Ref. Ares(2018)1141793 - 28/02/2018

GRACE grant no 679266

# Experimental technical report for in-situ burning of oil on sea ice based on initial results

D4.2

WP4: Combat of oil spill in coastal arctic water - effectiveness and environmental effects

Prepared under contract from the European Commission

Contract n° 679266

Research and Innovation Action

Innovation and Networks Executive Agency

Horizon 2020 BG-2014-2015/BG2015-2

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|---|---|
| Project acronym: | GRACE |
| Project full title: | Integrated oil spill response actions and environmental effects |
| Start of the project: | 01 March 2016 |
| Duration: | 42 months |
| Project coordinator: | Finnish Environment Institute (SYKE) |
| Project website | http://www.grace-oil-project.eu |

| | |
|---|---|
| Deliverable title: | Experimental technical report for in-situ burning of oil on sea ice based on initial results |
| Deliverable n°: | D4.2 |
| Nature of the deliverable: | Report |
| Dissemination level: | Public |

| | |
|---|---|
| WP responsible: | WP4 |
| Lead beneficiary: | AU |

| | |
|---|---|
| Due date of deliverable: | 28th February 2018 |
| Actual submission date: | 28th February 2018 |

Deliverable status:

| Version | Status | Date | Author | Approved by |
|---|---|---|---|---|
| 1.0 | draft | 27th February 2018 | Chris Petrich<br>Kim Gustavson<br>Janne Fritt-Rasmussen | Kim Gustavson<br>28.2.2018 |
| 1.0 | final | 28th February 2018 | | Steering group<br>28th February 2018 |

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## Executive Summary

In situ burning is one of the countermeasures available for responding to oil spills. This report summarizes the experience of a dry run and first test burn of Troll B Crude oil in a simulated melt pond on ice. The purpose of the experiment is to determine the heat flux into the ice. In a sea ice environment, such heat flux induces a positive feedback on the burn by increasing the rate of oil release to the surface.

Experiments took place at the Roskilde campus of Aarhus University. The dry run of took place on 6 October 2017 and a subsequent first experimental burn performed on 24 October 2017. Procedures for ice growth were improved based on the experiences of the first burn. A series of burns to verify this was performed on 15 and 16 November 2017. The final burns are planned for March 2018.

## Background

In situ burning is one of the countermeasures available for responding to oil spills in marine but also in other environments e.g. ice/snow, freshwater, marshes. During an in situ burning operation the oil is ignited on the sea surface and through this burning, the oil volume is substantially reduced. The method has been hardly ever used, until 2010 during the Deepwater Horizon incident in the Gulf of Mexico, where between 220,000 and 310,000 barrels of oil where burned during more than 400 burns (Mabile 2012). In situ burning has also been found to be an effective measure for oil spills in Arctic ice filled conditions (e.g. Sørstrøm et al. 2010).

The principle behind *in situ* burning is that the spilled oil is ignited directly on the spill site. To do so, it requires oxygen, a thick (> 1 cm) and relatively fresh oil slick and an igniter that is able to heat the oil to its fire point. The fire point is the temperature where the oil is warm enough to release sufficient vapours to maintain continuous burning (as burning is related to the vapour phase) and typically a few degrees above the flash point (Buist et al. 2013). The oil is thickened by either fire-resistant booms or in ice conditions the ice can act as the containment. Chemical herding agents have also been shown to be able to contract the oil to ignitable thicknesses.

The present measurements are designed to measure the energy feedback from the flame into the ice. The technical background of the experiments was summarized by Fritt-Rasmussen and Petrich (2017). Measurement of energy transfer is achieved by means of temperature measurements in the oil, meltwater, and ice during the burn, and measurements of surface ablation of the ice. This report is on experiences of a dry run (i.e., without ignition) and the first test burn performed in October 2017. The final experiments are set to take place in spring 2018.

## Methods

### Ice Preparation

Ice was grown in slanted metal pans 1.0 x 1.0 m x 0.3 m, filled with tap water to 0.05 m below the upper rim. A thermocouple probe was built from high-temperature K-Type thermocouple (TC) wire with a vertical arrangement of TCs placed at the center of the tank. The TCs were held in place by feeding them through horizontal holes in a vertical support wooden support pole. TCs that were supposed to record temperatures in the ice were mounted before the probe was installed in the water with the remaining TCs mounted after ice formation shortly before the burn. The wires of the ice TCs were routed along the bottom of the tank to the edge where they left the tank at the surface (Figure 1).

In order to obtain a circular oil pan with well-defined edges, a rubber baking form was added into the water surface prior to onset of freezing. A hole was cut in the center of the form to allow the temperature support pole to penetrate. The form, including the containing ice, was easily removed after ice formation (Figure 2).

Ice was grown at -20 °C air temperature in a commercial refrigeration cargo container (cf. Figure 1).

After removal of the form, thermocouples were inserted into the support through pre-drilled holes. These TCs covered the range through the thickness of the oil lens into the air above (Figure 3). Additional thermocouples were mounted higher above the oil pan from sideways support poles in order to record flame temperatures.

Figure 1. Simultaneous ice growth for multiple experiments in the cold room. Wires of the thermocouples measuring ice temperatures (green) can be seen to emerge at the left hand side of the tanks.

Figure 2. Oil pool depth and diameter were defined by a rubber baking form frozen into the ice at the surface. The form was easily removed from the ice at the beginning of the experiment.

Figure 3. The thermocouples intended to record temperatures above the original ice interface were

placed into the probe support just prior to the start of the experiment. Insert: close-up of the thermocouples protruding from the support.

## Experiment Setup

Burn experiments take place outdoors in a sheltered area. Wind and spray protection is installed to a height of 1.5 m at three sides (Figure 4) while the 4$^{th}$ side is protected by a container located 5 m from the pool. A weather station (wind, temperature, pressure) is located at 2.2 m above ground, 2 m from the burn site (Figure 4). The multiplexer for the temperature sensors is placed in a box inside the shelter while the data logger itself is located behind the shelter.


Figure 4. Experiment set-up during dry run on 6 October 2017. The weather station can be seen behind the shelter, slightly to the right of the “Grace” sign. A camera set up to record the burn is seen in the front right of the photo.

## Data Acquisition

Data were logged with a battery-powered Campbell Scientific (CS) data logger CS1000 and a CS AM25T multiplexer to measure up to 25 thermocouple temperatures. In addition, the logger recorded weather data from an integrated Vaisala weather transducer, including air temperature, relative humidity, precipitation, wind speed and direction, and air pressure. The recording interval was 10 seconds and recording was started once all thermocouples were in place.

## Experiment Timing

The burn experiments are located at the Aarhus University facilities in Roskilde. The campus is shared with atmospheric research groups so that care needs to be taken to perform burn experiments only during suitable wind conditions. In particular, winds should come from easterly directions. On 6 October 2017, a “dry-run” of the experiment was performed but oil had not been ignited due to adverse wind direction. However, wind conditions were favourable on 24 October when a burn had been performed (Figure 5).

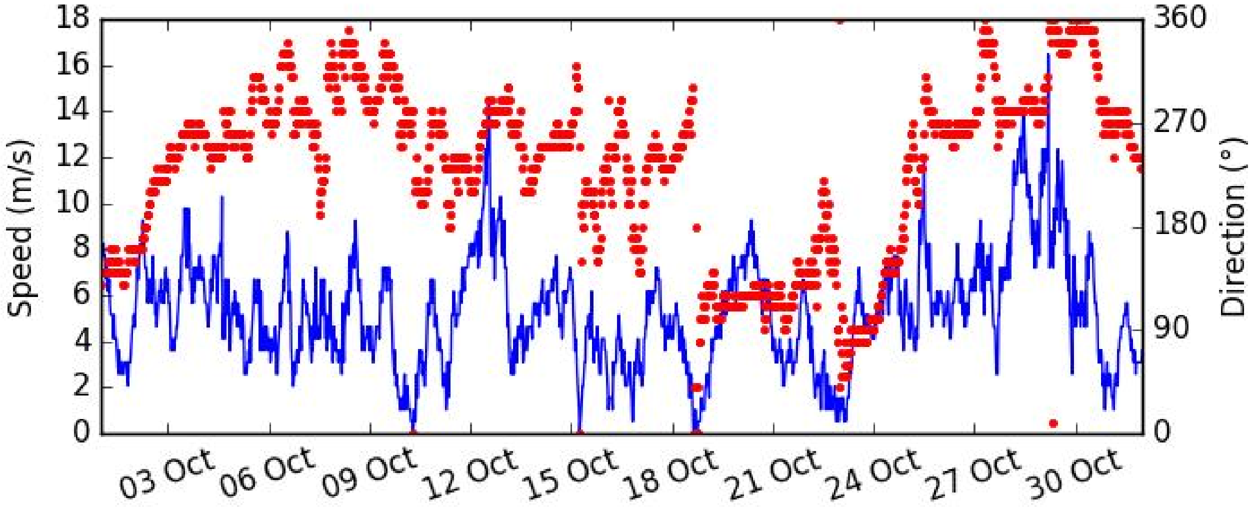

Figure 5. Wind speed (blue line) and direction (red dots) measured at Roskilde airport in October 2017.

## Ignition

Oil had been tapped from an outdoor drum holding Troll B crude oil and transported in an air-tight container to the burn site. Oil had been poured into the ice pan and ignited. The time between the end of pouring oil and ignition was approximately 1 minute.

Oil was ignited by a blow torch pointed down at the oil pool such as to avoid melt of surrounding ice by the flame (Figure 6).


Figure 6. Ignition of the oil pool. Photo of 15 Nov 2017, experiment 2.

## Surface Profile

The ice surface profile was measured just prior to the burn and after removal of the oil residue following the burn (Figure 7).

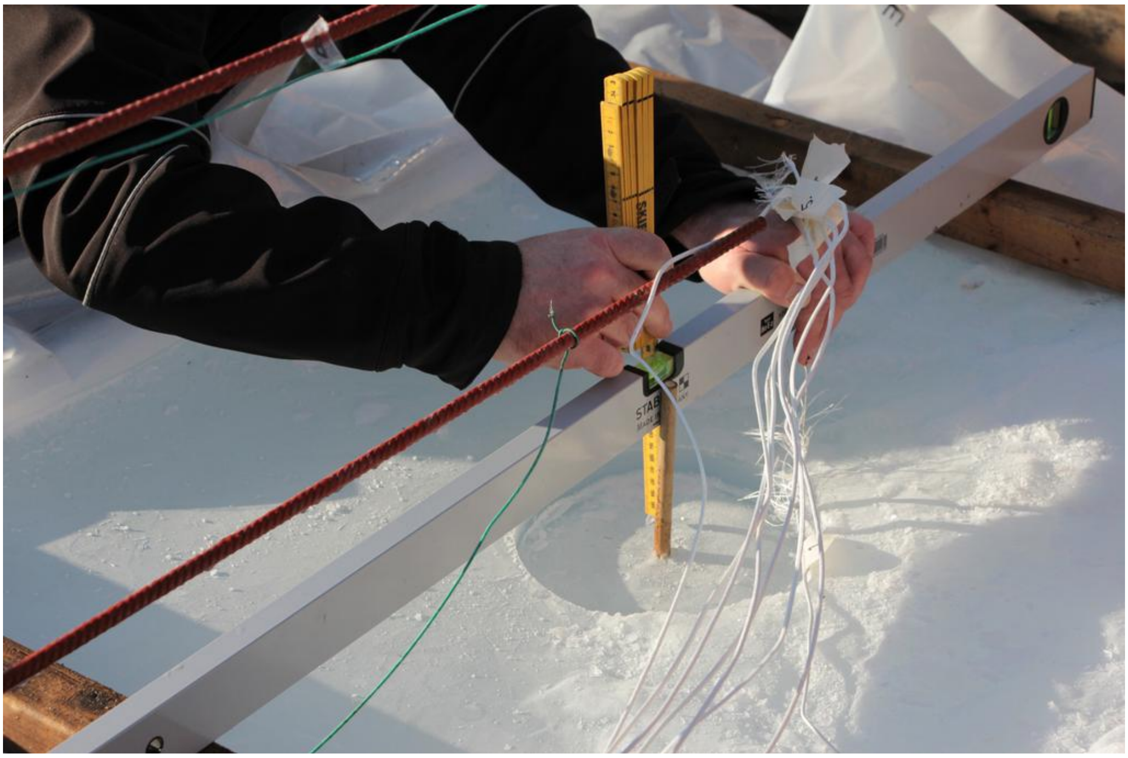

Figure 7. Surface profile measurement before the introduction of oil. Experiment 1 of 15 Nov 2017.

### Oil Residue

The original mass of oil and the mass of the oil residue after the burn was measured. Residue oil was collected with pre-weighted absorption pads.

### Flame Geometry

The burn was recorded by a GoPro camera to allow for the determination of flame dimensions, in particular flame width above the oil pond and height (Figure 4).

## Results and Discussion

The surface of the freshwater ice cover grown in October was cracked as a result of buckling which allowed some oil to drain out of the burn pan, reducing the actual burn time significantly. This was addressed in later experiments in November by introducing a pressure release mat on the inside walls of the tank (cf. ice cover in Figure 7).

The measurement period on 24 October lasted from 13:55:00 when all thermocouples were connected until 14:13:40 when the logger was turned off. The actual burn lasted from 14:05 until 14:07 (Figure 8). Figures 8 to 11 give an overview of the temperature measurements, Table 1 summarizes basic measurements.

As seen in Figure 9, there are two distinct burn periods with recorded peak temperatures between 400 and 450 °C. This was due to tunring winds.

As seen in Figure 10, the upper-most temperature sensor in the ice, T(12), melted out shortly after ignition and failed for much of the remaining burn period only to recover to reasonable readings once the flames extinguished. The final temperature suggests that the sensor was in air. Operational failure seems to have taken place at the time the ice melted. The next deeper sensor in the ice, T(11), reached 0 °C quickly (+2 °C for one measurement) and stabilized at 0 °C through the end of the experiment. I.e., it probably remained frozen for the duration of the experiment. The third sensor in the ice, T(10), appears to show temperature increase responding to the 0 °C “boundary” at T(11). Lower temperature sensors in the ice showed a temperature increase that was most likely due to conductive heat transfer in response to surface warming from T(11) (Figure 11).

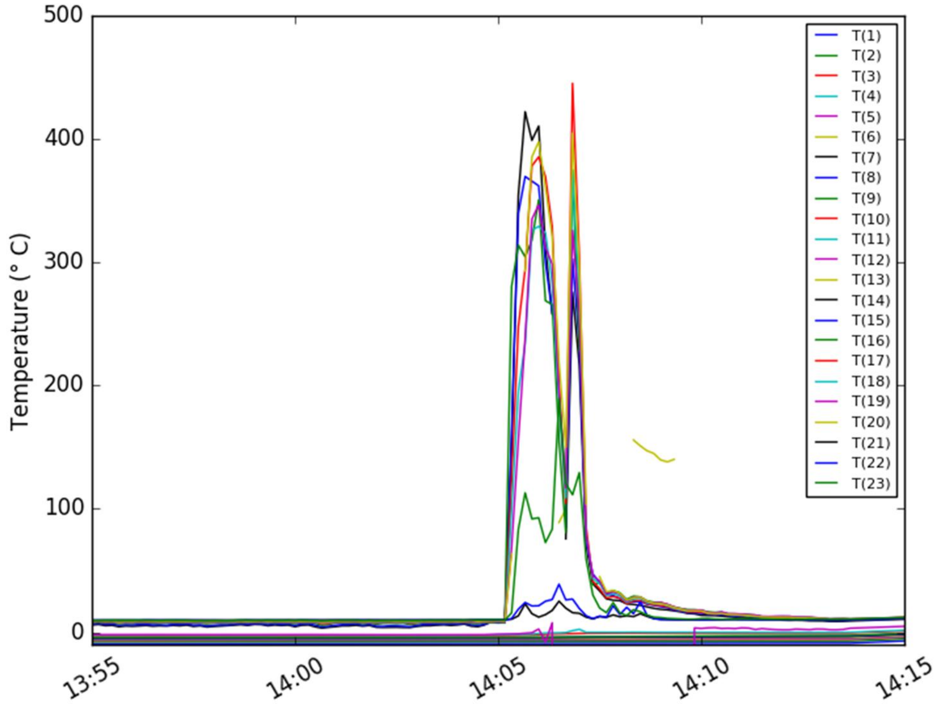


Figure 8. Overview of temperature measurements. T(1) through T(12) are in the ice, cf. Table 1.

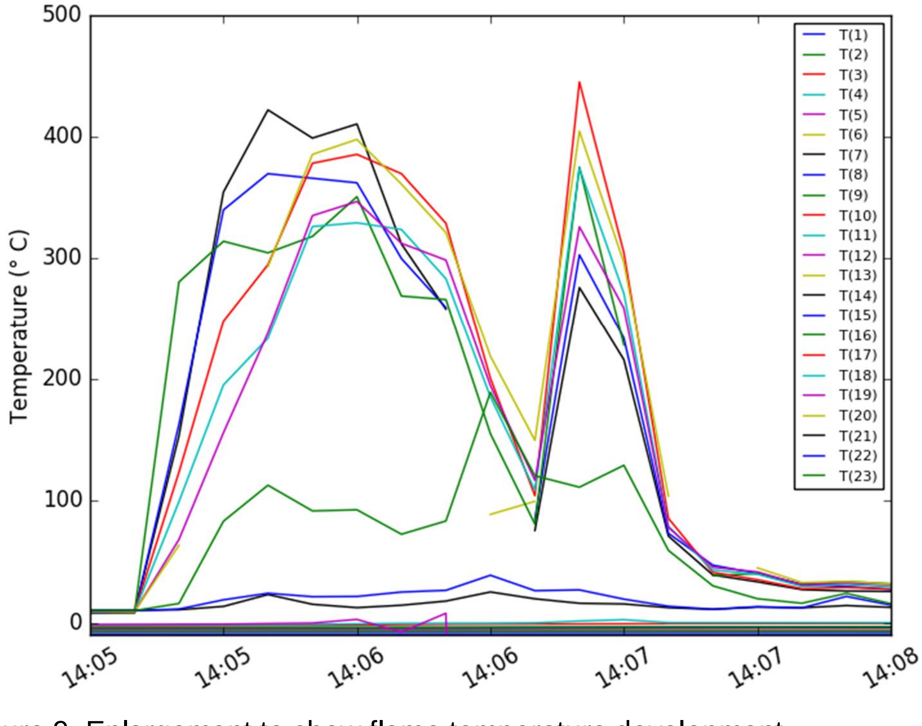


Figure 9. Enlargement to show flame temperature development.

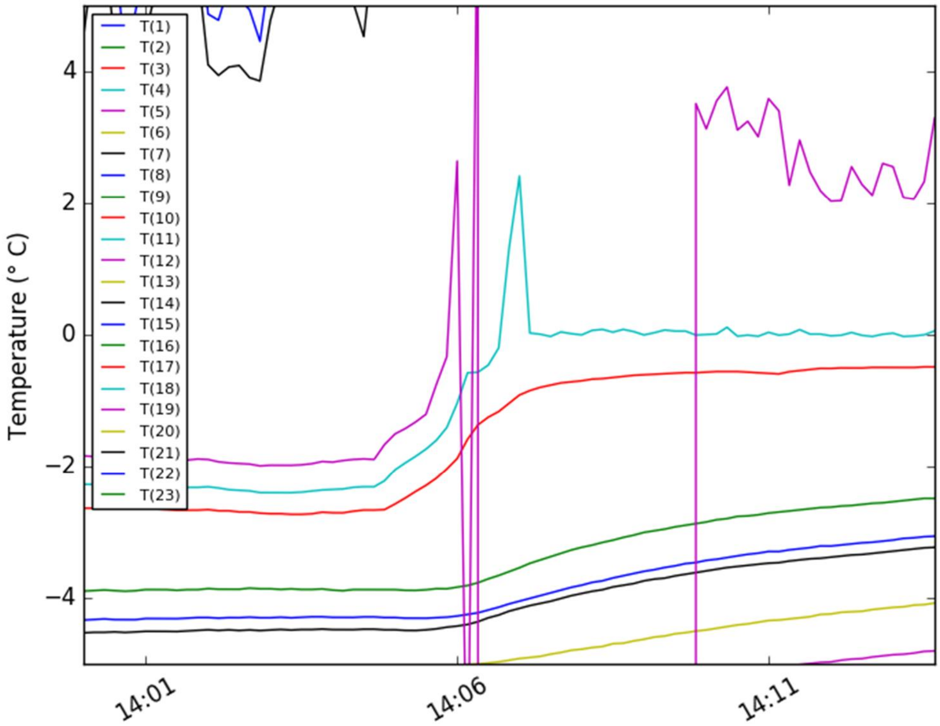


Figure 10. Enlargement to show temperature development in the upper ice layer. T(10) and T(11) are shown in red and cyan, respectively.

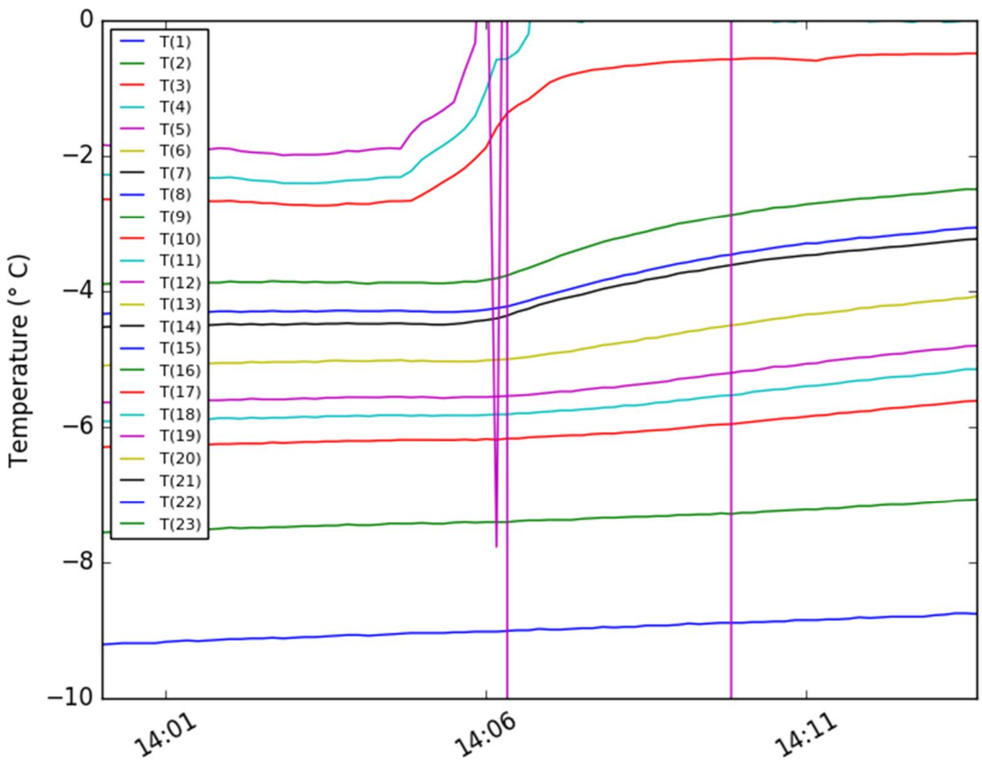


Figure 11. Enlargement to show temperature development in the lower ice layer.

Table 1. Temperatures registered by the thermocouples

| Sensor | Initial Temperature 14:00:00 | Maximum Temperature | Final Temperature 14:13:40 | Comment |
|---|---|---|---|---|
| **T(1)** | -9.2 °C | -8.8 °C | -8.8 °C | Ice (lowest/bottom) |
| **T(2)** | -7.6 °C | -7.1 °C | -7.1 °C | Ice |
| **T(3)** | -6.3 °C | -5.6 °C | -5.6 °C | Ice |
| **T(4)** | -5.9 °C | -5.2 °C | -5.2 °C | Ice |
| **T(5)** | -5.6 °C | -4.8 °C | -4.8 °C | Ice |
| **T(6)** | -5.1 °C | -4.1 °C | -4.1 °C | Ice |
| **T(7)** | -4.5 °C | -3.2 °C | -3.2 °C | Ice |
| **T(8)** | -4.3 °C | -3.1 °C | -3.1 °C | Ice |
| **T(9)** | -3.9 °C | -2.5 °C | -2.5 °C | Ice |
| **T(10)** | -2.6 °C | -0.5 °C | -0.5 °C | Ice |
| **T(11)** | -2.3 °C | 2.4 °C | 0.1 °C | Ice |
| **T(12)** | -1.8 °C | 7.7 °C | 3.3 °C | Ice (highest) |
| **T(13)** | (no reading) | 155.8 °C | (no reading) | Pool (defective) |
| **T(14)** | 4.5 °C | 422.2 °C | 9.2 °C | Pool |
| **T(15)** | 5.5 °C | 369.7 °C | 9.7 °C | Pool |
| **T(16)** | 7.0 °C | 375.1 °C | 10.4 °C | Flame, center |
| **T(17)** | 7.7 °C | 445.2 °C | 10.6 °C | Flame, center |
| **T(18)** | 7.9 °C | 374.3 °C | 10.6 °C | Flame, center |
| **T(19)** | 8.2 °C | 346.8 °C | 10.8 °C | Flame, center |
| **T(20)** | 8.6 °C | 404.7 °C | 10.6 °C | Flame, side |
| **T(21)** | 9.9 °C | 25.2 °C | 10.2 °C | Flame, side |
| **T(22)** | 9.6 °C | 39.0 °C | 10.2 °C | Flame, side |
| **T(23)** | 9.5 °C | 189.5 °C | 10.7 °C | Flame, side |
| **T(24)** | 4.6 °C | 8.0 °C | 3.9 °C | Spare |
| **T(25)** | 14.6 °C | 17.4 °C | 11.4 °C | Spare |

# Lessons Learned for Main Experiments

## General

All technical aspects of the experiment worked as planned with the exception of the ice interface topography.

## Ice Interface

The major issue uncovered in the preliminary burn was the generation of a flat ice cover. Volume expansion of ice during formation and thermal contraction of the surrounding basin acted to exert stress on the ice that led to buckling and crack formation. This problem had been successfully addressed prior to the burns in November by using cushioning on the inside of the tank, allowing ice to expand and the surface to remain flat.

# References

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