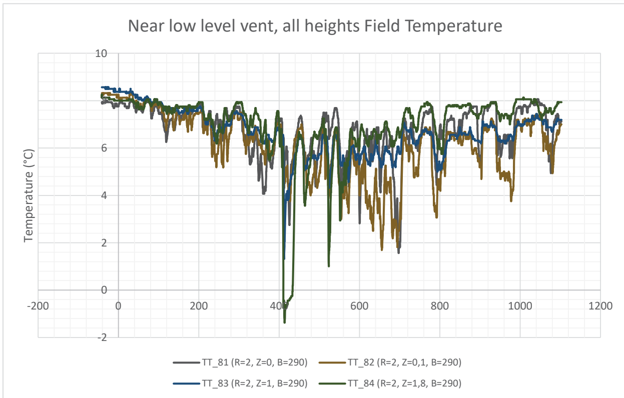
Notes: No significant temperature drop in the field.Low temps registered near low level vent

Test Name	Test11		FOR AVERAGING		
Hole Size	13	mm	Start	50	sec
Orientation	Downwards		End	550	sec









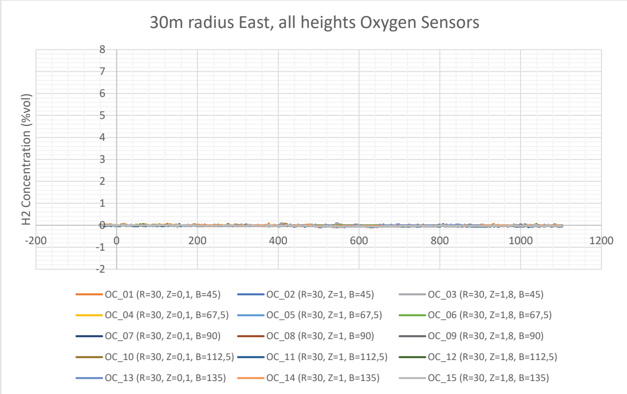
Sensor	Average	Max	Min	STDEV	units
TT_49 (R=30, Z=0, B=45)	6,8	6,9	6,7	0,1	°C
TT_50 (R=30, Z=0,1, B=45)	7,9	8,1	7,8	0,1	°C
TT_51 (R=30, Z=1, B=45)	8,0	8,1	7,8	0,1	°C
TT_52 (R=30, Z=1,8, B=45)	8,1	8,3	7,9	0,1	°C
TT_53 (R=30, Z=0, B=67,5)	7,9	8,1	7,7	0,0	°C
TT_54 (R=30, Z=0,1, B=67,5)	7,9	8,1	7,8	0,0	°C
TT_55 (R=30, Z=1, B=67,5)	8,0	8,1	7,8	0,1	°C
TT_56 (R=30, Z=1,8, B=67,5)	7,9	8,0	7,8	0,0	°C
TT_57 (R=30, Z=0, B=90)	7,9	8,0	7,8	0,1	°C
TT_58 (R=30, Z=0,1, B=90)	7,8	8,0	7,7	0,1	°C
TT_59 (R=30, Z=1, B=90)	7,6	7,7	7,4	0,0	°C
TT_60 (R=30, Z=1,8, B=90)	6,4	6,5	6,4	0,0	°C
TT_61 (R=30, Z=0, B=112,5)	8,2	8,3	8,1	0,0	°C
TT_62 (R=30, Z=0,1, B=112,5)	8,2	8,4	8,1	0,1	°C
TT_63 (R=30, Z=1, B=112,5)	8,4	8,4	8,3	0,1	°C
TT_64 (R=30, Z=1,8, B=112,5)	8,1	8,2	8,1	0,0	°C
TT_65 (R=30, Z=0, B=135)	6,5	6,6	6,4	0,1	°C
TT_66 (R=30, Z=0,1, B=135)	8,3	8,4	8,2	0,0	°C
TT_67 (R=30, Z=1, B=135)	8,3	8,3	8,2	0,0	°C
TT_68 (R=30, Z=1,8, B=135)	7,9	8,0	7,9	0,0	°C
TT_69 (R=13,84, Z=5,14, B=37,1)	8,1	8,3	7,8	0,1	°C
TT_70 (R=13,84, Z=5,24, B=37,1)	8,4	8,8	6,8	0,3	°C
TT_71 (R=13,84, Z=6,14, B=37,1)	8,1	8,3	7,3	0,2	°C
TT_72 (R=13,84, Z=6,94, B=37,1)	7,8	8,0	6,7	0,2	°C
TT_73 (R=50, Z=0, B=90)	7,3	7,5	7,2	0,1	°C
TT_74 (R=50, Z=0,1, B=90)	8,3	8,4	8,1	0,1	°C
TT_75 (R=50, Z=1, B=90)	8,4	8,6	8,3	0,1	°C
TT_76 (R=50, Z=1,8, B=90)	8,1	8,2	7,9	0,1	°C
TT_77 (R=11,51, Z=5,14, B=16,45)	8,2	8,4	7,3	0,2	°C
TT_78 (R=11,51, Z=5,24, B=16,45)	8,2	8,4	7,4	0,2	°C
TT_79 (R=11,51, Z=6,14, B=16,45)	8,5	8,9	7,3	0,3	°C
TT_80 (R=11,51, Z=6,94, B=16,45)	8,4	8,8	7,0	0,3	°C
TT_81 (R=2, Z=0, B=290)	6,8	7,9	2,8	1,0	°C
TT_82 (R=2, Z=0,1, B=290)	6,5	8,1	3,8	1,0	°C
TT_83 (R=2, Z=1, B=290)	6,8	8,2	1,3	1,0	°C
TT_84 (R=2, Z=1,8, B=290)	6,6	8,1	-1,4	1,9	°C
TT_85 (R=11,19, Z=5,14, B=350,6)	8,2	8,3	7,9	0,1	°C
TT_86 (R=11,19, Z=5,24, B=350,6)	8,2	8,4	7,3	0,2	°C
TT_87 (R=11,19, Z=6,14, B=350,6)	8,2	8,4	6,8	0,3	°C
TT_88 (R=11,19, Z=6,94, B=350,6)	7,9	8,1	7,2	0,2	°C

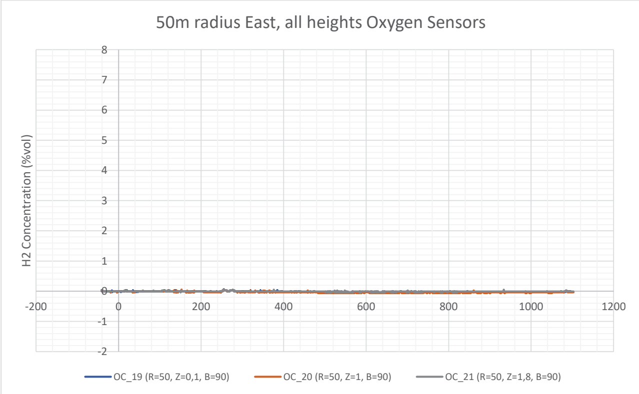
Gas Concentrations

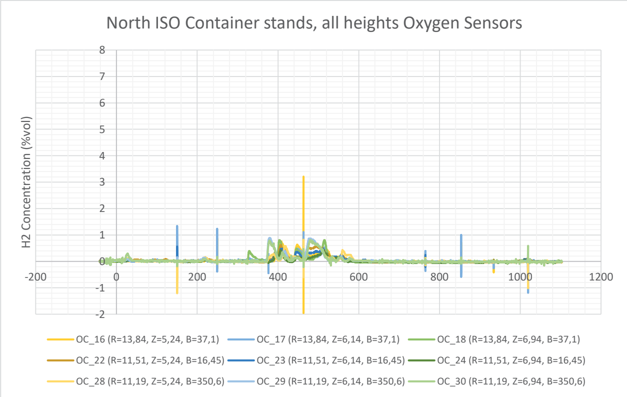
Test Name	Test11		FOR AVERAGING	
Hole Size	13	mm	Start	50 sec
Orientation	Downwards		End	550 sec

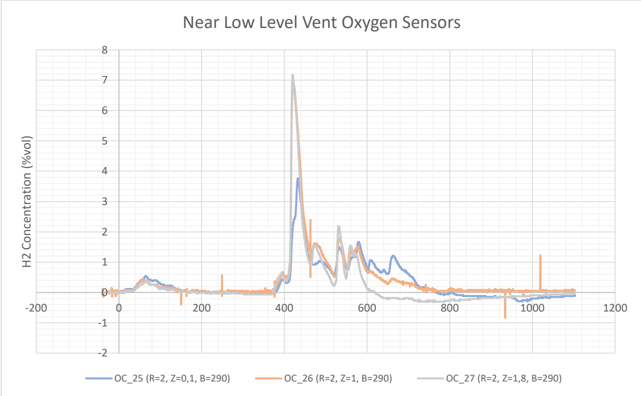
Notes: No H2 detected in the field. Small concentration detected following polythene sheet tear at the top of ISO container and near low level vent. Very high concentrations within the TCS. Sensors were likely affected by cold temperatures, so decay measurements are likely affected. Correction to be applied if possible.

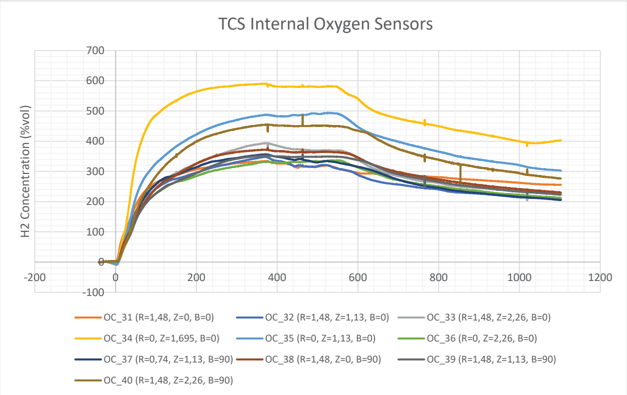
Sensor	Average	Max	Min	STDEV	units
OC_01 (R=30, Z=0,1, B=45)	0,0	0,1	0,0	0,0	%vol
OC_02 (R=30, Z=1, B=45)	0,0	0,1	-0,1	0,0	%vol
OC_03 (R=30, Z=1,8, B=45)	0,0	0,1	0,0	0,0	%vol
OC_04 (R=30, Z=0,1, B=67,5)	0,0	0,0	0,0	0,0	%vol
OC_05 (R=30, Z=1, B=67,5)	0,0	0,1	-0,1	0,0	%vol
OC_06 (R=30, Z=1,8, B=67,5)	0,0	0,0	0,0	0,0	%vol
OC_07 (R=30, Z=0,1, B=90)	0,0	0,1	-0,1	0,0	%vol
OC_08 (R=30, Z=1, B=90)	0,0	0,0	-0,1	0,0	%vol
OC_09 (R=30, Z=1,8, B=90)	0,0	0,0	-0,1	0,0	%vol
OC_10 (R=30, Z=0,1, B=112,5)	0,0	0,0	0,0	0,0	%vol
OC_11 (R=30, Z=1, B=112,5)	0,0	0,0	-0,1	0,0	%vol
OC_12 (R=30, Z=1,8, B=112,5)	0,0	0,1	-0,1	0,0	%vol
OC_13 (R=30, Z=0,1, B=135)	0,0	0,0	0,0	0,0	%vol
OC_14 (R=30, Z=1, B=135)	0,0	0,0	0,0	0,0	%vol
OC_15 (R=30, Z=1,8, B=135)	0,0	0,0	-0,1	0,0	%vol
OC_16 (R=13,84, Z=5,24, B=37,1)	0,1	3,2	-1,9	0,2	%vol
OC_17 (R=13,84, Z=6,14, B=37,1)	0,1	1,3	-0,4	0,1	%vol
OC_18 (R=13,84, Z=6,94, B=37,1)	0,1	0,8	-0,1	0,2	%vol
OC_19 (R=50, Z=0,1, B=90)	0,0	0,1	-0,1	0,0	%vol
OC_20 (R=50, Z=1, B=90)	0,0	0,1	-0,1	0,0	%vol
OC_21 (R=50, Z=1,8, B=90)	0,0	0,1	0,0	0,0	%vol
OC_22 (R=11,51, Z=5,24, B=16,45)	0,1	0,6	0,0	0,2	%vol
OC_23 (R=11,51, Z=6,14, B=16,45)	0,1	0,6	0,0	0,1	%vol
OC_24 (R=11,51, Z=6,94, B=16,45)	0,0	0,4	-0,1	0,1	%vol
OC_25 (R=2, Z=0,1, B=290)	0,5	3,8	-0,1	0,7	%vol
OC_26 (R=2, Z=1, B=290)	0,7	6,9	-0,4	1,3	%vol
OC_27 (R=2, Z=1,8, B=290)	0,6	7,2	-0,1	1,3	%vol
OC_28 (R=11,19, Z=5,24, B=350,6)	0,1	0,8	-1,2	0,2	%vol
OC_29 (R=11,19, Z=6,14, B=350,6)	0,1	0,9	0,0	0,2	%vol
OC_30 (R=11,19, Z=6,94, B=350,6)	0,1	0,8	-0,2	0,2	%vol
OC_31 (R=1,48, Z=0, B=0)	305,7	334,1	187,7	29,9	%vol
OC_32 (R=1,48, Z=1,13, B=0)	303,0	347,9	167,0	39,2	%vol
OC_33 (R=1,48, Z=2,26, B=0)	337,9	393,6	148,3	57,9	%vol
OC_34 (R=0, Z=1,695, B=0)	556,0	589,9	332,5	50,0	%vol
OC_35 (R=0, Z=1,13, B=0)	436,6	493,2	213,0	68,1	%vol
OC_36 (R=0, Z=2,26, B=0)	297,1	336,8	150,0	44,7	%vol
OC_37 (R=0,74, Z=1,13, B=90)	317,5	356,6	156,0	41,4	%vol
OC_38 (R=1,48, Z=0, B=90)	330,6	378,8	146,6	54,3	%vol
OC_39 (R=1,48, Z=1,13, B=90)	310,7	352,6	138,1	52,9	%vol
OC_40 (R=1,48, Z=2,26, B=90)	402,7	485,9	162,6	71,4	%vol











DNV·GL

FFI: LH2 Releases

Notes

The aim of this test was to perform a release as before and apply a nitrogen purge immediately after stopping the release. This was not possible because polythene sheet teared 314s into release. Maybe offset in temperature - no measurements reach liquid temp, need to investigate.

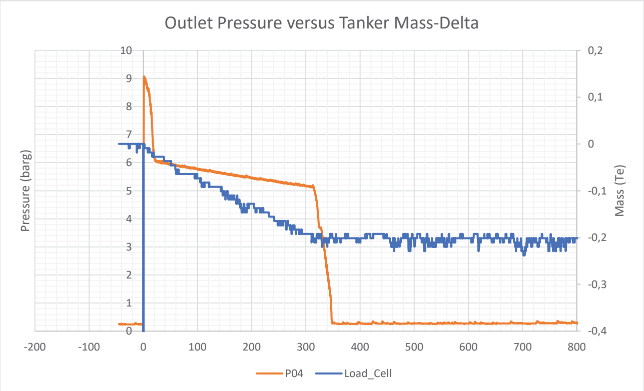
Test Name: Test12
Hole Size: 13 mm
Orientation: Downwards

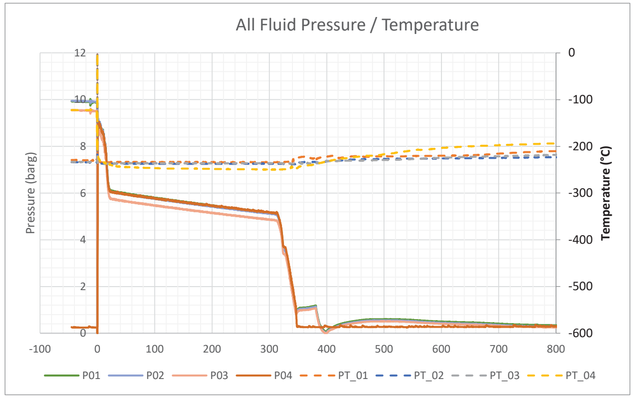
FOR PLOTS
Start Time: -80 sec
End Time: 1200 sec

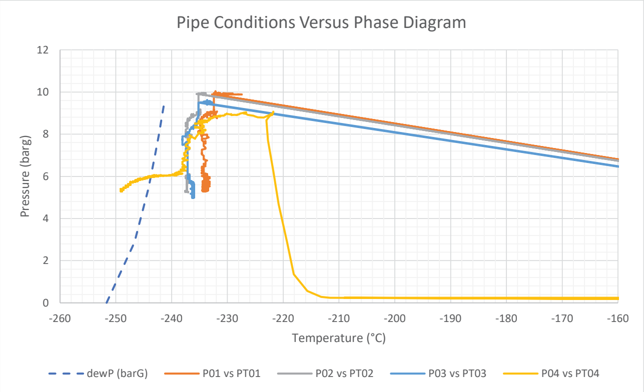
Date: 16.01.2020

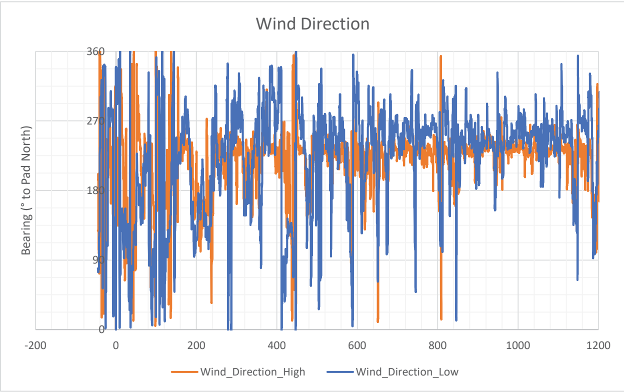
FOR AVERAGING
Start: 50 sec
End: 300 sec

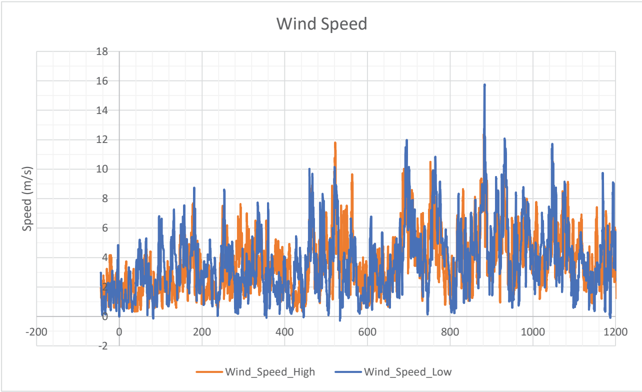
Sensor	Average	Max	Min	STDEV	units
Load_Cell	-0,120	-0,037	-0,192	0,043	Te
P01	5,55	5,98	5,16	0,23	Barg
P02	5,51	5,94	5,11	0,24	Barg
P03	5,24	5,66	4,85	0,22	Barg
P04	5,54	5,96	5,16	0,22	Barg
PT_01	-233,9	-233,2	-234,6	0,3	°C
PT_02	-237,2	-236,9	-237,6	0,1	°C
PT_03	-236,1	-235,8	-236,6	0,1	°C
PT_04	-247,7	-244,3	-249,8	1,4	°C
MassFlow	0,592				kg/s
Wind_Direction_High	203,4	376,8	4,5	53,3	0,0
Wind_Direction_Low	192,9	360,6	-16,5	79,8	Deg
Wind_Speed_High	2,7	7,7	0,5	1,4	m/s
Wind_Speed_Low	3,2	8,7	-0,1	1,7	m/s









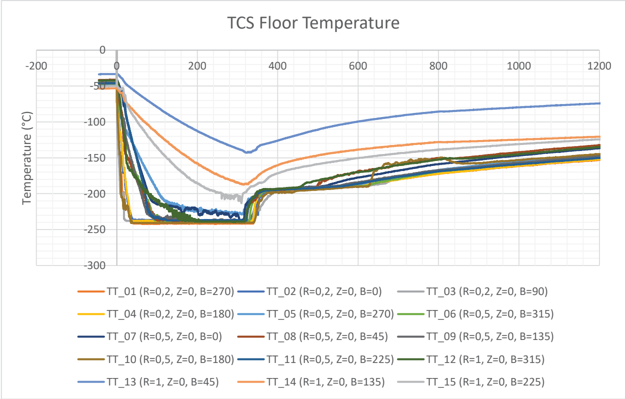


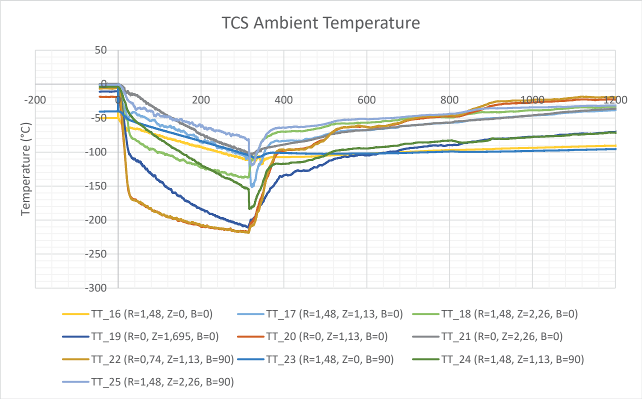
TCS Temperature

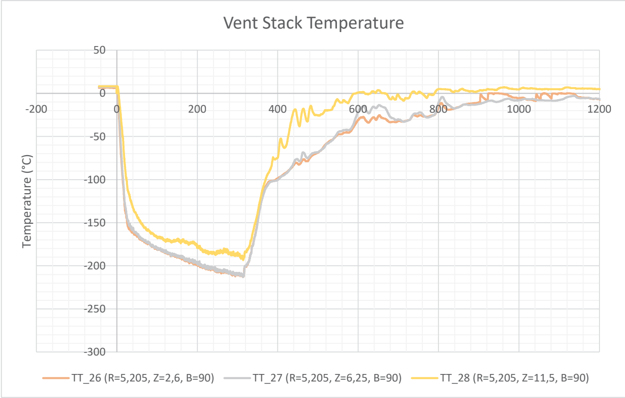
Test Name	Test12		FOR AVERAGING		
Hole Size	13	mm	Start	50	sec
Orientation	Downwards		End	550	sec

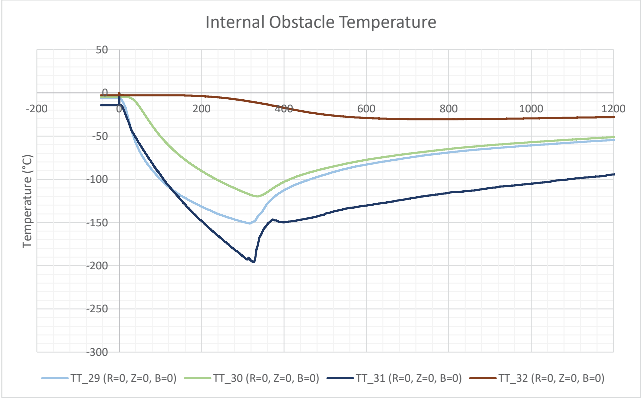
Notes: Liquid H2 observed on TCS floor surface @0.2m. Around 100s after end of release most floor temperatures register ca. -200°C for over 3 minutes. Ambient temperature within chamber reached -200°C, these quickly increased as soon as the polythene teared and the release stopped. Temperature sensors show low temps in stack. The closest temperature sensor to the end of the stack registered a higher temperature than the other two, as expected.

Sensor	Average	Max	Min	STDEV	units
TT_01 (R=0,2, Z=0, B=270)	-222,6	-191,3	-242,3	22,7	°C
TT_02 (R=0,2, Z=0, B=0)	-219,1	-189,4	-237,2	21,1	°C
TT_03 (R=0,2, Z=0, B=90)	-220,8	-190,8	-238,1	20,9	°C
TT_04 (R=0,2, Z=0, B=180)	-219,4	-189,7	-238,1	21,9	°C
TT_05 (R=0,5, Z=0, B=270)	-203,6	-141,8	-228,6	18,6	°C
TT_06 (R=0,5, Z=0, B=315)	-216,5	-174,4	-238,7	21,7	°C
TT_07 (R=0,5, Z=0, B=0)	-206,7	-150,0	-236,9	17,8	°C
TT_08 (R=0,5, Z=0, B=45)	-214,8	-173,9	-239,6	22,9	°C
TT_09 (R=0,5, Z=0, B=135)	-215,3	-180,2	-238,2	21,2	°C
TT_10 (R=0,5, Z=0, B=180)	-222,8	-192,2	-240,5	21,2	°C
TT_11 (R=0,5, Z=0, B=225)	-214,8	-151,8	-237,9	22,2	°C
TT_12 (R=1, Z=0, B=315)	-210,0	-175,2	-239,3	22,8	°C
TT_13 (R=1, Z=0, B=45)	-112,8	-59,4	-142,9	20,6	°C
TT_14 (R=1, Z=0, B=135)	-152,4	-89,1	-187,4	23,4	°C
TT_15 (R=1, Z=0, B=225)	-169,9	-98,8	-213,3	24,6	°C
TT_16 (R=1,48, Z=0, B=0)	-97,9	-66,1	-117,9	12,8	°C
TT_17 (R=1,48, Z=1,13, B=0)	-82,0	-44,7	-151,7	19,4	°C
TT_18 (R=1,48, Z=2,26, B=0)	-95,7	-57,7	-137,6	26,5	°C
TT_19 (R=0, Z=1,695, B=0)	-156,0	-106,4	-210,9	32,4	°C
TT_20 (R=0, Z=1,13, B=0)	-157,7	-63,6	-218,3	55,5	°C
TT_21 (R=0, Z=2,26, B=0)	-74,6	-18,2	-107,3	21,0	°C
TT_22 (R=0,74, Z=1,13, B=90)	-157,7	-63,1	-218,9	55,7	°C
TT_23 (R=1,48, Z=0, B=90)	-91,2	-57,6	-108,2	14,6	°C
TT_24 (R=1,48, Z=1,13, B=90)	-114,7	-58,2	-183,4	25,7	°C
TT_25 (R=1,48, Z=2,26, B=90)	-63,1	-34,4	-119,8	15,3	°C
TT_26 (R=5,205, Z=2,6, B=90)	-148,8	-47,6	-213,0	55,9	°C
TT_27 (R=5,205, Z=6,25, B=90)	-148,1	-45,1	-213,2	56,0	°C
TT_28 (R=5,205, Z=11,5, B=90)	-122,8	-6,7	-193,4	66,4	°C
TT_29 (R=0, Z=0, B=0)	-116,9	-68,3	-151,2	21,4	°C
TT_30 (R=0, Z=0, B=0)	-88,7	-16,7	-119,8	24,1	°C
TT_31 (R=0, Z=0, B=0)	-142,5	-59,9	-196,0	30,3	°C
TT_32 (R=0, Z=0, B=0)	-11,6	-2,8	-27,5	8,6	°C





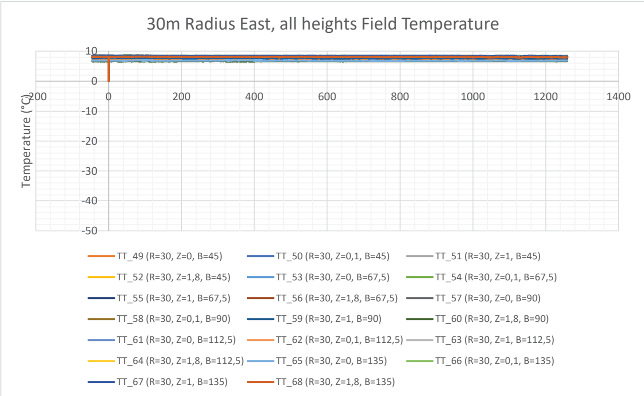


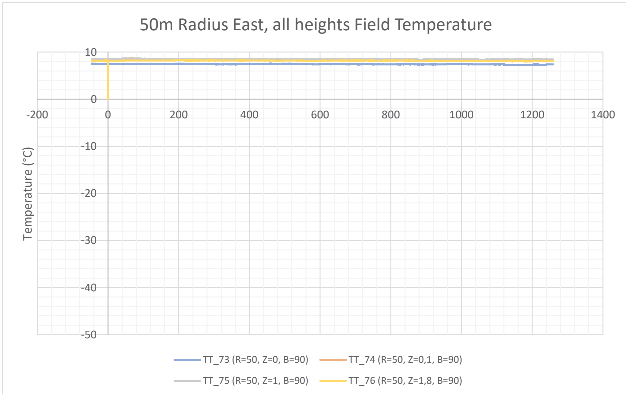


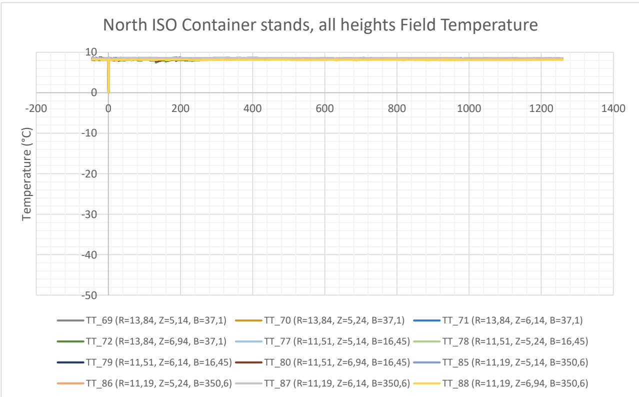
Notes: No significant temperature drop in the field.Low temps registered near low level vent

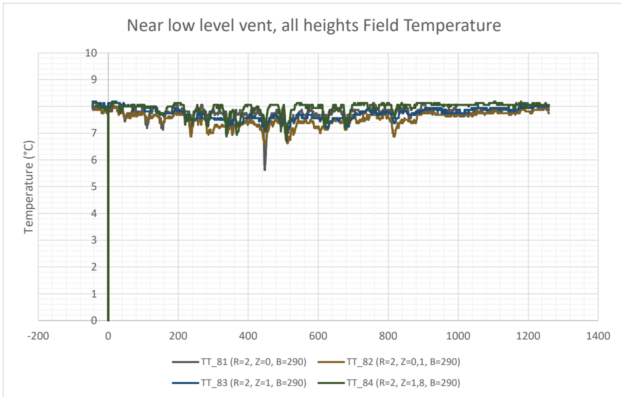
Field Temperature

Test Name	Test12		FOR AVERAGING		
Hole Size	13	mm	Start	50	sec
Orientation	Downwards		End	550	sec









Sensor	Average	Max	Min	STDEV	units
TT_49 (R=30, Z=0, B=45)	7,1	7,2	7,1	0,0	°C
TT_50 (R=30, Z=0,1, B=45)	8,1	8,2	7,9	0,1	°C
TT_51 (R=30, Z=1, B=45)	8,1	8,3	7,9	0,1	°C
TT_52 (R=30, Z=1,8, B=45)	8,2	8,3	8,0	0,1	°C
TT_53 (R=30, Z=0, B=67,5)	8,0	8,1	7,8	0,1	°C
TT_54 (R=30, Z=0,1, B=67,5)	8,1	8,3	8,0	0,0	°C
TT_55 (R=30, Z=1, B=67,5)	8,1	8,2	8,0	0,1	°C
TT_56 (R=30, Z=1,8, B=67,5)	8,0	8,2	7,9	0,1	°C
TT_57 (R=30, Z=0, B=90)	7,9	8,1	7,7	0,1	°C
TT_58 (R=30, Z=0,1, B=90)	7,9	8,1	7,7	0,1	°C
TT_59 (R=30, Z=1, B=90)	7,7	7,8	7,5	0,1	°C
TT_60 (R=30, Z=1,8, B=90)	6,7	6,8	6,6	0,0	°C
TT_61 (R=30, Z=0, B=112,5)	8,3	8,4	8,1	0,1	°C
TT_62 (R=30, Z=0,1, B=112,5)	8,4	8,5	8,2	0,1	°C
TT_63 (R=30, Z=1, B=112,5)	8,5	8,6	8,4	0,0	°C
TT_64 (R=30, Z=1,8, B=112,5)	8,3	8,4	8,2	0,0	°C
TT_65 (R=30, Z=0, B=135)	6,9	6,9	6,8	0,0	°C
TT_66 (R=30, Z=0,1, B=135)	8,5	8,7	8,4	0,1	°C
TT_67 (R=30, Z=1, B=135)	8,4	8,6	8,3	0,1	°C
TT_68 (R=30, Z=1,8, B=135)	8,1	8,2	7,9	0,0	°C
TT_69 (R=13,84, Z=5,14, B=37,1)	8,4	8,5	8,1	0,1	°C
TT_70 (R=13,84, Z=5,24, B=37,1)	8,4	8,5	8,1	0,1	°C
TT_71 (R=13,84, Z=6,14, B=37,1)	8,3	8,4	8,0	0,1	°C
TT_72 (R=13,84, Z=6,94, B=37,1)	8,1	8,2	7,4	0,1	°C
TT_73 (R=50, Z=0, B=90)	7,5	7,6	7,4	0,0	°C
TT_74 (R=50, Z=0,1, B=90)	8,5	8,6	8,4	0,0	°C
TT_75 (R=50, Z=1, B=90)	8,5	8,6	8,4	0,0	°C
TT_76 (R=50, Z=1,8, B=90)	8,2	8,3	8,1	0,0	°C
TT_77 (R=11,51, Z=5,14, B=16,45)	8,5	8,6	8,3	0,0	°C
TT_78 (R=11,51, Z=5,24, B=16,45)	8,5	8,6	8,4	0,0	°C
TT_79 (R=11,51, Z=6,14, B=16,45)	8,5	8,6	8,3	0,1	°C
TT_80 (R=11,51, Z=6,94, B=16,45)	8,2	8,3	7,9	0,1	°C
TT_81 (R=2, Z=0, B=290)	7,7	8,1	5,6	0,3	°C
TT_82 (R=2, Z=0,1, B=290)	7,4	7,8	6,6	0,3	°C
TT_83 (R=2, Z=1, B=290)	7,6	8,1	7,1	0,2	°C
TT_84 (R=2, Z=1,8, B=290)	7,8	8,1	6,7	0,3	°C
TT_85 (R=11,19, Z=5,14, B=350,6)	8,5	8,6	8,4	0,0	°C
TT_86 (R=11,19, Z=5,24, B=350,6)	8,5	8,6	8,4	0,0	°C
TT_87 (R=11,19, Z=6,14, B=350,6)	8,6	8,6	8,4	0,1	°C
TT_88 (R=11,19, Z=6,94, B=350,6)	8,1	8,2	8,1	0,0	°C

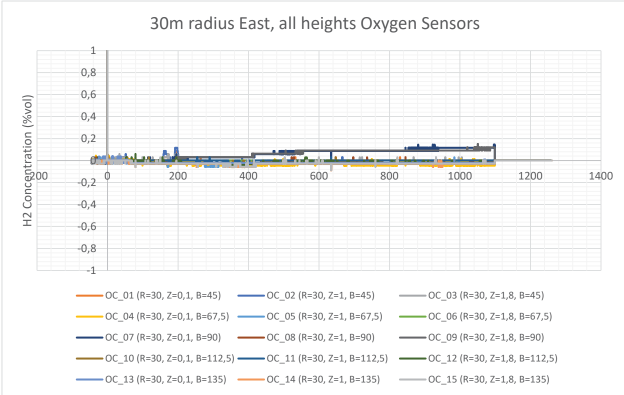
DNV·GL

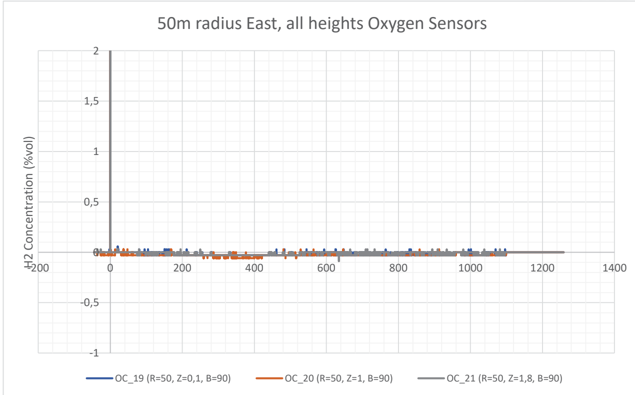
Gas Concentrations

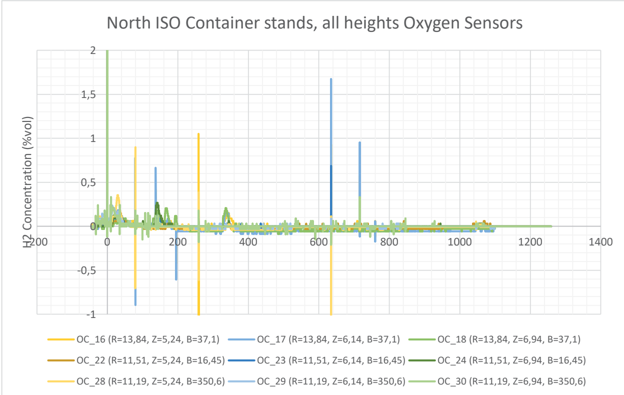
Test Name	Test12		FOR AVERAGING		
Hole Size	13	mm	Start	50	sec
Orientation	Downwards		End	550	sec

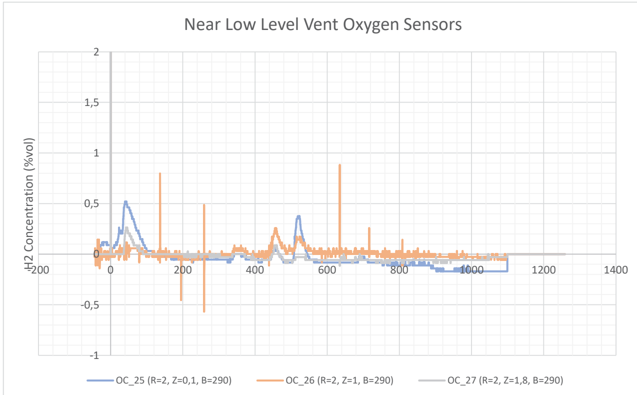
Notes: No H2 detected in the field. Small amounts detected near low level vent at the beginning of the release. Very high concentrations within the TCS. Sensors were likely affected by cold temperatures, so decay measurements are likely affected. Correction to be applied if possible.

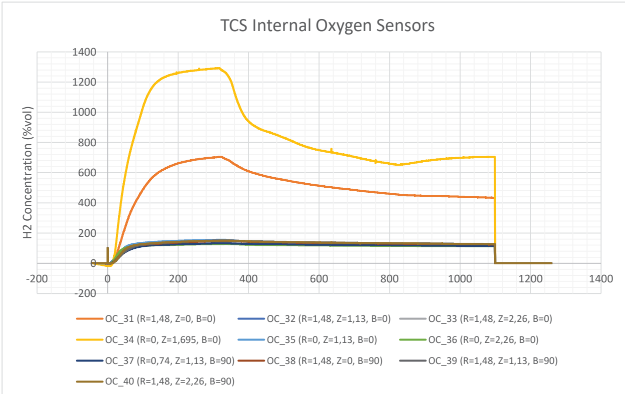
Sensor	Average	Max	Min	STDEV	units
OC_01 (R=30, Z=0,1, B=45)	0,0	0,1	0,0	0,0	%vol
OC_02 (R=30, Z=1, B=45)	0,0	0,1	0,0	0,0	%vol
OC_03 (R=30, Z=1,8, B=45)	0,0	0,1	0,0	0,0	%vol
OC_04 (R=30, Z=0,1, B=67,5)	0,0	0,0	0,0	0,0	%vol
OC_05 (R=30, Z=1, B=67,5)	0,0	0,0	-0,1	0,0	%vol
OC_06 (R=30, Z=1,8, B=67,5)	0,0	0,0	0,0	0,0	%vol
OC_07 (R=30, Z=0,1, B=90)	0,0	0,1	0,0	0,0	%vol
OC_08 (R=30, Z=1, B=90)	0,0	0,0	-0,1	0,0	%vol
OC_09 (R=30, Z=1,8, B=90)	0,0	0,1	0,0	0,0	%vol
OC_10 (R=30, Z=0,1, B=112,5)	0,0	0,0	-0,1	0,0	%vol
OC_11 (R=30, Z=1, B=112,5)	0,0	0,0	0,0	0,0	%vol
OC_12 (R=30, Z=1,8, B=112,5)	0,0	0,1	-0,1	0,0	%vol
OC_13 (R=30, Z=0,1, B=135)	0,0	0,0	0,0	0,0	%vol
OC_14 (R=30, Z=1, B=135)	0,0	0,0	-0,1	0,0	%vol
OC_15 (R=30, Z=1,8, B=135)	0,0	0,0	-0,1	0,0	%vol
OC_16 (R=13,84, Z=5,24, B=37,1)	0,0	1,0	-1,3	0,0	%vol
OC_17 (R=13,84, Z=6,14, B=37,1)	0,0	0,8	-0,9	0,1	%vol
OC_18 (R=13,84, Z=6,94, B=37,1)	0,0	0,2	-0,1	0,1	%vol
OC_19 (R=50, Z=0,1, B=90)	0,0	0,0	0,0	0,0	%vol
OC_20 (R=50, Z=1, B=90)	0,0	0,0	-0,1	0,0	%vol
OC_21 (R=50, Z=1,8, B=90)	0,0	0,0	0,0	0,0	%vol
OC_22 (R=11,51, Z=5,24, B=16,45)	0,0	0,1	0,0	0,0	%vol
OC_23 (R=11,51, Z=6,14, B=16,45)	0,0	0,1	-0,2	0,0	%vol
OC_24 (R=11,51, Z=6,94, B=16,45)	0,0	0,3	0,0	0,0	%vol
OC_25 (R=2, Z=0,1, B=290)	0,0	0,5	-0,1	0,1	%vol
OC_26 (R=2, Z=1, B=290)	0,0	0,8	-0,6	0,1	%vol
OC_27 (R=2, Z=1,8, B=290)	0,0	0,2	-0,1	0,0	%vol
OC_28 (R=11,19, Z=5,24, B=350,6)	0,0	0,9	-0,7	0,0	%vol
OC_29 (R=11,19, Z=6,14, B=350,6)	0,0	0,1	0,0	0,0	%vol
OC_30 (R=11,19, Z=6,94, B=350,6)	0,0	0,2	-0,2	0,0	%vol
OC_31 (R=1,48, Z=0, B=0)	597,1	704,5	239,3	94,3	%vol
OC_32 (R=1,48, Z=1,13, B=0)	124,3	131,6	95,3	6,1	%vol
OC_33 (R=1,48, Z=2,26, B=0)	122,9	131,3	89,9	6,8	%vol
OC_34 (R=0, Z=1,695, B=0)	1064,4	1292,3	582,8	198,1	%vol
OC_35 (R=0, Z=1,13, B=0)	143,1	155,4	106,9	9,1	%vol
OC_36 (R=0, Z=2,26, B=0)	121,5	128,2	101,3	4,6	%vol
OC_37 (R=0,74, Z=1,13, B=90)	123,7	131,9	74,7	9,8	%vol
OC_38 (R=1,48, Z=0, B=90)	136,5	147,1	86,1	10,9	%vol
OC_39 (R=1,48, Z=1,13, B=90)	139,5	151,7	77,9	13,2	%vol
OC_40 (R=1,48, Z=2,26, B=90)	139,9	149,5	93,1	9,8	%vol











Notes

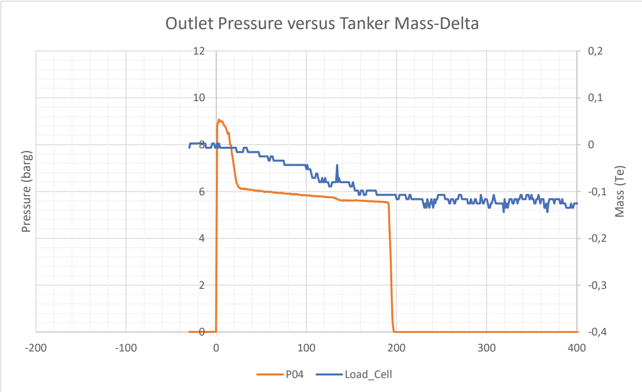
FFI: LH2 Releases

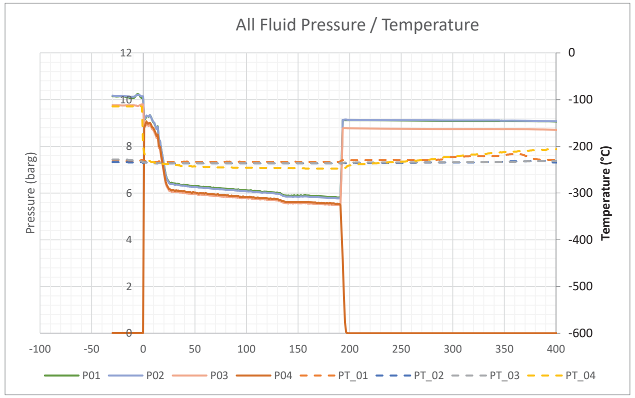
Test Name	Test13
Hole Size	13 mm
Orientation	Downwards

FOR PLOTS

Start Time	-30	sec
End Time	3900	sec

Date 16.01.2020

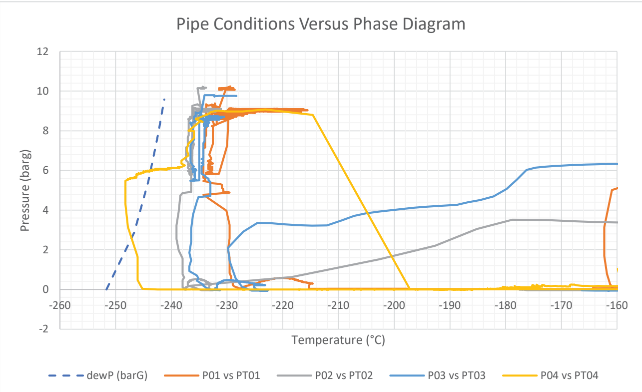


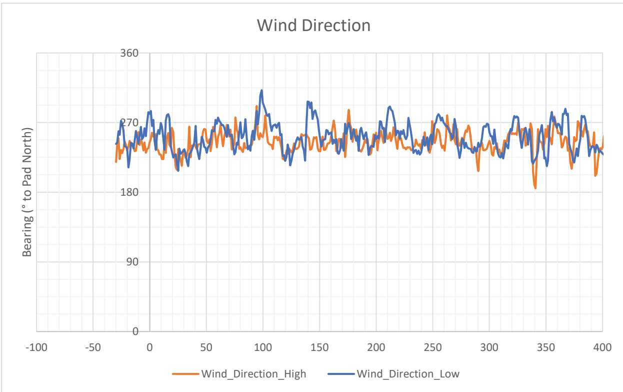


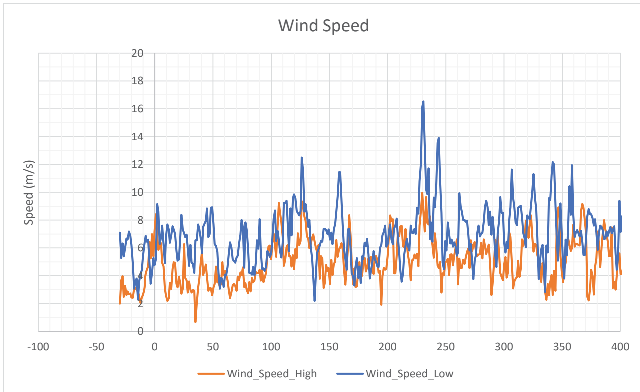
FOR AVERAGING

Start	50	sec
End	180	sec

Sensor	Average	Max	Min	STDEV	units
Load_Cell		-0,025	-0,107		Te
P01	6,05	6,30	5,83	0,15	Barg
P02	6,01	6,26	5,79	0,15	Barg
P03	5,72	5,96	5,51	0,14	Barg
P04	5,77	6,02	5,56	0,14	Barg
PT_01	-233,1	-232,7	-233,8	0,2	°C
PT_02	-236,5	-236,4	-236,6	0,1	°C
PT_03	-235,9	-235,6	-236,1	0,1	°C
PT_04	-246,0	-243,4	-247,8	1,1	°C
MassFlow		0,673			kg/s
Wind_Direction_High	247,4	291,4	222,2	12,7	0,0
Wind_Direction_Low	256,5	311,8	214,6	19,4	Deg
Wind_Speed_High	5,0	9,4	2,4	1,6	m/s
Wind_Speed_Low	6,4	12,5	2,2	2,0	m/s







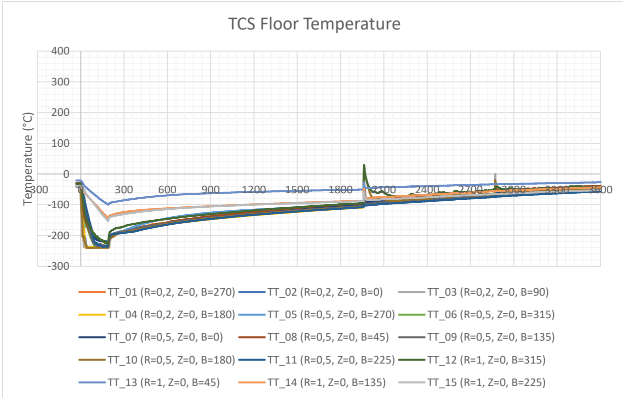
TCS Temperature

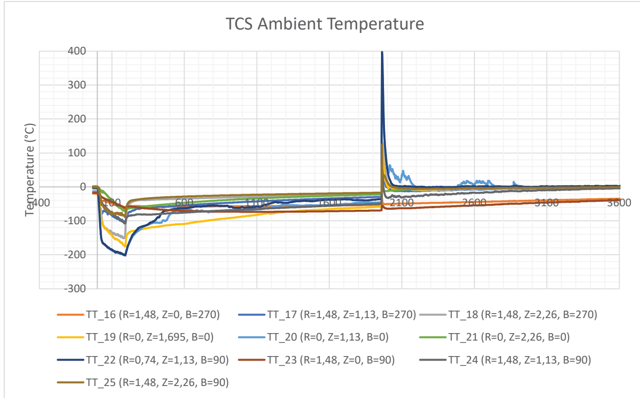
Test Name	Test13		FOR AVERAGING		
Hole Size	13	mm	Start	50	sec
Orientation	Downwards		End	550	sec

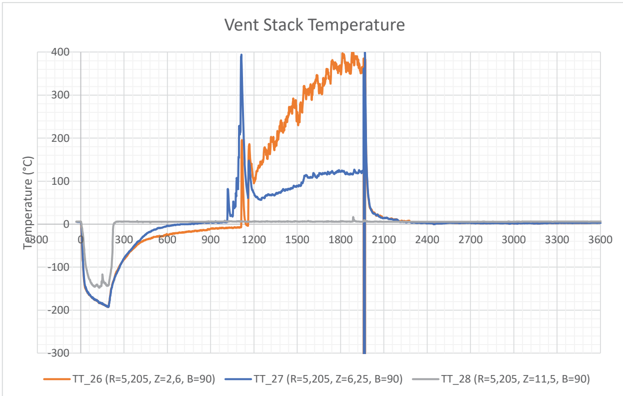
Notes:

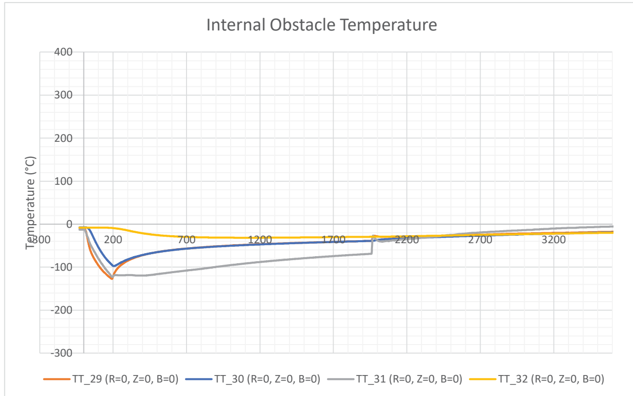
Liquid H2 observed on TCS floor surface @0.2m. Around 100s after end of release most floor temperatures register ca. -200°C for over 2.5 minutes. Ambient temperature within chamber reached -200°C, these quickly increased as soon as the release stopped. Temperature sensors show low temps in stack. The closest temperature sensor to the end of the stack registered a higher temperature than the other two, as expected.

Sensor	Average	Max	Min	STDEV	units
TT_01 (R=0,2, Z=0, B=270)	-196,8	-160,4	-240,2	29,8	°C
TT_02 (R=0,2, Z=0, B=0)	-195,7	-162,3	-237,1	28,0	°C
TT_03 (R=0,2, Z=0, B=90)	-197,4	-164,9	-237,8	28,0	°C
TT_04 (R=0,2, Z=0, B=180)	-199,3	-168,3	-238,1	26,1	°C
TT_05 (R=0,5, Z=0, B=270)	-182,5	-148,6	-228,4	22,5	°C
TT_06 (R=0,5, Z=0, B=315)	-195,5	-166,0	-237,9	23,1	°C
TT_07 (R=0,5, Z=0, B=0)	-187,6	-135,3	-220,9	18,9	°C
TT_08 (R=0,5, Z=0, B=45)	-193,3	-161,9	-237,9	23,5	°C
TT_09 (R=0,5, Z=0, B=135)	-192,3	-163,6	-237,6	23,7	°C
TT_10 (R=0,5, Z=0, B=180)	-200,3	-166,6	-240,6	27,3	°C
TT_11 (R=0,5, Z=0, B=225)	-194,2	-139,1	-237,6	21,8	°C
TT_12 (R=1, Z=0, B=315)	-175,6	-149,3	-227,6	22,3	°C
TT_13 (R=1, Z=0, B=45)	-80,0	-49,4	-99,9	10,1	°C
TT_14 (R=1, Z=0, B=135)	-117,9	-74,0	-144,3	13,5	°C
TT_15 (R=1, Z=0, B=225)	-122,9	-72,9	-152,4	15,3	°C
TT_16 (R=1,48, Z=0, B=270)	-56,3	-41,6	-67,4	4,4	°C
TT_17 (R=1,48, Z=1,13, B=270)	-70,5	-55,6	-109,3	14,0	°C
TT_18 (R=1,48, Z=2,26, B=270)	-68,4	-35,2	-151,1	45,0	°C
TT_19 (R=0, Z=1,695, B=0)	-129,5	-110,2	-175,4	17,1	°C
TT_20 (R=0, Z=1,13, B=0)	-136,0	-69,5	-202,6	42,0	°C
TT_21 (R=0, Z=2,26, B=0)	-53,4	-17,4	-72,2	10,5	°C
TT_22 (R=0,74, Z=1,13, B=90)	-129,2	-64,3	-201,3	47,1	°C
TT_23 (R=1,48, Z=0, B=90)	-59,5	-34,4	-69,8	9,0	°C
TT_24 (R=1,48, Z=1,13, B=90)	-82,0	-56,3	-107,5	8,5	°C
TT_25 (R=1,48, Z=2,26, B=90)	-47,2	-29,2	-88,9	20,1	°C
TT_26 (R=5,205, Z=2,6, B=90)	-99,5	-27,3	-193,0	60,8	°C
TT_27 (R=5,205, Z=6,25, B=90)	-94,8	-8,7	-193,2	66,2	°C
TT_28 (R=5,205, Z=11,5, B=90)	-42,3	6,9	-147,6	66,7	°C
TT_29 (R=0, Z=0, B=0)	-86,2	-62,4	-127,3	19,1	°C
TT_30 (R=0, Z=0, B=0)	-72,6	-20,0	-97,5	16,0	°C
TT_31 (R=0, Z=0, B=0)	-110,1	-50,6	-123,3	17,2	°C
TT_32 (R=0, Z=0, B=0)	-15,7	-7,9	-26,9	6,8	°C





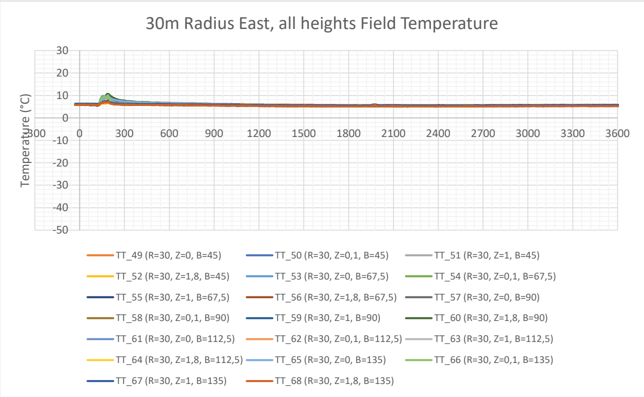


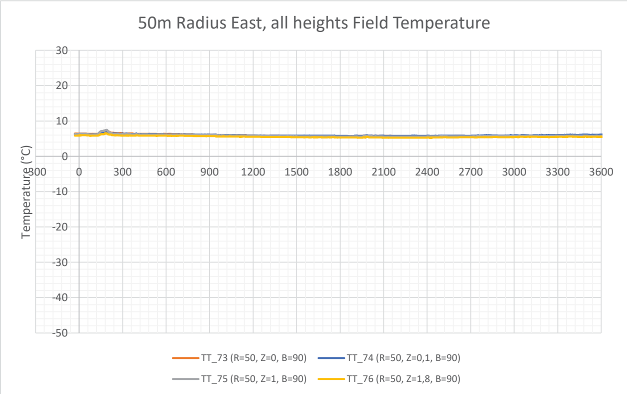


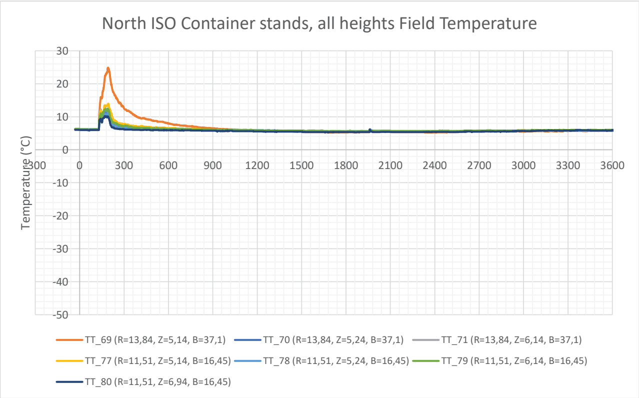
Notes: No significant temperature drop in the field.Low temps registered near low level vent

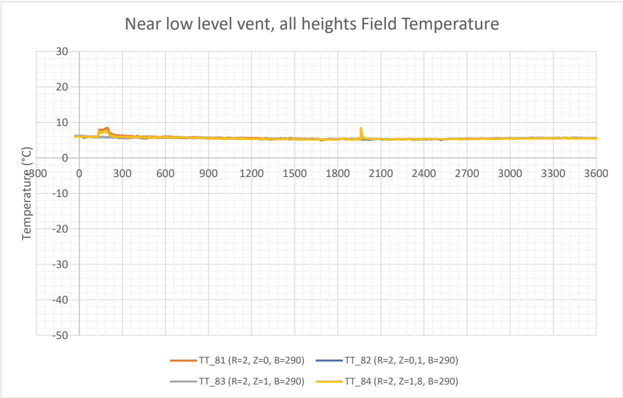
Field Temperature

Test Name	Test13		FOR AVERAGING		
Hole Size	13	mm	Start	50	sec
Orientation	Downwards		End	550	sec









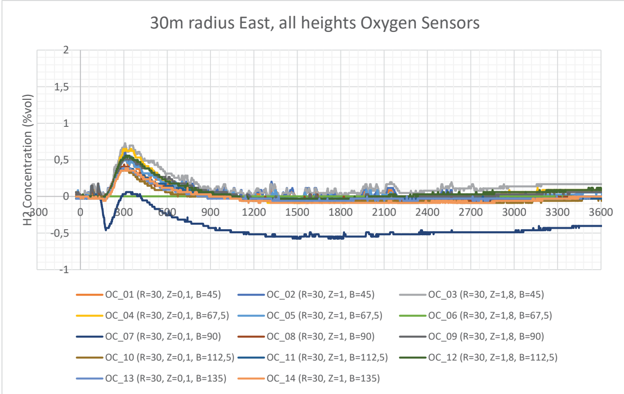
Sensor	Average	Max	Min	STDEV	units
TT_49 (R=30, Z=0, B=45)	7,1	8,6	6,2	0,6	°C
TT_50 (R=30, Z=0,1, B=45)	6,5	9,5	5,7	0,8	°C
TT_51 (R=30, Z=1, B=45)	6,3	8,8	5,7	0,7	°C
TT_52 (R=30, Z=1,8, B=45)	6,3	9,1	5,8	0,8	°C
TT_53 (R=30, Z=0, B=67,5)	6,7	10,7	5,7	1,2	°C
TT_54 (R=30, Z=0,1, B=67,5)	6,5	9,9	5,8	1,0	°C
TT_55 (R=30, Z=1, B=67,5)	6,0	7,6	5,4	0,4	°C
TT_56 (R=30, Z=1,8, B=67,5)	6,2	9,3	5,4	0,9	°C
TT_57 (R=30, Z=0, B=90)	7,0	10,6	6,0	1,2	°C
TT_58 (R=30, Z=0,1, B=90)	6,4	9,3	5,8	0,9	°C
TT_59 (R=30, Z=1, B=90)	6,7	9,8	5,8	1,0	°C
TT_60 (R=30, Z=1,8, B=90)	7,4	10,8	5,8	1,2	°C
TT_61 (R=30, Z=0, B=112,5)	6,7	10,1	6,1	1,0	°C
TT_62 (R=30, Z=0,1, B=112,5)	6,6	9,3	6,1	0,8	°C
TT_63 (R=30, Z=1, B=112,5)	6,7	9,6	6,2	0,8	°C
TT_64 (R=30, Z=1,8, B=112,5)	6,2	6,9	5,9	0,2	°C
TT_65 (R=30, Z=0, B=135)	7,2	9,6	6,1	0,9	°C
TT_66 (R=30, Z=0,1, B=135)	6,8	10,1	6,2	1,0	°C
TT_67 (R=30, Z=1, B=135)	6,4	7,4	6,1	0,3	°C
TT_68 (R=30, Z=1,8, B=135)	6,0	7,1	5,8	0,3	°C
TT_69 (R=13,84, Z=5,14, B=37,1)	11,8	24,9	6,0	4,9	°C
TT_70 (R=13,84, Z=5,24, B=37,1)	7,3	11,6	6,1	1,5	°C
TT_71 (R=13,84, Z=6,14, B=37,1)	7,1	12,9	6,1	1,9	°C
TT_72 (R=13,84, Z=6,94, B=37,1)	6,8	12,9	5,6	2,0	°C
TT_73 (R=50, Z=0, B=90)	6,5	7,3	6,3	0,2	°C
TT_74 (R=50, Z=0,1, B=90)	6,4	6,9	6,2	0,1	°C
TT_75 (R=50, Z=1, B=90)	6,4	7,5	6,2	0,3	°C
TT_76 (R=50, Z=1,8, B=90)	6,0	6,6	5,8	0,2	°C
TT_77 (R=11,51, Z=5,14, B=16,45)	8,0	14,0	6,1	2,1	°C
TT_78 (R=11,51, Z=5,24, B=16,45)	7,1	11,2	6,1	1,4	°C
TT_79 (R=11,51, Z=6,14, B=16,45)	7,5	12,4	6,1	1,7	°C
TT_80 (R=11,51, Z=6,94, B=16,45)	6,6	10,1	5,8	1,2	°C
TT_81 (R=2, Z=0, B=290)	6,4	8,6	5,8	0,7	°C
TT_82 (R=2, Z=0,1, B=290)	5,7	6,0	5,4	0,1	°C
TT_83 (R=2, Z=1, B=290)	5,8	6,1	5,6	0,1	°C
TT_84 (R=2, Z=1,8, B=290)	6,1	7,6	5,8	0,5	°C
TT_85 (R=11,19, Z=5,14, B=350,6)	7,3	12,1	6,1	1,5	°C
TT_86 (R=11,19, Z=5,24, B=350,6)	6,7	9,5	6,0	0,8	°C
TT_87 (R=11,19, Z=6,14, B=350,6)	6,7	9,4	6,0	0,8	°C
TT_88 (R=11,19, Z=6,94, B=350,6)	7,2	13,4	5,8	2,1	°C

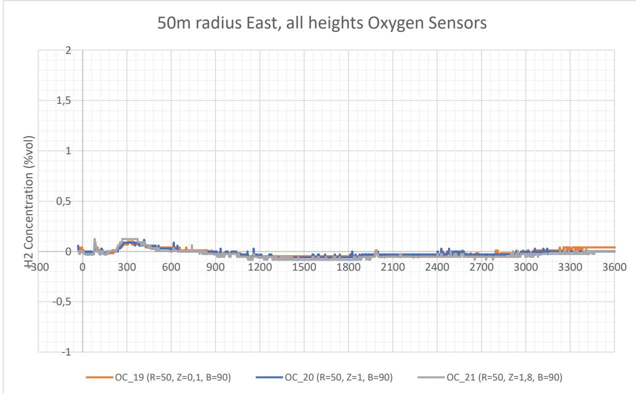
Gas Concentrations

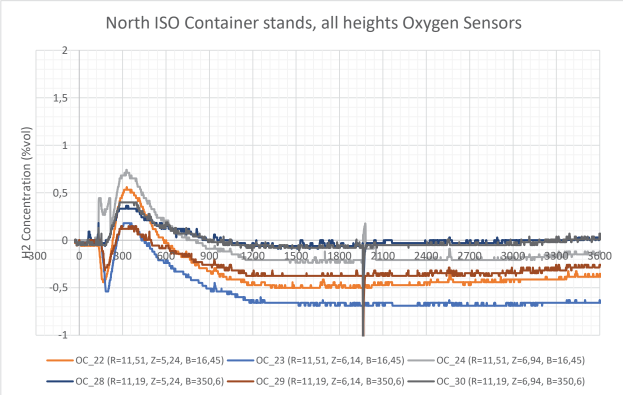
Test Name	Test13		FOR AVERAGING		
Hole Size	13	mm	Start	50	sec
Orientation	Downwards		End	180	sec

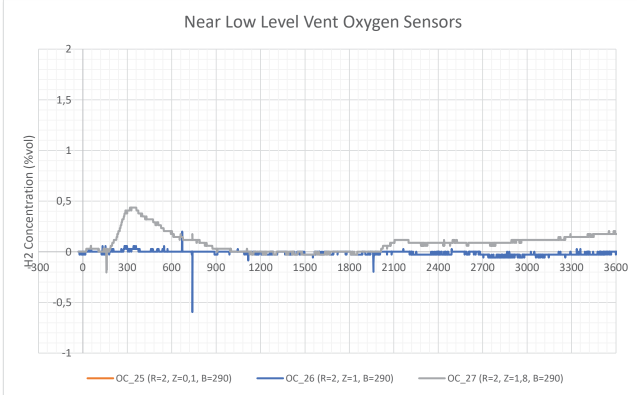
Notes: No H2 detected in the field. Small amounts detected near low level vent at the beginning of the release. Very high concentrations within the TCS: Linear correction has been applied assuming 100%H2 maximum, see 'Plot Data' tab for details. Field concentrations show low level H2 but after ignition - suspect +ve temperature effects.

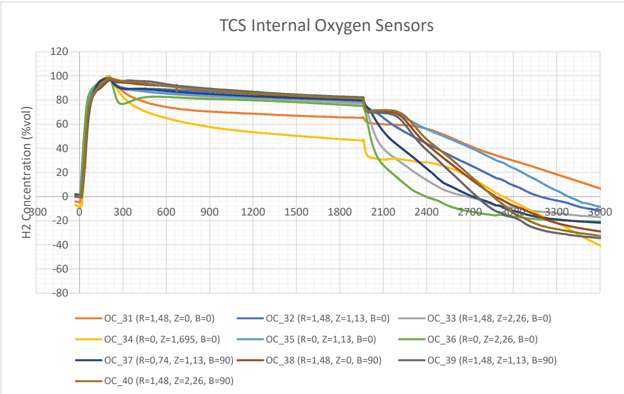
Sensor	Average	Max	Min	STDEV	units
OC_01 (R=30, Z=0,1, B=45)	0,0	0,1	0,0	0,0	%vol
OC_02 (R=30, Z=1, B=45)	0,0	0,1	0,0	0,0	%vol
OC_03 (R=30, Z=1,8, B=45)	0,1	0,2	0,0	0,0	%vol
OC_04 (R=30, Z=0,1, B=67,5)	0,0	0,1	0,0	0,0	%vol
OC_05 (R=30, Z=1, B=67,5)	0,0	0,2	0,0	0,1	%vol
OC_06 (R=30, Z=1,8, B=67,5)	0,0	0,0	0,0	0,0	%vol
OC_07 (R=30, Z=0,1, B=90)	-0,1	0,0	-0,5	0,1	%vol
OC_08 (R=30, Z=1, B=90)	0,0	0,1	0,0	0,0	%vol
OC_09 (R=30, Z=1,8, B=90)	0,0	0,2	0,0	0,1	%vol
OC_10 (R=30, Z=0,1, B=112,5)	0,0	0,0	0,0	0,0	%vol
OC_11 (R=30, Z=1, B=112,5)	0,0	0,0	0,0	0,0	%vol
OC_12 (R=30, Z=1,8, B=112,5)	0,0	0,0	0,0	0,0	%vol
OC_13 (R=30, Z=0,1, B=135)	0,0	0,0	0,0	0,0	%vol
OC_14 (R=30, Z=1, B=135)	0,0	0,0	-0,1	0,0	%vol
OC_15 (R=30, Z=1,8, B=135)	0,0	0,0	0,0	0,0	%vol
OC_16 (R=13,84, Z=5,24, B=37,1)	-0,2	0,2	-0,8	0,3	%vol
OC_17 (R=13,84, Z=6,14, B=37,1)	-0,1	0,3	-0,2	0,1	%vol
OC_18 (R=13,84, Z=6,94, B=37,1)	0,0	0,1	0,0	0,0	%vol
OC_19 (R=50, Z=0,1, B=90)	0,0	0,0	0,0	0,0	%vol
OC_20 (R=50, Z=1, B=90)	0,0	0,1	0,0	0,0	%vol
OC_21 (R=50, Z=1,8, B=90)	0,0	0,1	0,0	0,0	%vol
OC_22 (R=11,51, Z=5,24, B=16,45)	-0,1	0,0	-0,4	0,1	%vol
OC_23 (R=11,51, Z=6,14, B=16,45)	-0,1	0,1	-0,5	0,1	%vol
OC_24 (R=11,51, Z=6,94, B=16,45)	0,1	0,4	0,0	0,2	%vol
OC_25 (R=2, Z=0,1, B=290)					%vol
OC_26 (R=2, Z=1, B=290)	0,0	0,1	0,0	0,0	%vol
OC_27 (R=2, Z=1,8, B=290)	0,0	0,1	-0,2	0,0	%vol
OC_28 (R=11,19, Z=5,24, B=350,6)	0,0	0,2	-0,1	0,0	%vol
OC_29 (R=11,19, Z=6,14, B=350,6)	0,0	0,1	-0,3	0,1	%vol
OC_30 (R=11,19, Z=6,94, B=350,6)	0,0	0,1	-0,1	0,0	%vol
OC_31 (R=1,48, Z=0, B=0)	89,9	98,7	66,7	8,1	%vol
OC_32 (R=1,48, Z=1,13, B=0)	90,5	96,3	74,6	5,5	%vol
OC_33 (R=1,48, Z=2,26, B=0)	90,7	96,3	73,5	5,4	%vol
OC_34 (R=0, Z=1,695, B=0)	85,4	98,9	47,4	13,0	%vol
OC_35 (R=0, Z=1,13, B=0)	89,2	96,7	71,4	6,0	%vol
OC_36 (R=0, Z=2,26, B=0)	91,0	96,3	76,7	4,7	%vol
OC_37 (R=0,74, Z=1,13, B=90)	86,4	97,7	51,8	12,2	%vol
OC_38 (R=1,48, Z=0, B=90)	84,3	93,9	58,6	8,3	%vol
OC_39 (R=1,48, Z=1,13, B=90)	83,6	94,8	48,7	11,2	%vol
OC_40 (R=1,48, Z=2,26, B=90)	86,4	96,3	61,2	8,3	%vol











FFI: LH2 Releases

Notes

Second ignited test. Ignition at top of stack. Low level vent open to atmosphere. Double layer plastic vent with polystyrene layer to avoid rupture due to cold temperature. Release lasted approx. 2 minutes. Ignition ocurred on initiation of first firework. Themperature in stack rised quickly and explosion event happened within the enclosure. Explosion was vented, but significant damage occurred to the stack and floor of the enclosure.
Maybe offset in temperature - no measurements reach liquid temp, need to investigate

Test Name	Test14	
Hole Size	13	mm
Orientation	Downwards	

FOR PLOTS

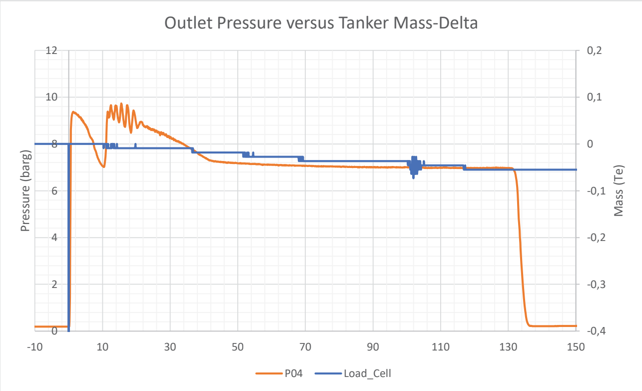
Start Time	-66	sec
End Time	1600	sec

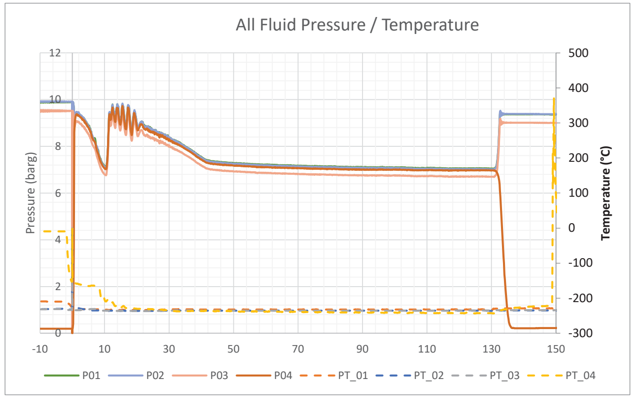
Date 15.01.2020

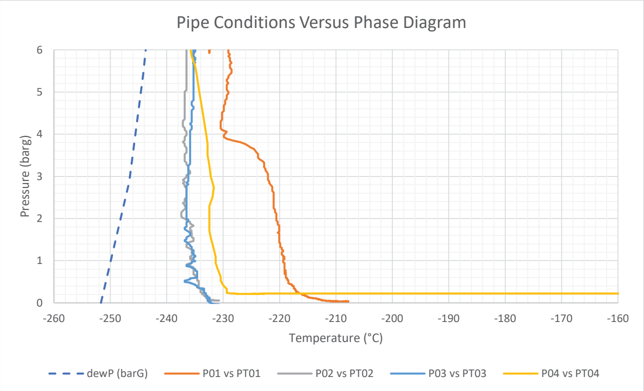
FOR AVERAGING

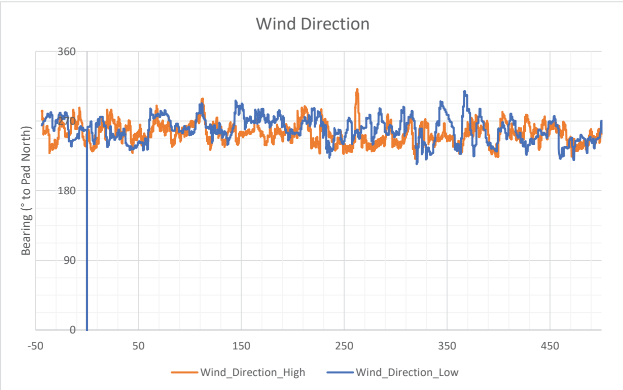
Start	50	sec
End	120	sec

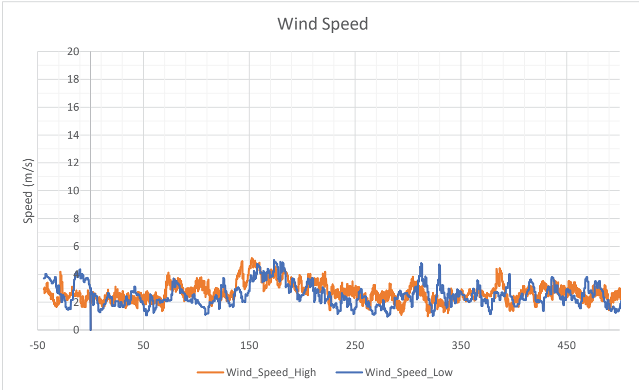
Sensor	Average	Max	Min	STDEV	units
Load_Cell	-0,037	-0,018	-0,073	0,009	Te
P01	7,14	7,29	7,04	0,06	Barg
P02	7,11	7,26	7,02	0,06	Barg
P03	6,79	6,93	6,69	0,06	Barg
P04	7,04	7,18	6,95	0,06	Barg
PT_01	-232,3	-231,1	-232,8	0,2	°C
PT_02	-235,7	-235,3	-236,2	0,2	°C
PT_03	-235,8	-234,6	-235,9	0,2	°C
PT_04	-240,3	-236,5	-242,8	1,5	°C
MassFlow	0,370				kg/s
Wind_Direction_High	259,2	299,2	232,5	13,1	0,0
Wind_Direction_Low	265,1	293,0	232,0	13,8	Deg
Wind_Speed_High	2,6	4,1	1,4	0,6	m/s
Wind_Speed_Low	2,1	3,7	1,1	0,6	m/s











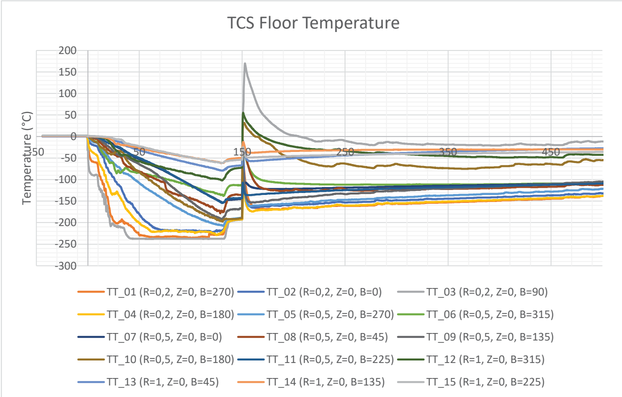
TCS Temperature

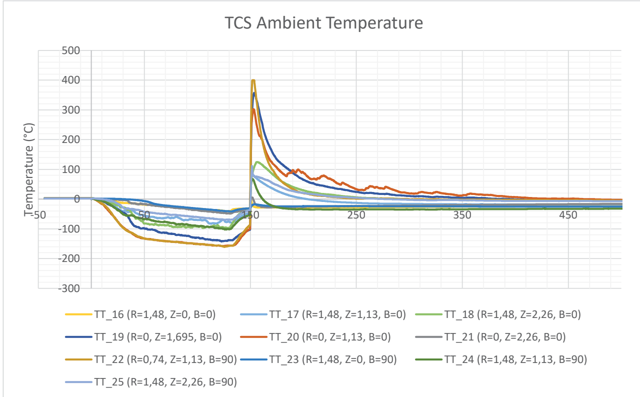
Test Name	Test14		FOR AVERAGING		
Hole Size	13	mm	Start	50	sec
Orientation	Downwards		End	120	sec

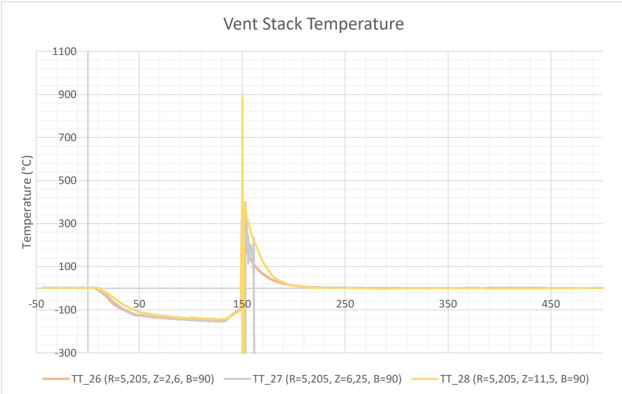
Notes:

Liquid H2 observed on TCS floor surface @0.2m. Around 100s after end of release most floor temperatures register ca. -200°C for over 2.5 minutes. Ambient temperature within chamber reached -200°C, these quickly increased as soon as the release stopped. Temperature sensors show low temps in stack. The closest temperature sensor to the end of the stack registered a higher temperature than the other two, as expected.

Sensor	Average	Max	Min	STDEV	units
TT_01 (R=0,2, Z=0, B=270)	-232,8	-226,5	-235,7	1,7	°C
TT_02 (R=0,2, Z=0, B=0)	-214,2	-180,3	-223,8	9,3	°C
TT_03 (R=0,2, Z=0, B=90)	-237,6	-236,9	-237,9	0,1	°C
TT_04 (R=0,2, Z=0, B=180)	-218,8	-200,7	-223,9	4,4	°C
TT_05 (R=0,5, Z=0, B=270)	-159,8	-107,9	-200,7	27,3	°C
TT_06 (R=0,5, Z=0, B=315)	-105,2	-83,2	-129,1	13,5	°C
TT_07 (R=0,5, Z=0, B=0)	-94,4	-52,3	-139,7	25,4	°C
TT_08 (R=0,5, Z=0, B=45)	-125,5	-81,6	-164,1	25,1	°C
TT_09 (R=0,5, Z=0, B=135)	-122,4	-64,3	-181,8	36,2	°C
TT_10 (R=0,5, Z=0, B=180)	-140,5	-82,8	-188,0	30,8	°C
TT_11 (R=0,5, Z=0, B=225)	-93,4	-49,9	-140,5	26,8	°C
TT_12 (R=1, Z=0, B=315)	-78,2	-57,8	-97,6	11,1	°C
TT_13 (R=1, Z=0, B=45)	-53,2	-31,6	-72,8	11,8	°C
TT_14 (R=1, Z=0, B=135)	-42,5	-27,2	-56,6	8,3	°C
TT_15 (R=1, Z=0, B=225)	-41,0	-23,1	-57,8	10,1	°C
TT_16 (R=1,48, Z=0, B=0)	-28,5	-18,6	-37,9	5,7	°C
TT_17 (R=1,48, Z=1,13, B=0)	-67,6	-55,9	-82,8	7,1	°C
TT_18 (R=1,48, Z=2,26, B=0)	-90,5	-81,5	-97,3	3,8	°C
TT_19 (R=0, Z=1,695, B=0)	-121,1	-98,3	-138,8	11,8	°C
TT_20 (R=0, Z=1,13, B=0)	-145,7	-132,1	-156,8	6,8	°C
TT_21 (R=0, Z=2,26, B=0)	-31,4	-16,8	-45,3	7,9	°C
TT_22 (R=0,74, Z=1,13, B=90)	-145,8	-132,9	-156,4	6,7	°C
TT_23 (R=1,48, Z=0, B=90)	-25,7	-6,8	-38,3	8,2	°C
TT_24 (R=1,48, Z=1,13, B=90)	-83,6	-66,4	-97,9	8,5	°C
TT_25 (R=1,48, Z=2,26, B=90)	-55,6	-42,9	-68,0	7,0	°C
TT_26 (R=5,205, Z=2,6, B=90)	-141,8	-125,5	-152,7	7,5	°C
TT_27 (R=5,205, Z=6,25, B=90)	-140,4	-122,2	-152,3	8,2	°C
TT_28 (R=5,205, Z=11,5, B=90)	-130,9	-111,0	-142,4	9,1	°C



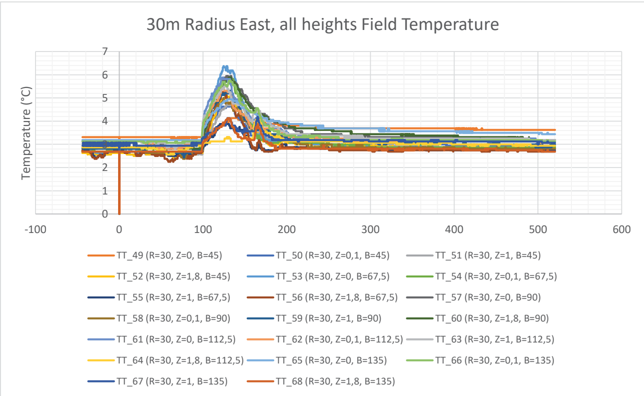


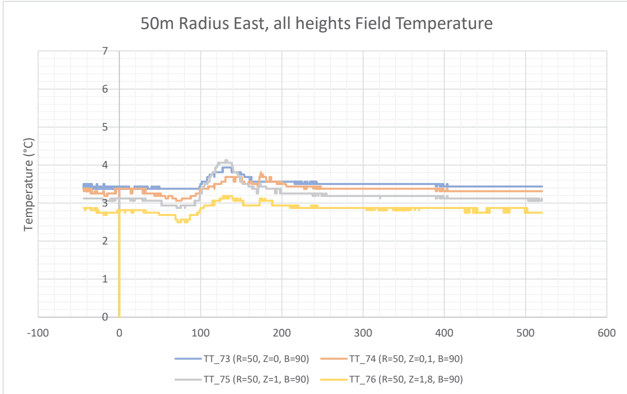


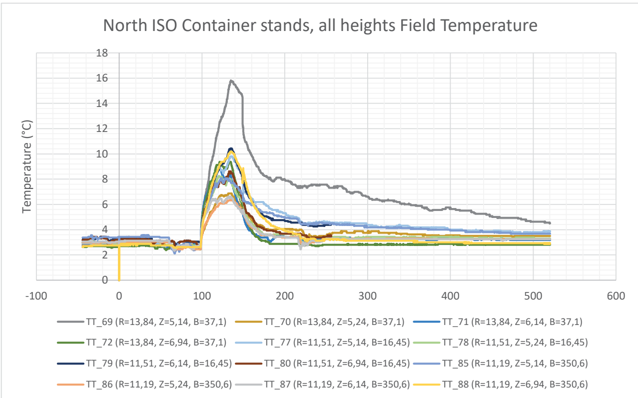
Field Temperature

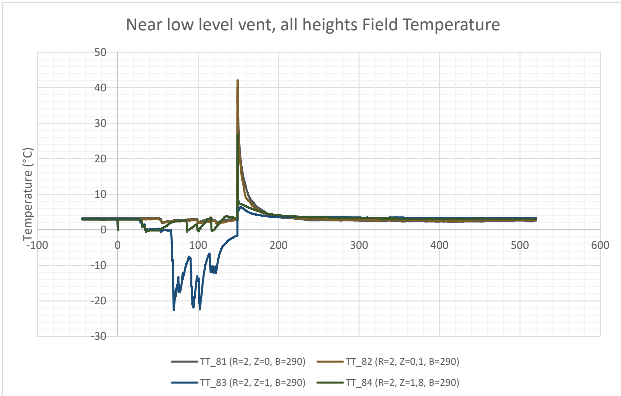
Notes: No significant temperature drop in the field or on top of ISO containers.Low temps registered near low level vent

Test Name	Test14		FOR AVERAGING		
Hole Size	13	mm	Start	50	sec
Orientation	Downwards		End	120	sec









Sensor	Average	Max	Min	STDEV	units
TT_49 (R=30, Z=0, B=45)	3,4	3,8	3,3	0,1	°C
TT_50 (R=30, Z=0,1, B=45)	3,0	4,5	2,4	0,6	°C
TT_51 (R=30, Z=1, B=45)	2,9	4,3	2,5	0,5	°C
TT_52 (R=30, Z=1,8, B=45)	3,0	4,9	2,4	0,7	°C
TT_53 (R=30, Z=0, B=67,5)	3,2	5,9	2,6	1,0	°C
TT_54 (R=30, Z=0,1, B=67,5)	3,2	5,5	2,6	0,9	°C
TT_55 (R=30, Z=1, B=67,5)	2,8	3,8	2,5	0,4	°C
TT_56 (R=30, Z=1,8, B=67,5)	2,9	4,9	2,3	0,8	°C
TT_57 (R=30, Z=0, B=90)	3,4	5,4	2,8	0,8	°C
TT_58 (R=30, Z=0,1, B=90)	3,1	4,8	2,4	0,7	°C
TT_59 (R=30, Z=1, B=90)	3,1	5,0	2,4	0,8	°C
TT_60 (R=30, Z=1,8, B=90)	3,3	5,3	2,8	0,8	°C
TT_61 (R=30, Z=0, B=112,5)	3,5	5,6	2,8	1,0	°C
TT_62 (R=30, Z=0,1, B=112,5)	3,4	5,1	2,8	0,7	°C
TT_63 (R=30, Z=1, B=112,5)	3,5	5,3	2,8	0,8	°C
TT_64 (R=30, Z=1,8, B=112,5)	2,9	3,1	2,6	0,2	°C
TT_65 (R=30, Z=0, B=135)	3,5	4,6	3,2	0,5	°C
TT_66 (R=30, Z=0,1, B=135)	3,6	5,4	3,1	0,8	°C
TT_67 (R=30, Z=1, B=135)	3,1	3,8	2,9	0,3	°C
TT_68 (R=30, Z=1,8, B=135)	2,9	3,8	2,7	0,3	°C
TT_69 (R=13,84, Z=5,14, B=37,1)	4,5	12,0	2,7	2,9	°C
TT_70 (R=13,84, Z=5,24, B=37,1)	3,5	6,4	2,6	1,2	°C
TT_71 (R=13,84, Z=6,14, B=37,1)	4,1	8,8	2,5	2,1	°C
TT_72 (R=13,84, Z=6,94, B=37,1)	4,0	9,1	2,4	2,3	°C
TT_73 (R=50, Z=0, B=90)	3,5	3,8	3,4	0,1	°C
TT_74 (R=50, Z=0,1, B=90)	3,2	3,5	3,1	0,1	°C
TT_75 (R=50, Z=1, B=90)	3,1	3,9	2,9	0,3	°C
TT_76 (R=50, Z=1,8, B=90)	2,7	3,1	2,5	0,2	°C
TT_77 (R=11,51, Z=5,14, B=16,45)	3,9	8,7	2,4	2,0	°C
TT_78 (R=11,51, Z=5,24, B=16,45)	3,8	8,2	2,6	1,7	°C
TT_79 (R=11,51, Z=6,14, B=16,45)	4,2	8,8	2,8	1,9	°C
TT_80 (R=11,51, Z=6,94, B=16,45)	4,0	7,6	2,4	1,7	°C
TT_81 (R=2, Z=0, B=290)	2,7	3,3	1,8	0,3	°C
TT_82 (R=2, Z=0,1, B=290)	2,4	3,0	1,8	0,2	°C
TT_83 (R=2, Z=1, B=290)	-10,3	0,3	-22,6	6,9	°C
TT_84 (R=2, Z=1,8, B=290)	1,4	3,5	-0,6	1,1	°C
TT_85 (R=11,19, Z=5,14, B=350,6)	3,8	7,7	2,1	1,7	°C
TT_86 (R=11,19, Z=5,24, B=350,6)	3,3	5,9	2,4	1,1	°C
TT_87 (R=11,19, Z=6,14, B=350,6)	3,6	6,4	2,3	1,4	°C
TT_88 (R=11,19, Z=6,94, B=350,6)	3,9	8,9	2,6	2,0	°C

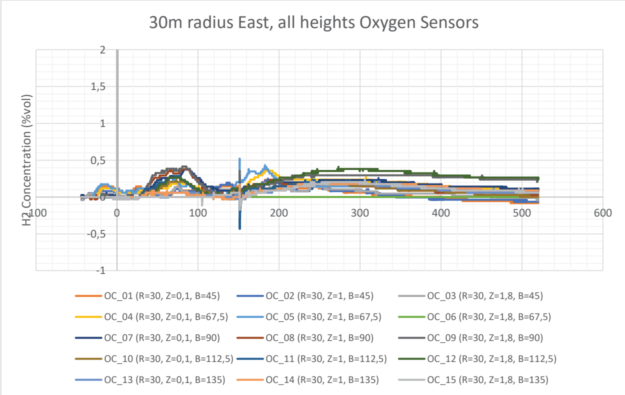
DNV·GL

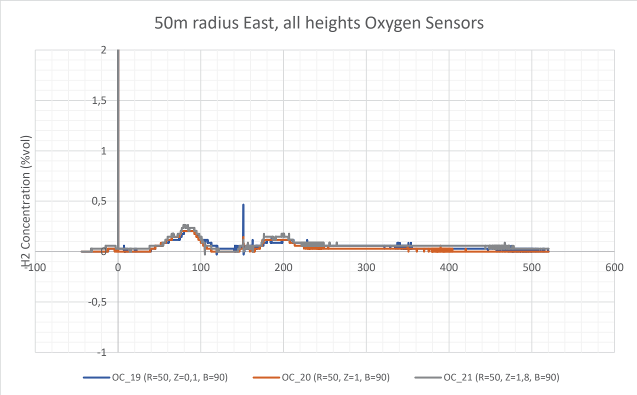
Gas Concentrations

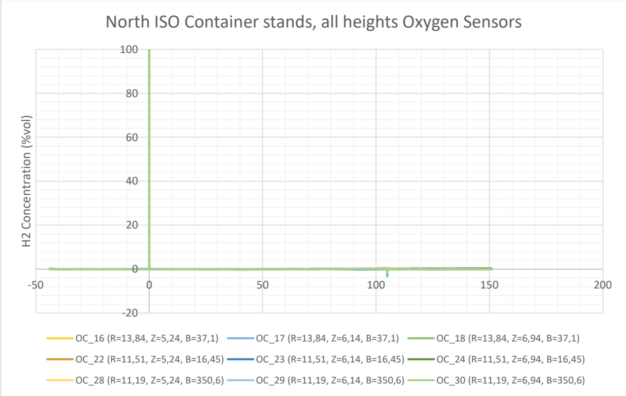
Test Name	Test14		FOR AVERAGING		
Hole Size	13	mm	Start	50	sec
Orientation	Downwards		End	120	sec

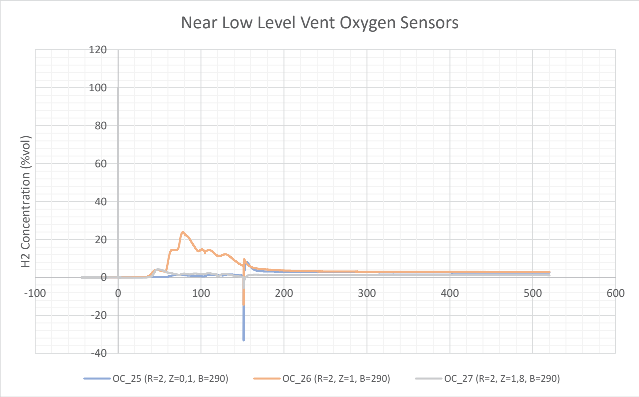
Notes: No H2 detected in the field. H2 detected near low level vent at the beginning of the release. Very high concentrations within the TCS. Sensors were likely affected by cold temperatures, so decay measurements are likely affected. Correction to be applied if possible.

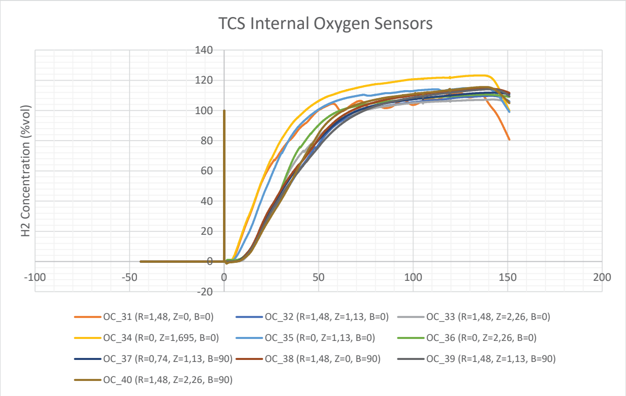
Sensor	Average	Max	Min	STDEV	units
OC_01 (R=30, Z=0,1, B=45)	0,1	0,1	-0,1	0,0	%vol
OC_02 (R=30, Z=1, B=45)	0,1	0,1	0,0	0,0	%vol
OC_03 (R=30, Z=1,8, B=45)	0,1	0,1	-0,1	0,0	%vol
OC_04 (R=30, Z=0,1, B=67,5)	0,1	0,2	0,0	0,0	%vol
OC_05 (R=30, Z=1, B=67,5)	0,1	0,2	0,0	0,1	%vol
OC_06 (R=30, Z=1,8, B=67,5)	0,0	0,0	0,0	0,0	%vol
OC_07 (R=30, Z=0,1, B=90)	0,3	0,4	0,1	0,1	%vol
OC_08 (R=30, Z=1, B=90)	0,3	0,4	0,1	0,1	%vol
OC_09 (R=30, Z=1,8, B=90)	0,3	0,4	0,0	0,1	%vol
OC_10 (R=30, Z=0,1, B=112,5)	0,1	0,2	0,0	0,1	%vol
OC_11 (R=30, Z=1, B=112,5)	0,2	0,3	0,0	0,1	%vol
OC_12 (R=30, Z=1,8, B=112,5)	0,2	0,3	0,0	0,1	%vol
OC_13 (R=30, Z=0,1, B=135)	0,0	0,1	0,0	0,0	%vol
OC_14 (R=30, Z=1, B=135)	0,0	0,1	-0,1	0,0	%vol
OC_15 (R=30, Z=1,8, B=135)	0,0	0,1	-0,1	0,0	%vol
OC_16 (R=13,84, Z=5,24, B=37,1)	0,0	0,5	-2,7	0,1	%vol
OC_17 (R=13,84, Z=6,14, B=37,1)	0,0	0,7	-3,3	0,1	%vol
OC_18 (R=13,84, Z=6,94, B=37,1)	0,0	0,1	-0,1	0,0	%vol
OC_19 (R=50, Z=0,1, B=90)	0,1	0,2	0,0	0,0	%vol
OC_20 (R=50, Z=1, B=90)	0,1	0,2	0,0	0,1	%vol
OC_21 (R=50, Z=1,8, B=90)	0,1	0,3	0,0	0,1	%vol
OC_22 (R=11,51, Z=5,24, B=16,45)	0,1	0,2	-0,1	0,1	%vol
OC_23 (R=11,51, Z=6,14, B=16,45)	0,0	0,2	-0,9	0,1	%vol
OC_24 (R=11,51, Z=6,94, B=16,45)	0,1	0,4	-0,6	0,2	%vol
OC_25 (R=2, Z=0,1, B=290)	0,9	1,4	0,2	0,4	%vol
OC_26 (R=2, Z=1, B=290)	14,3	23,9	3,1	5,4	%vol
OC_27 (R=2, Z=1,8, B=290)	2,1	4,2	0,8	0,6	%vol
OC_28 (R=11,19, Z=5,24, B=350,6)	0,1	0,7	-1,3	0,2	%vol
OC_29 (R=11,19, Z=6,14, B=350,6)	0,1	0,4	-0,7	0,2	%vol
OC_30 (R=11,19, Z=6,94, B=350,6)	0,0	0,5	-1,8	0,1	%vol
OC_31 (R=1,48, Z=0, B=0)	104,5	111,1	99,5	2,6	%vol
OC_32 (R=1,48, Z=1,13, B=0)	100,2	108,4	77,4	7,4	%vol
OC_33 (R=1,48, Z=2,26, B=0)	100,4	106,8	82,7	6,1	%vol
OC_34 (R=0, Z=1,695, B=0)	117,1	122,2	106,3	4,3	%vol
OC_35 (R=0, Z=1,13, B=0)	110,4	114,1	100,7	3,3	%vol
OC_36 (R=0, Z=2,26, B=0)	104,4	109,6	90,2	4,5	%vol
OC_37 (R=0,74, Z=1,13, B=90)	101,9	110,4	80,3	7,6	%vol
OC_38 (R=1,48, Z=0, B=90)	104,1	113,4	81,1	8,1	%vol
OC_39 (R=1,48, Z=1,13, B=90)	101,3	112,7	75,8	9,6	%vol
OC_40 (R=1,48, Z=2,26, B=90)	105,9	114,4	84,6	7,0	%vol











Pipe Conditions

Notes

Two releases were performed, after first release data on gas concentration decay at different location within the closed room was collected.
Following the second time, concentration level near ignitor location was monitored. As concentration decay was slow it was agreed to ignite mixture when concentration fell to 50%vol.
P04 and PT04 non-functioning after explosion event in Test14.

Test Name	Test15	
Hole Size	13	mm
Orientation	Downwards	

FOR PLOTS

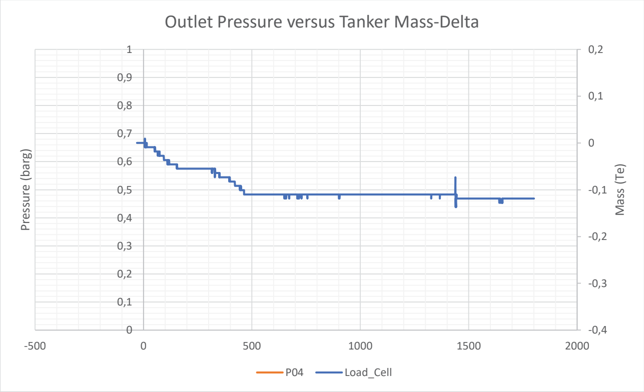
Start Time	-30	sec
End Time	1800	sec

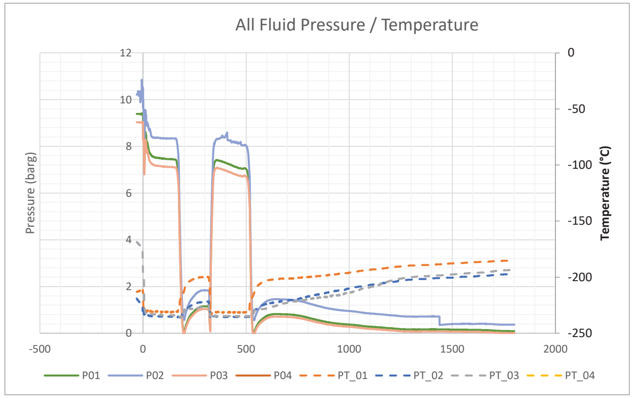
Date 17.01.2020

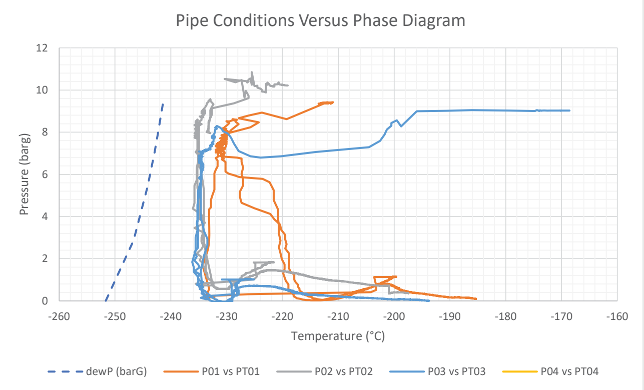
FOR AVERAGING

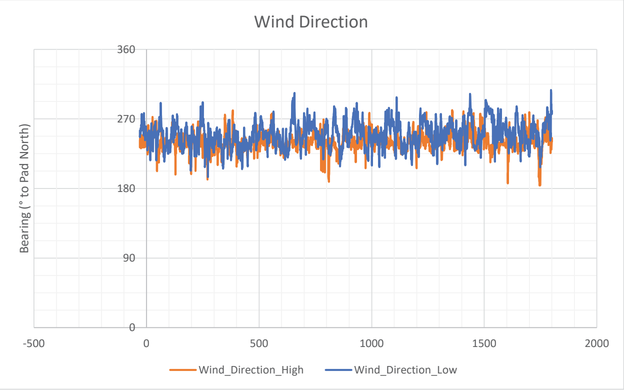
Start	380	sec
End	480	sec

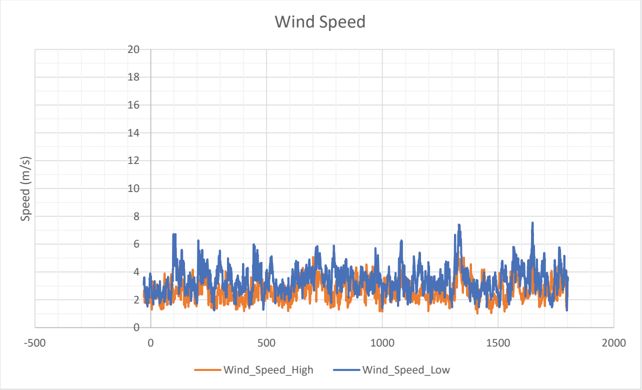
Sensor	Average	Max	Min	STDEV	units
Load_Cell		-0,073	-0,110		Te
P01	7,19	7,36	7,04	0,10	Barg
P02	8,25	8,60	8,05	0,13	Barg
P03	6,86	7,03	6,71	0,10	Barg
P04					Barg
PT_01	-231,3	-230,8	-231,9	0,2	°C
PT_02	-235,4	-235,3	-235,6	0,2	°C
PT_03	-234,7	-234,6	-234,9	0,1	°C
PT_04					°C
MassFlow	0,410				kg/s
Wind_Direction_High	237,8	281,1	208,3	11,4	0,0
Wind_Direction_Low	238,8	271,6	205,0	12,9	Deg
Wind_Speed_High	2,3	3,9	1,2	0,6	m/s
Wind_Speed_Low	3,4	6,0	1,6	1,1	m/s









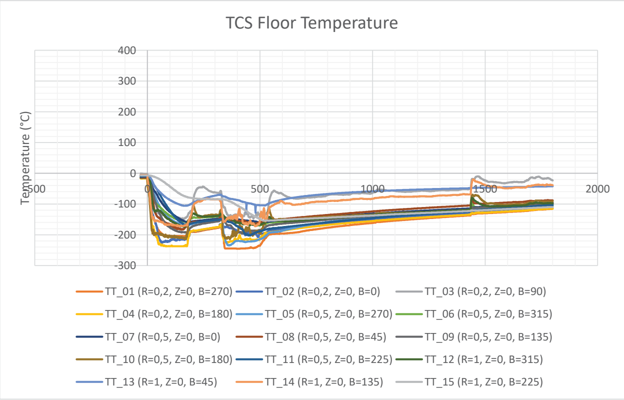


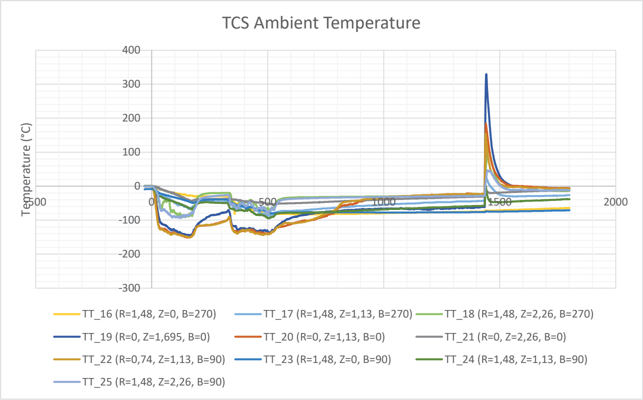
TCS Temperature

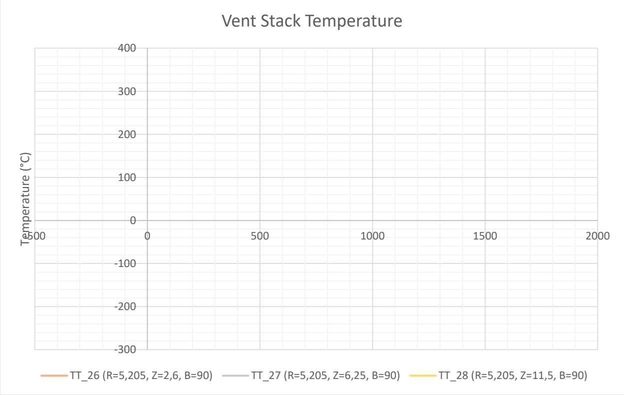
Test Name	Test15		FOR AVERAGING		
Hole Size	13	mm	Start	380	sec
Orientation	Downwards		End	480	sec

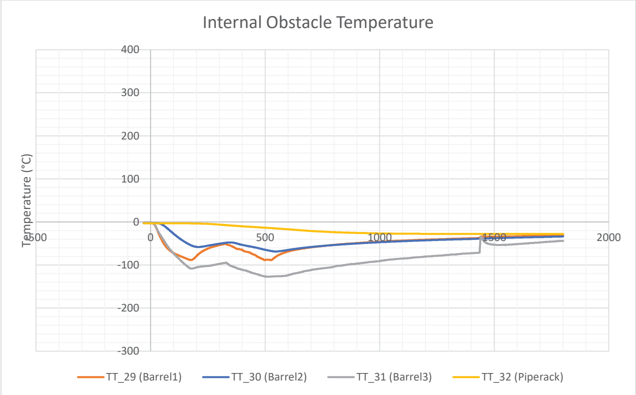
Notes: Liquid H2 observed on TCS floor surface @0.2m. No stack after explosion event in Test14. Flame registered in chamber ~1440s.

Sensor	Average	Max	Min	STDEV	units
TT_01 (R=0,2, Z=0, B=270)	-244,0	-240,4	-245,1	1,2	°C
TT_02 (R=0,2, Z=0, B=0)	-192,6	-179,9	-202,1	5,5	°C
TT_03 (R=0,2, Z=0, B=90)	-137,0	-127,3	-147,8	4,1	°C
TT_04 (R=0,2, Z=0, B=180)	-214,3	-200,3	-219,9	3,7	°C
TT_05 (R=0,5, Z=0, B=270)	-221,7	-219,8	-227,9	1,5	°C
TT_06 (R=0,5, Z=0, B=315)	-160,3	-150,9	-170,4	5,5	°C
TT_07 (R=0,5, Z=0, B=0)	-152,8	-148,9	-156,7	2,7	°C
TT_08 (R=0,5, Z=0, B=45)	-157,9	-153,4	-165,1	3,5	°C
TT_09 (R=0,5, Z=0, B=135)	-189,6	-178,9	-196,1	3,3	°C
TT_10 (R=0,5, Z=0, B=180)	-187,9	-167,3	-204,6	9,7	°C
TT_11 (R=0,5, Z=0, B=225)	-186,8	-162,8	-202,4	13,0	°C
TT_12 (R=1, Z=0, B=315)	-163,4	-153,1	-169,9	3,9	°C
TT_13 (R=1, Z=0, B=45)	-94,0	-84,1	-128,1	7,0	°C
TT_14 (R=1, Z=0, B=135)	-152,5	-115,1	-172,6	14,4	°C
TT_15 (R=1, Z=0, B=225)	-118,8	-96,3	-141,4	13,5	°C
TT_16 (R=1,48, Z=0, B=270)	-68,0	-53,4	-78,9	6,5	°C
TT_17 (R=1,48, Z=1,13, B=270)	-67,0	-60,3	-84,3	7,2	°C
TT_18 (R=1,48, Z=2,26, B=270)	-52,3	-40,1	-72,0	9,7	°C
TT_19 (R=0, Z=1,695, B=0)	-127,5	-122,6	-133,5	3,3	°C
TT_20 (R=0, Z=1,13, B=0)	-132,7	-127,6	-138,2	3,2	°C
TT_21 (R=0, Z=2,26, B=0)	-45,8	-41,1	-49,7	2,0	°C
TT_22 (R=0,74, Z=1,13, B=90)	-135,1	-128,3	-143,4	4,8	°C
TT_23 (R=1,48, Z=0, B=90)	-64,5	-56,9	-71,7	4,5	°C
TT_24 (R=1,48, Z=1,13, B=90)	-76,9	-68,3	-85,9	6,0	°C
TT_25 (R=1,48, Z=2,26, B=90)	-58,9	-46,8	-73,3	7,5	°C
TT_26 (R=5,205, Z=2,6, B=90)					°C
TT_27 (R=5,205, Z=6,25, B=90)					°C
TT_28 (R=5,205, Z=11,5, B=90)					°C
TT_29 (Barrel1)	-71,9	-62,8	-84,1	6,4	°C
TT_30 (Barrel2)	-56,5	-50,8	-62,3	3,2	°C
TT_31 (Barrel3)	-115,9	-107,9	-124,0	4,7	°C
TT_32 (Piperack)	-11,1	-9,4	-12,7	1,0	°C





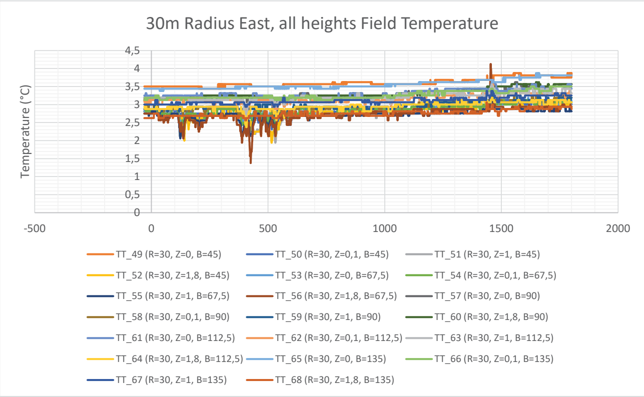


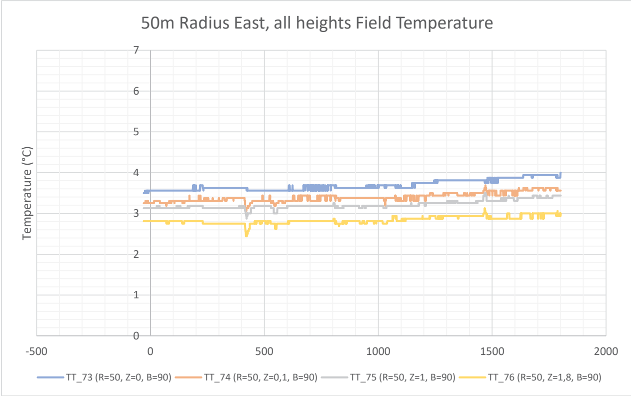


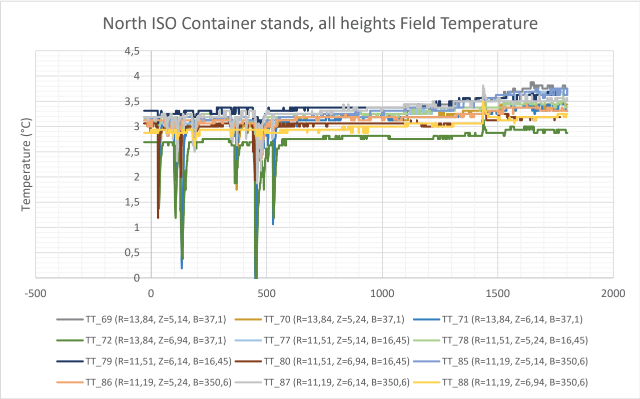
Notes: No significant temperature drop in the field >~1°C. Nothing greater than -3°C on top of ISO containers. Low temps registered near low level vent prior to ignition.

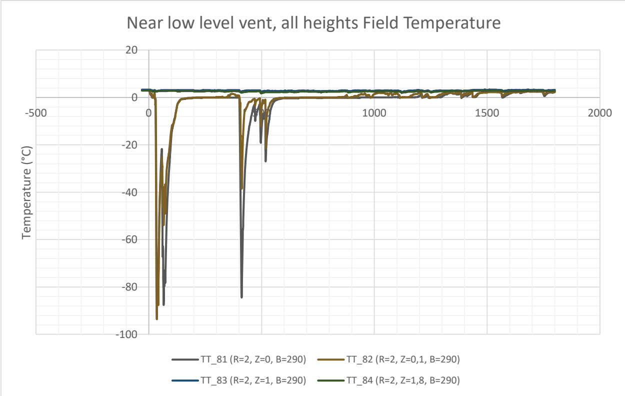
Field Temperature

Test Name	Test15			FOR AVERAGING		
Hole Size	13	mm	Start	380	sec
Orientation	Downwards		End	480	sec









Sensor	Average	Max	Min	STDEV	units
TT_49 (R=30, Z=0, B=45)	3,5	3,6	3,5	0,0	°C
TT_50 (R=30, Z=0,1, B=45)	2,6	2,9	2,5	0,1	°C
TT_51 (R=30, Z=1, B=45)	2,4	2,7	2,2	0,2	°C
TT_52 (R=30, Z=1,8, B=45)	2,4	2,6	2,2	0,2	°C
TT_53 (R=30, Z=0, B=67,5)	2,7	2,9	2,5	0,1	°C
TT_54 (R=30, Z=0,1, B=67,5)	2,7	2,9	2,4	0,1	°C
TT_55 (R=30, Z=1, B=67,5)	2,5	2,8	2,1	0,2	°C
TT_56 (R=30, Z=1,8, B=67,5)	2,3	2,7	1,4	0,3	°C
TT_57 (R=30, Z=0, B=90)	3,2	3,3	3,1	0,0	°C
TT_58 (R=30, Z=0,1, B=90)	2,8	3,0	2,6	0,1	°C
TT_59 (R=30, Z=1, B=90)	2,9	3,0	2,7	0,1	°C
TT_60 (R=30, Z=1,8, B=90)	3,2	3,3	3,2	0,0	°C
TT_61 (R=30, Z=0, B=112,5)	3,1	3,3	2,6	0,2	°C
TT_62 (R=30, Z=0,1, B=112,5)	3,0	3,1	2,4	0,2	°C
TT_63 (R=30, Z=1, B=112,5)	3,1	3,2	2,6	0,1	°C
TT_64 (R=30, Z=1,8, B=112,5)	2,8	2,9	2,4	0,1	°C
TT_65 (R=30, Z=0, B=135)	3,5	3,5	3,4	0,0	°C
TT_66 (R=30, Z=0,1, B=135)	3,2	3,2	3,2	0,0	°C
TT_67 (R=30, Z=1, B=135)	3,0	3,1	2,9	0,0	°C
TT_68 (R=30, Z=1,8, B=135)	2,7	2,8	2,6	0,0	°C
TT_69 (R=13,84, Z=5,14, B=37,1)	2,9	3,1	2,4	0,2	°C
TT_70 (R=13,84, Z=5,24, B=37,1)	2,8	3,1	1,5	0,4	°C
TT_71 (R=13,84, Z=6,14, B=37,1)	2,6	3,1	-0,3	0,8	°C
TT_72 (R=13,84, Z=6,94, B=37,1)	2,2	2,7	-0,4	0,8	°C
TT_73 (R=50, Z=0, B=90)	3,6	3,6	3,6	0,0	°C
TT_74 (R=50, Z=0,1, B=90)	3,3	3,4	3,1	0,1	°C
TT_75 (R=50, Z=1, B=90)	3,1	3,2	2,9	0,1	°C
TT_76 (R=50, Z=1,8, B=90)	2,7	2,8	2,4	0,1	°C
TT_77 (R=11,51, Z=5,14, B=16,45)	3,1	3,2	2,8	0,1	°C
TT_78 (R=11,51, Z=5,24, B=16,45)	3,0	3,2	2,4	0,2	°C
TT_79 (R=11,51, Z=6,14, B=16,45)	3,3	3,4	3,0	0,1	°C
TT_80 (R=11,51, Z=6,94, B=16,45)	2,9	3,1	1,9	0,2	°C
TT_81 (R=2, Z=0, B=290)	-18,3	-0,1	-84,4	21,6	°C
TT_82 (R=2, Z=0,1, B=290)	-5,0	1,3	-38,5	8,7	°C
TT_83 (R=2, Z=1, B=290)	2,9	3,1	2,4	0,2	°C
TT_84 (R=2, Z=1,8, B=290)	2,5	2,7	2,1	0,2	°C
TT_85 (R=11,19, Z=5,14, B=350,6)	3,1	3,2	2,6	0,1	°C
TT_86 (R=11,19, Z=5,24, B=350,6)	2,9	3,1	2,3	0,3	°C
TT_87 (R=11,19, Z=6,14, B=350,6)	3,1	3,3	1,9	0,3	°C
TT_88 (R=11,19, Z=6,94, B=350,6)	2,9	2,9	2,8	0,0	°C

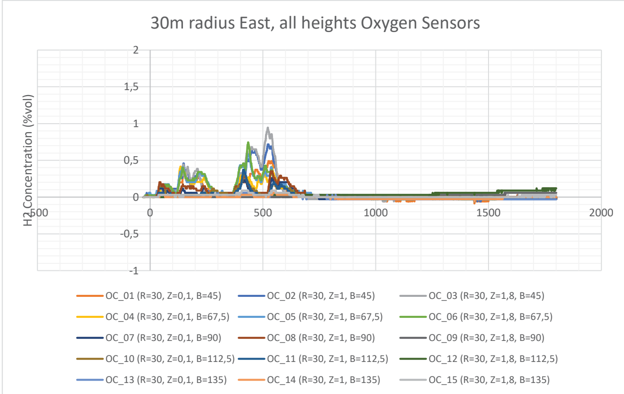
DNV·GL

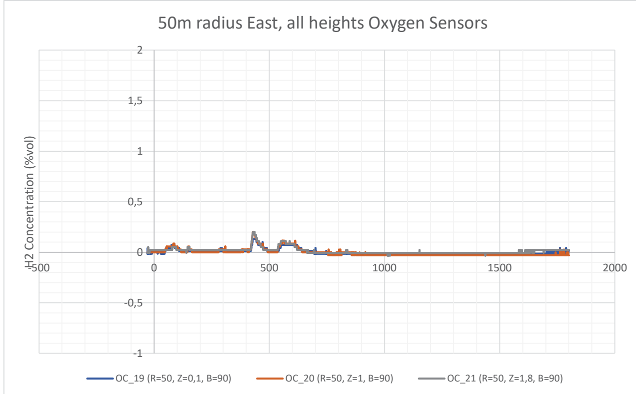
Gas Concentrations

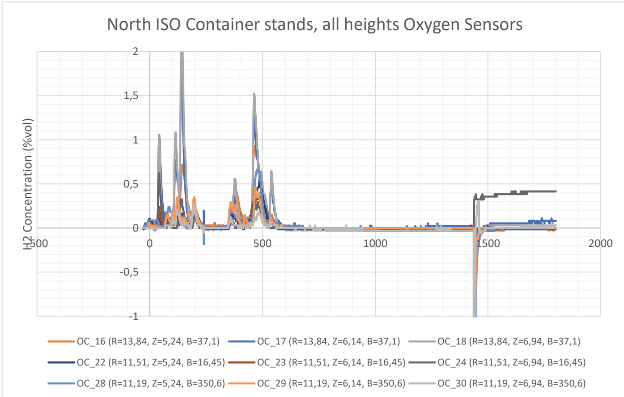
Test Name	Test15			FOR AVERAGING		
Hole Size	13	mm		Start	380	sec
Orientation	Downwards			End	480	sec

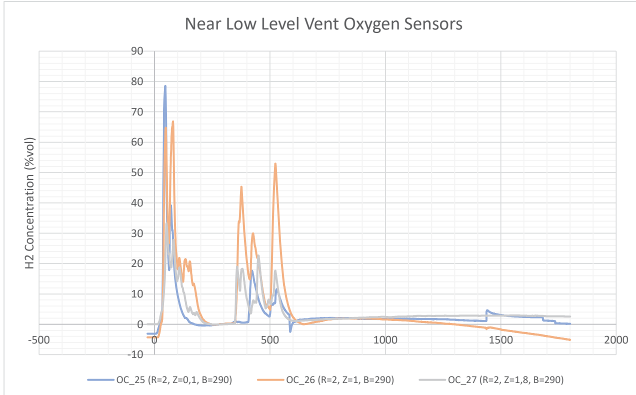
Notes: V.low levels (<1%vol) of H2 detected in field. H2 detected near low level vent throughout release, linear correction applied for second flow period to OC26, See 'Plot Data' tab for more details. Very high concentrations within the TCS. TCS O2 sensors non-functioning after explosion event in Test14. Included plot from H2 analyser showing ignition at ~1440s whilst SP02 was reporting ~50%vol

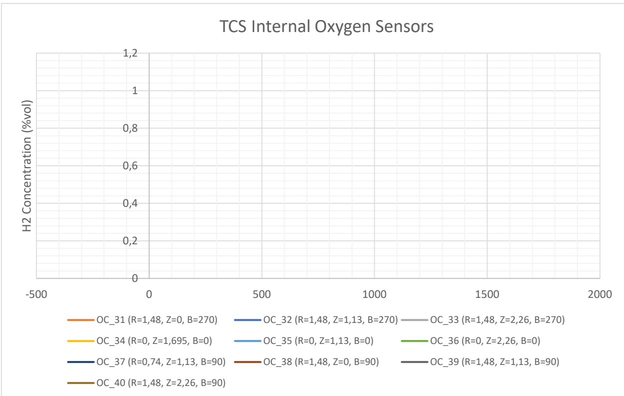
Sensor	Average	Max	Min	STDEV	units
OC_01 (R=30, Z=0,1, B=45)	0,2	0,4	0,1	0,1	%vol
OC_02 (R=30, Z=1, B=45)	0,4	0,6	0,1	0,2	%vol
OC_03 (R=30, Z=1,8, B=45)	0,5	0,7	0,1	0,2	%vol
OC_04 (R=30, Z=0,1, B=67,5)	0,2	0,3	0,1	0,1	%vol
OC_05 (R=30, Z=1, B=67,5)	0,4	0,6	0,1	0,1	%vol
OC_06 (R=30, Z=1,8, B=67,5)	0,4	0,7	0,2	0,1	%vol
OC_07 (R=30, Z=0,1, B=90)	0,1	0,2	0,0	0,1	%vol
OC_08 (R=30, Z=1, B=90)	0,2	0,3	0,1	0,1	%vol
OC_09 (R=30, Z=1,8, B=90)	0,0	0,0	0,0	0,0	%vol
OC_10 (R=30, Z=0,1, B=112,5)	0,2	0,3	0,1	0,1	%vol
OC_11 (R=30, Z=1, B=112,5)	0,1	0,4	0,0	0,1	%vol
OC_12 (R=30, Z=1,8, B=112,5)	0,0	0,0	0,0	0,0	%vol
OC_13 (R=30, Z=0,1, B=135)	0,0	0,1	0,0	0,0	%vol
OC_14 (R=30, Z=1, B=135)	0,0	0,0	0,0	0,0	%vol
OC_15 (R=30, Z=1,8, B=135)	0,1	0,1	0,0	0,0	%vol
OC_16 (R=13,84, Z=5,24, B=37,1)	0,3	0,9	0,1	0,3	%vol
OC_17 (R=13,84, Z=6,14, B=37,1)	0,3	1,3	0,1	0,4	%vol
OC_18 (R=13,84, Z=6,94, B=37,1)	0,4	1,5	0,0	0,5	%vol
OC_19 (R=50, Z=0,1, B=90)	0,1	0,1	0,0	0,0	%vol
OC_20 (R=50, Z=1, B=90)	0,1	0,2	0,0	0,1	%vol
OC_21 (R=50, Z=1,8, B=90)	0,1	0,2	0,0	0,1	%vol
OC_22 (R=11,51, Z=5,24, B=16,45)	0,1	0,5	0,0	0,1	%vol
OC_23 (R=11,51, Z=6,14, B=16,45)	0,1	0,4	0,0	0,1	%vol
OC_24 (R=11,51, Z=6,94, B=16,45)	0,1	0,3	0,0	0,1	%vol
OC_25 (R=2, Z=0,1, B=290)	7,0	17,7	0,5	5,6	%vol
OC_26 (R=2, Z=1, B=290)	21,1	40,8	6,7	7,7	%vol
OC_27 (R=2, Z=1,8, B=290)	10,6	22,7	3,5	5,3	%vol
OC_28 (R=11,19, Z=5,24, B=350,6)	0,2	0,7	0,0	0,2	%vol
OC_29 (R=11,19, Z=6,14, B=350,6)	0,1	0,5	0,0	0,1	%vol
OC_30 (R=11,19, Z=6,94, B=350,6)	0,0	0,2	0,0	0,0	%vol
OC_31 (R=1,48, Z=0, B=270)					%vol
OC_32 (R=1,48, Z=1,13, B=270)					%vol
OC_33 (R=1,48, Z=2,26, B=270)					%vol
OC_34 (R=0, Z=1,695, B=0)					%vol
OC_35 (R=0, Z=1,13, B=0)					%vol
OC_36 (R=0, Z=2,26, B=0)					%vol
OC_37 (R=0,74, Z=1,13, B=90)					%vol
OC_38 (R=1,48, Z=0, B=90)					%vol
OC_39 (R=1,48, Z=1,13, B=90)					%vol
OC_40 (R=1,48, Z=2,26, B=90)					%vol



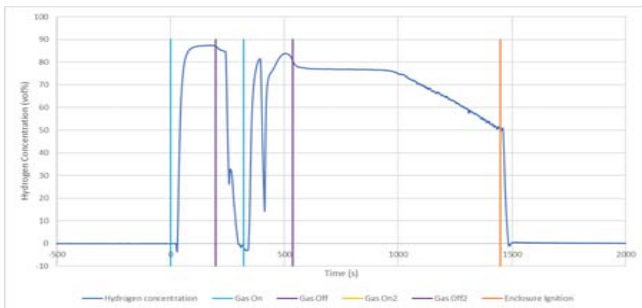








H2 Concentration from SP02 at time of ignition:



About FFI

The Norwegian Defence Research Establishment (FFI) was founded 11th of April 1946. It is organised as an administrative agency subordinate to the Ministry of Defence.

FFI's MISSION

FFI is the prime institution responsible for defence related research in Norway. Its principal mission is to carry out research and development to meet the requirements of the Armed Forces. FFI has the role of chief adviser to the political and military leadership. In particular, the institute shall focus on aspects of the development in science and technology that can influence our security policy or defence planning.

FFI's VISION

FFI turns knowledge and ideas into an efficient defence.

FFI's CHARACTERISTICS

Creative, daring, broad-minded and responsible.

Om FFI

Forsvarets forskningsinstitutt ble etablert 11. april 1946. Instituttet er organisert som et forvaltningsorgan med særskilte fullmakter underlagt Forsvarsdepartementet.

FFIs FORMÅL

Forsvarets forskningsinstitutt er Forsvarets sentrale forskningsinstitusjon og har som formål å drive forskning og utvikling for Forsvarets behov. Videre er FFI rådgiver overfor Forsvarets strategiske ledelse. Spesielt skal instituttet følge opp trekk ved vitenskapelig og militærteknisk utvikling som kan påvirke forutsetningene for sikkerhetspolitikken eller forsvarsplanleggingen.

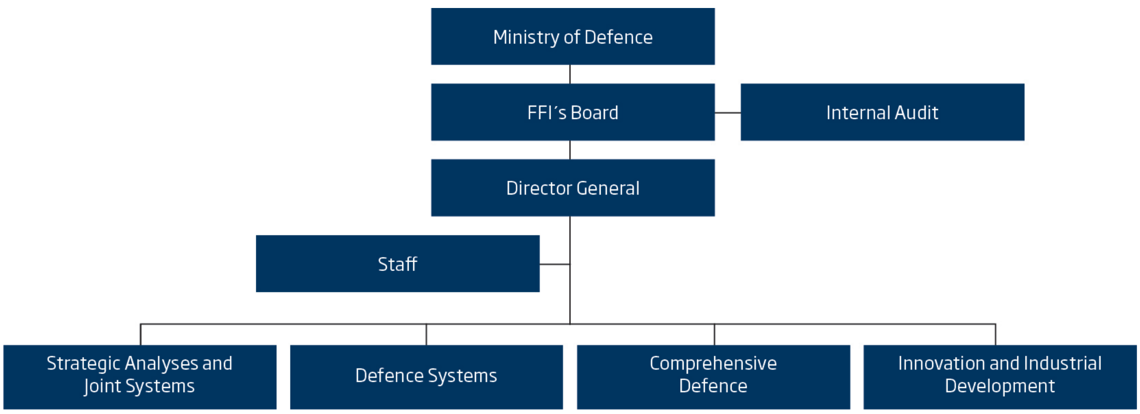
FFIs VISJON

FFI gjør kunnskap og ideer til et effektivt forsvar.

FFIs VERDIER

Skapende, drivende, vidsynt og ansvarlig.

FFI's organisation



Forsvarets forskningsinstitutt
Postboks 25
2027 Kjeller

Besøksadresse:
Instituttveien 20
2007 Kjeller

Telefon: 63 80 70 00
Telefaks: 63 80 71 15
Epost: ffi@ffi.no

Norwegian Defence Research Establishment (FFI)
P.O. Box 25
NO-2027 Kjeller

Office address:
Instituttveien 20
N-2007 Kjeller

Telephone: +47 63 80 70 00
Telefax: +47 63 80 71 15
Email: ffi@ffi.no

FFI Forsvarets forskningsinstitutt