Characterizing EV vs ICE Hazards in Parking Structures: Results of Full-Scale Testing

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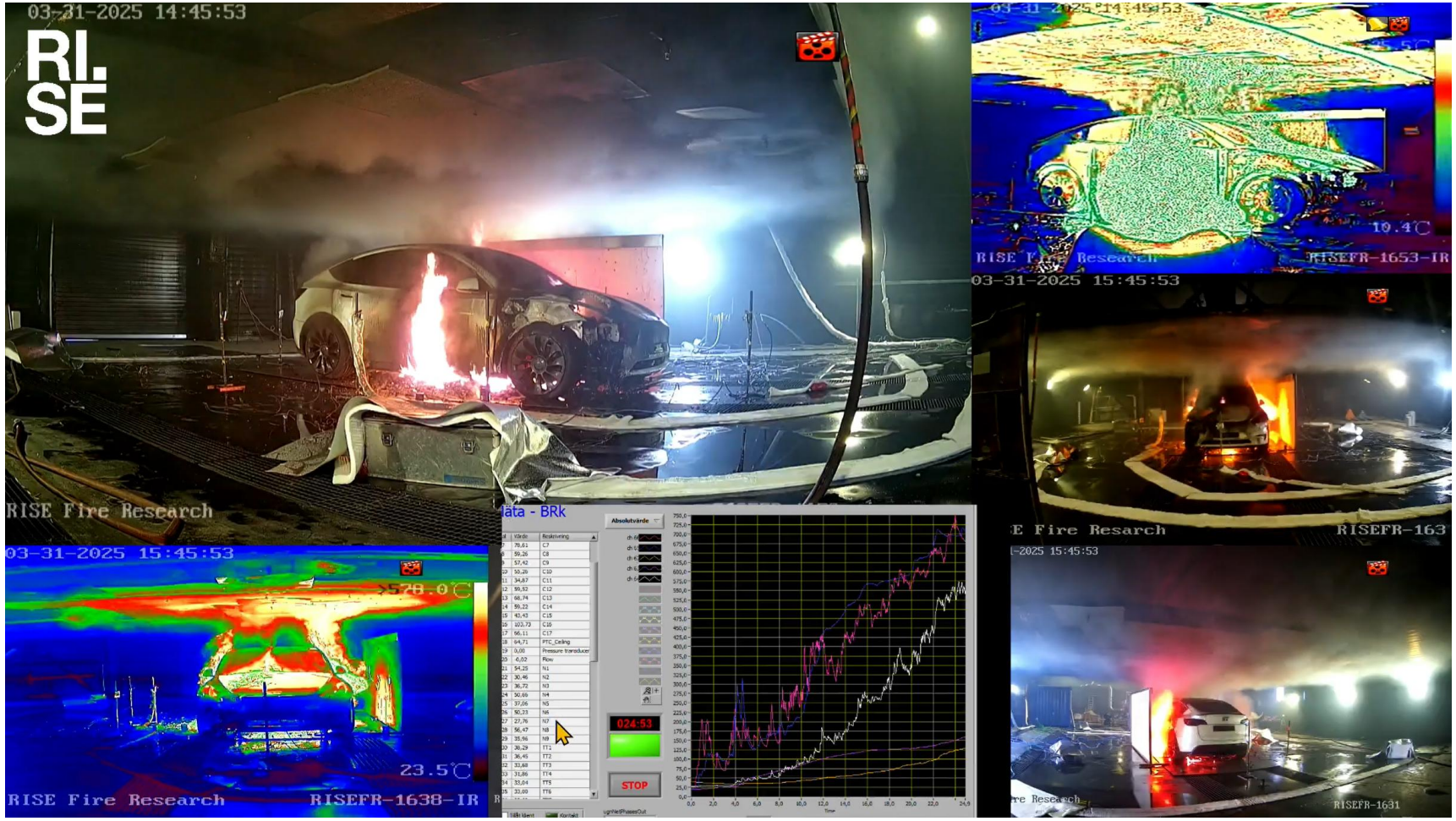
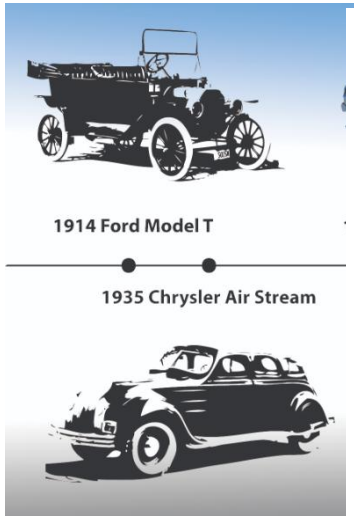
IWMA International Water Mist Association

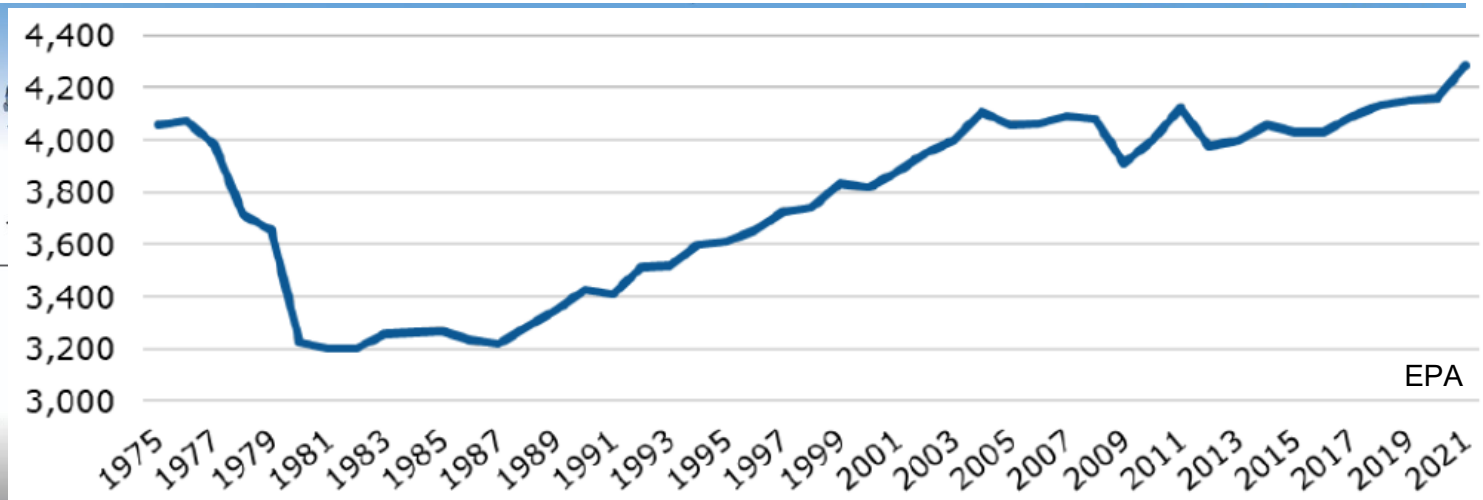
Outline

- Background
- Experimental Setup
  - Rig
  - Instrumentation
  - Test Matrix
- Results and Discussion
  - Baseline
  - Suppression
  - Activation Times
  - Gas temperatures
  - Damage on Target
- Conclusions



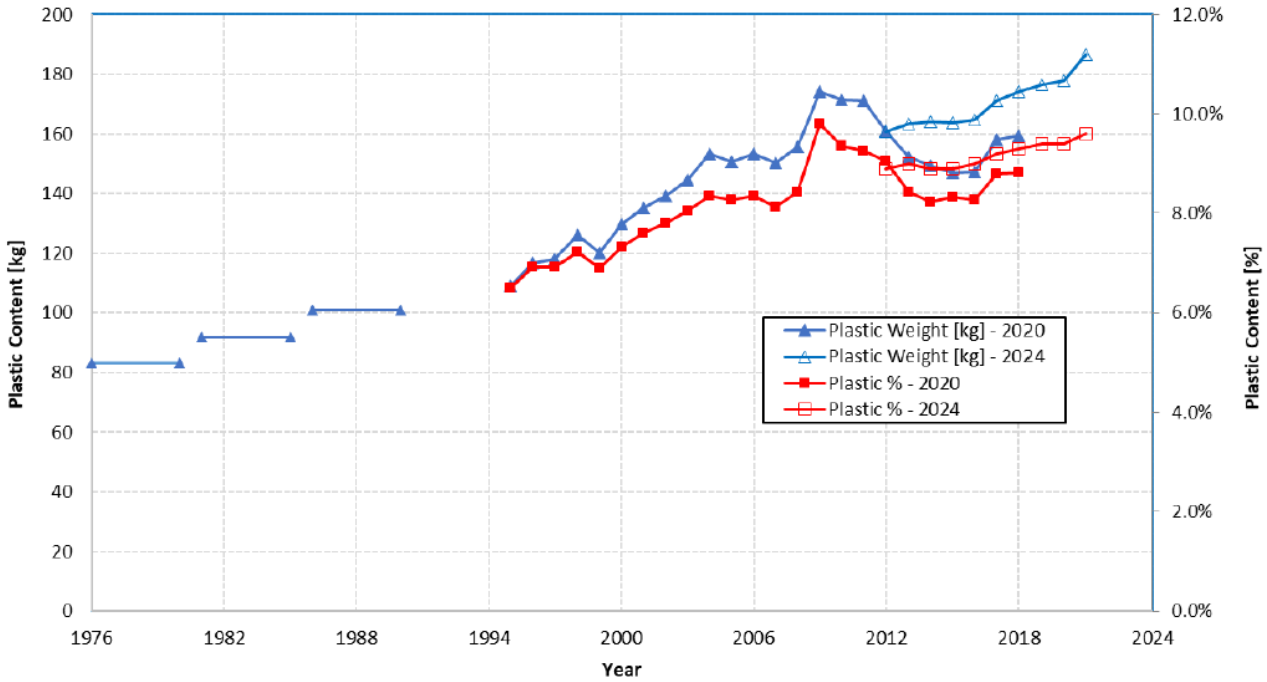
Background





Average Vehicle Weight (kg)

Vehicle plastic weight and weight percentage



American Chemistry Council [2023]

Background

January 7, 2020 - Stavanger Airport, Sola, Norway

- Unsprinklered.
- ICE – Engine compartment fire.
- More than 300 vehicles were involved.
- Partial collapse, unprotected steel, of the structure.

June 23, 2022 - Merriweather District, Columbia, Maryland, United States

- Unsprinklered
- Presumably built before fire codes required sprinkler systems in open-type garages.
- ICE – Engine compartment fire.
- 8 vehicles were involved.
- Vehicle damage at $70,000 and structural damage to the parking facility at $100,000.

October 10, 2023 - Luton Airport, London, United Kingdom

- Unsprinklered - open-type garages.
- ICE – Diesel engine.
- More than 1,400 vehicles were involved.
- Metal structure collapsed.

There have been little changes to the fundamental protection requirements in the NFPA 88A (**Standard for Parking Structures**) standard since the initial 1973 and 1979 editions.

Objective

- Validate the sprinkler protection criteria in NFPA 13 for protection against fire spread between modern vehicles in parking garages.
- Quantify fire hazard and spread characteristics of Battery Electric Vehicles (BEVs) in parking structures.
- Determine the appropriate sprinkler design density needed to prevent fire spread to adjacent vehicles.
- Inform fire protection requirements in applicable codes and standards.

Test Matrix

Table 19.2.3.1.1 Density/Area

Hazard	Density/Area [gpm/ft^2/ft^2 (mm/min/m^2)]
Light	0.1/1500 or 0.07/3000* (4.1/140 or 2.9/280)
Ordinary Group 1	0.15/1500 or 0.12/3000* (6.1/140 or 4.9/280)
Ordinary Group 2	0.2/1500 or 0.17/3000* (8.1/140 or 6.9/280)
Extra Group 1	0.3/2500 or 0.28/3000* (12.2/230 or 11.4/280)
Extra Group 2	0.4/2500 or 0.38/3000* (16.3/230 or 15.5/280)

*When required by 19.2.3.1.5.

EN 12845 OH2 – 5 mm/min for 144 m^2 (per EFSN position Paper)

#	Vehicle Type	Ignition Method	Sprinkler K-factor	Water Pressure (bar)	Water Flow Rate (L/min/nozzle)	Number of Activated Nozzles out of 9
1	BEV	Burner	-	-	-	-
2	ICE	Pool Fire	5.6	1.5	100	7
3	BEV	Burner	5.6	1.5	100	9
4	ICE	Pool Fire	11.2	0.5	113	6

Test Conditions

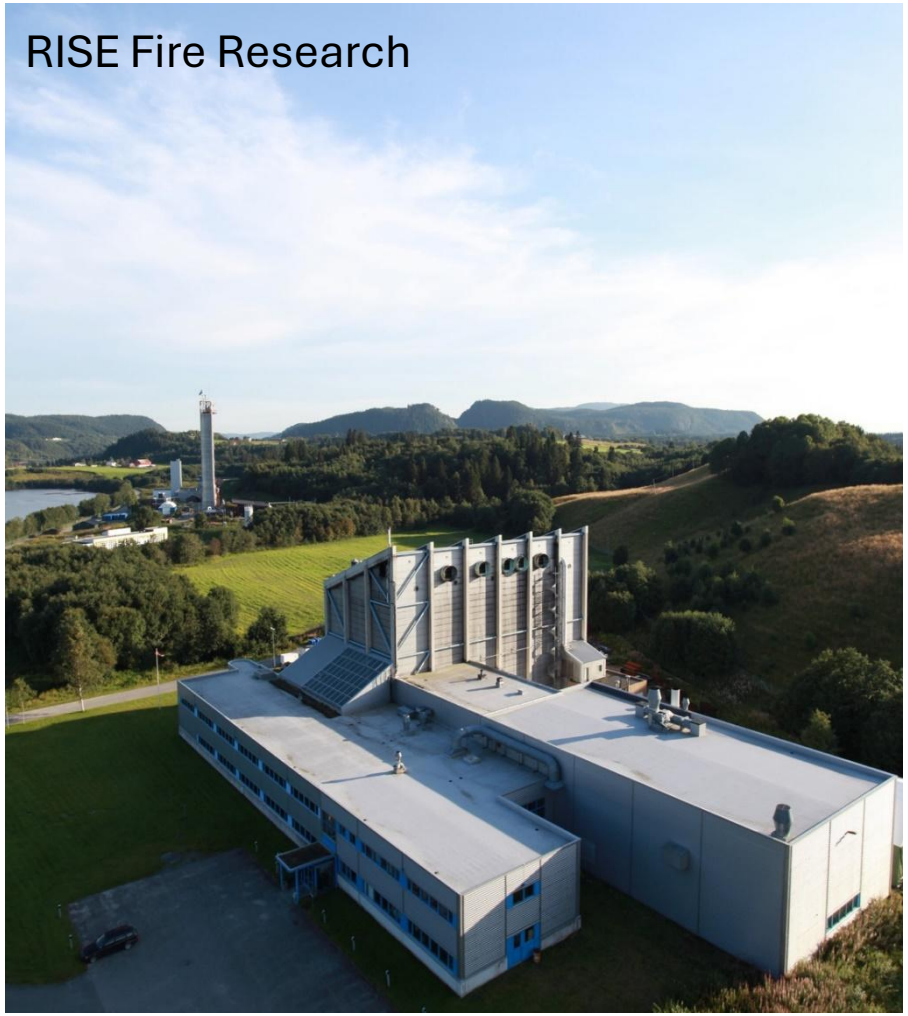
- **Parking Garage Dimensions:** 5.7 m long, 2.3 m wide, 2.5 m high. Open configuration [1].
- **Windows:** Closed [2, 3, 4]
- **Ignition Method for BEV:** Gas Burner [2, 3]. A single-point gas burner (oxy-acetylene) was placed beneath the vehicle to initiate the thermal runaway. Pilot flames were placed around the battery exhaust to ensure ignition.
- **Ignition Method for ICE:** A fuel tray was placed under the ICE vehicle and filled up with 60 liters of gasoline. The fuel in the ICE vehicle was drained. The mechanism placed in the tray will drain the water coming from the sprinklers to prevent overflow.

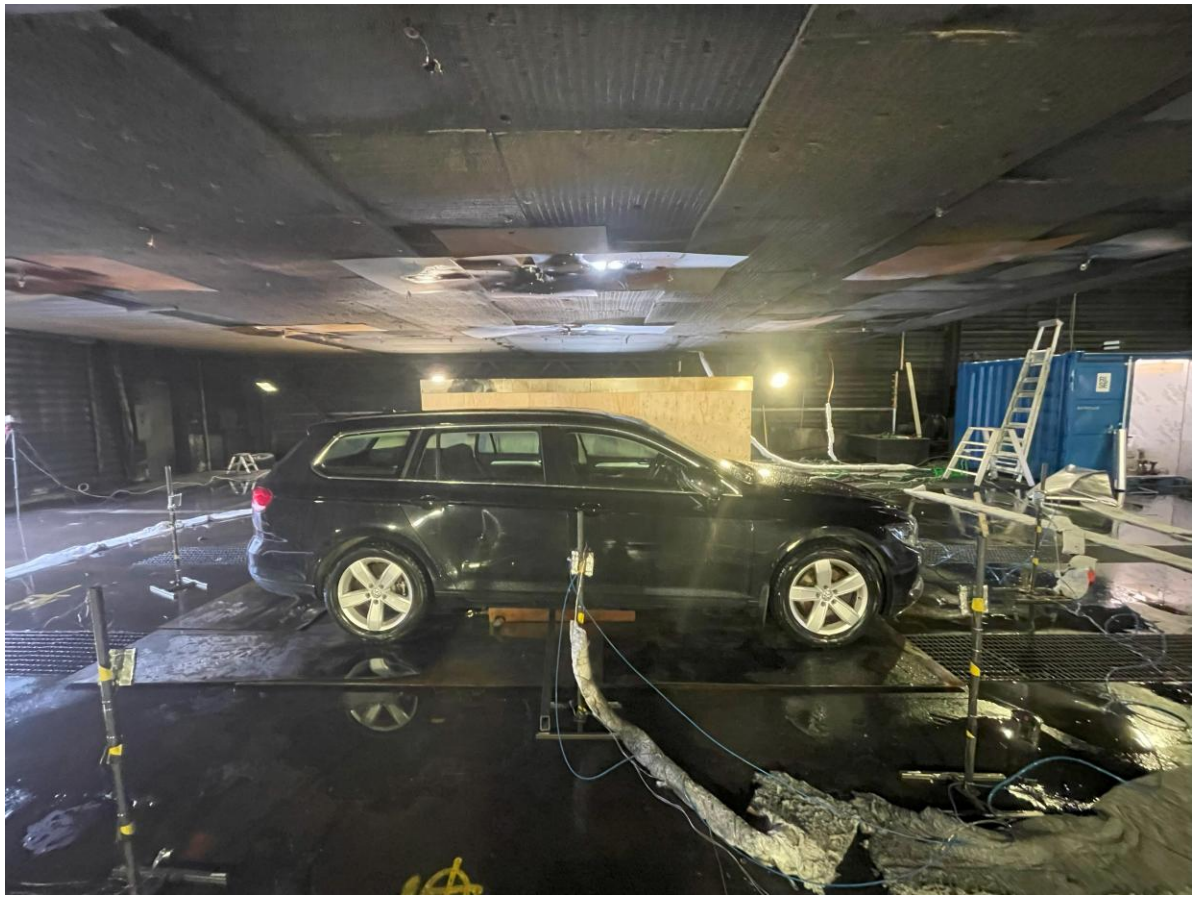
[1] S.M. Olenick, M.S. Klassen, N. Hussain, “Classification of Modern Vehicle Hazards in Parking Structures & Systems -Ph II Final Report”, 2024
[2] Jonna Hynynen, Ola Willstrand, Per Blomqvist, Petra Andersson, “Analysis of combustion gases from large-scale electric vehicle fire tests”, Fire Safety Journal, Volume 139, 2023
[3] C. Lam, D. MacNeil, R. Kroeker, G. Lougheed, and G. Lalime, “Full-Scale Fire Testing of Electric and Internal Combustion Engine Vehicles “, Fourth International Conference on Fire in Vehicles, October 5-6, 2016, Baltimore, USA
[4] N. Watanabe, O. Sugawa, T. Suwa, Y. Ogawa, “Comparison of Fire Behaviors of An Electric-Battery- Powered Vehicle and Gasoline-Powered Vehicle In a Real-Scale Fire Test”, Second International Conference of Fires in Vehicles, September 27-28, Chicago, USA

Test Conditions

- **Sprinkler Design:** NFPA 13 guidelines were followed to design the suppression system. Nine nozzles were used with 3 m x 4 m grid configuration.
  - The sprinklers were installed based on the specifications given in the datasheets. It was suggested to be flushed with the ceiling, but to be on the conservative side, the nozzles were lowered approximately 6 cm (0.2 ft) from the ceiling.
  - Dry pipe system was used based on the decision of the panel.
- **Assessment:** The data collected from the thermocouples, plate thermocouples, and visual observations were used to assess the efficiency of the water density.

Experimental Setup

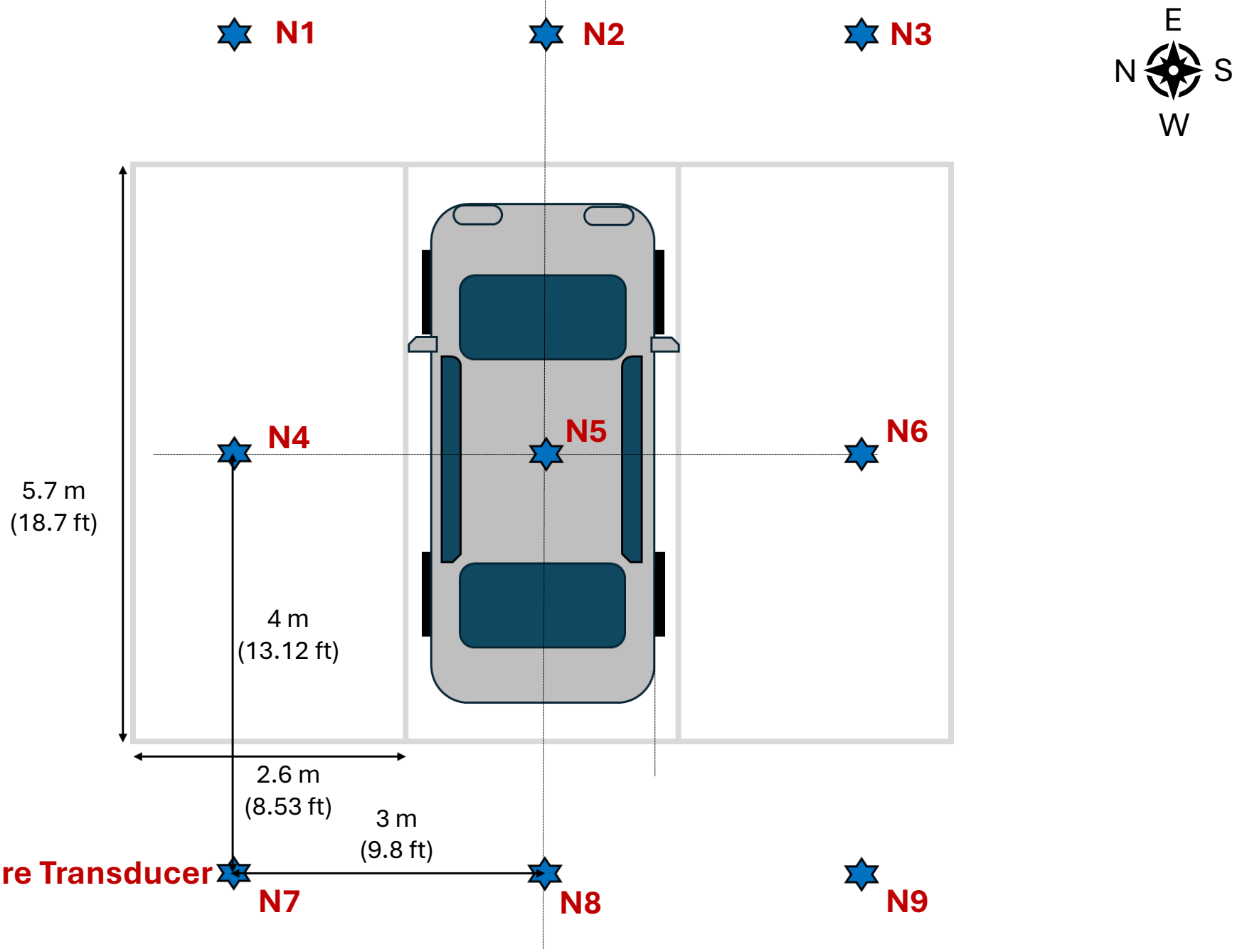




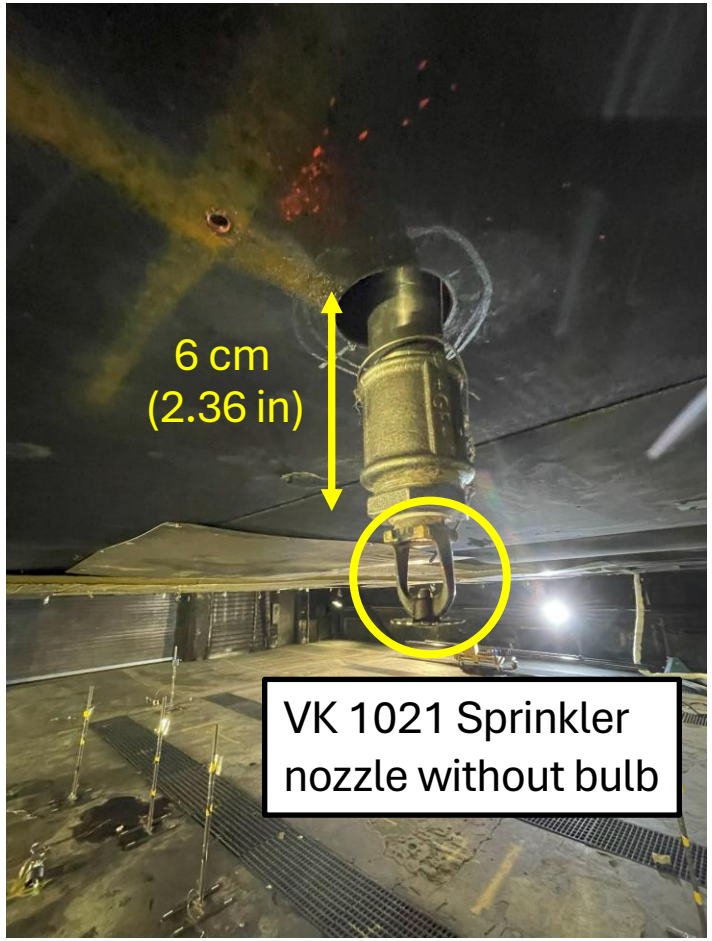
Test Setup – Nozzle Configuration

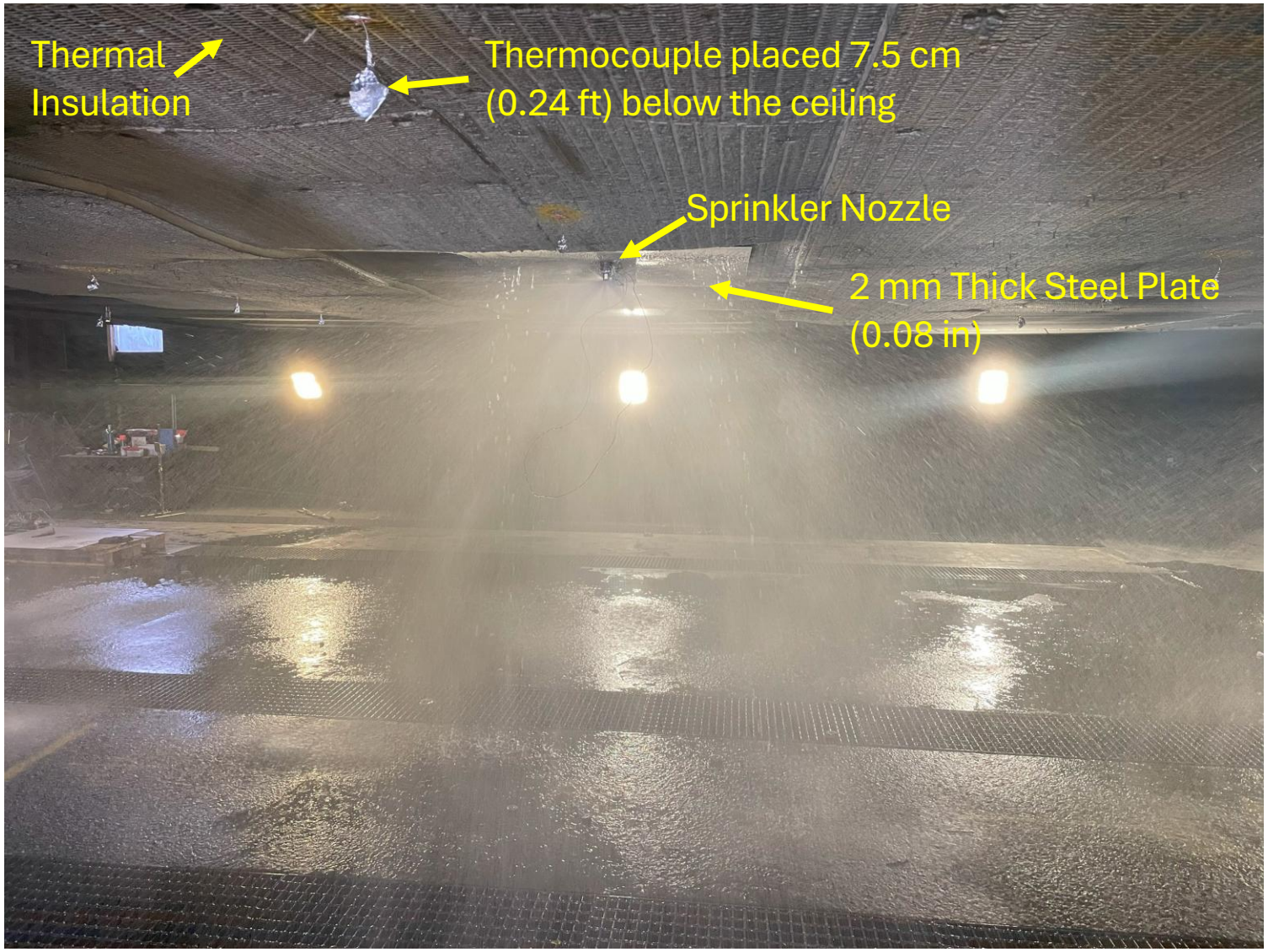
Nozzle

Operating Pressure: 1.5 bar
Expected flow rate = 900 l/min
(237 gal/min)

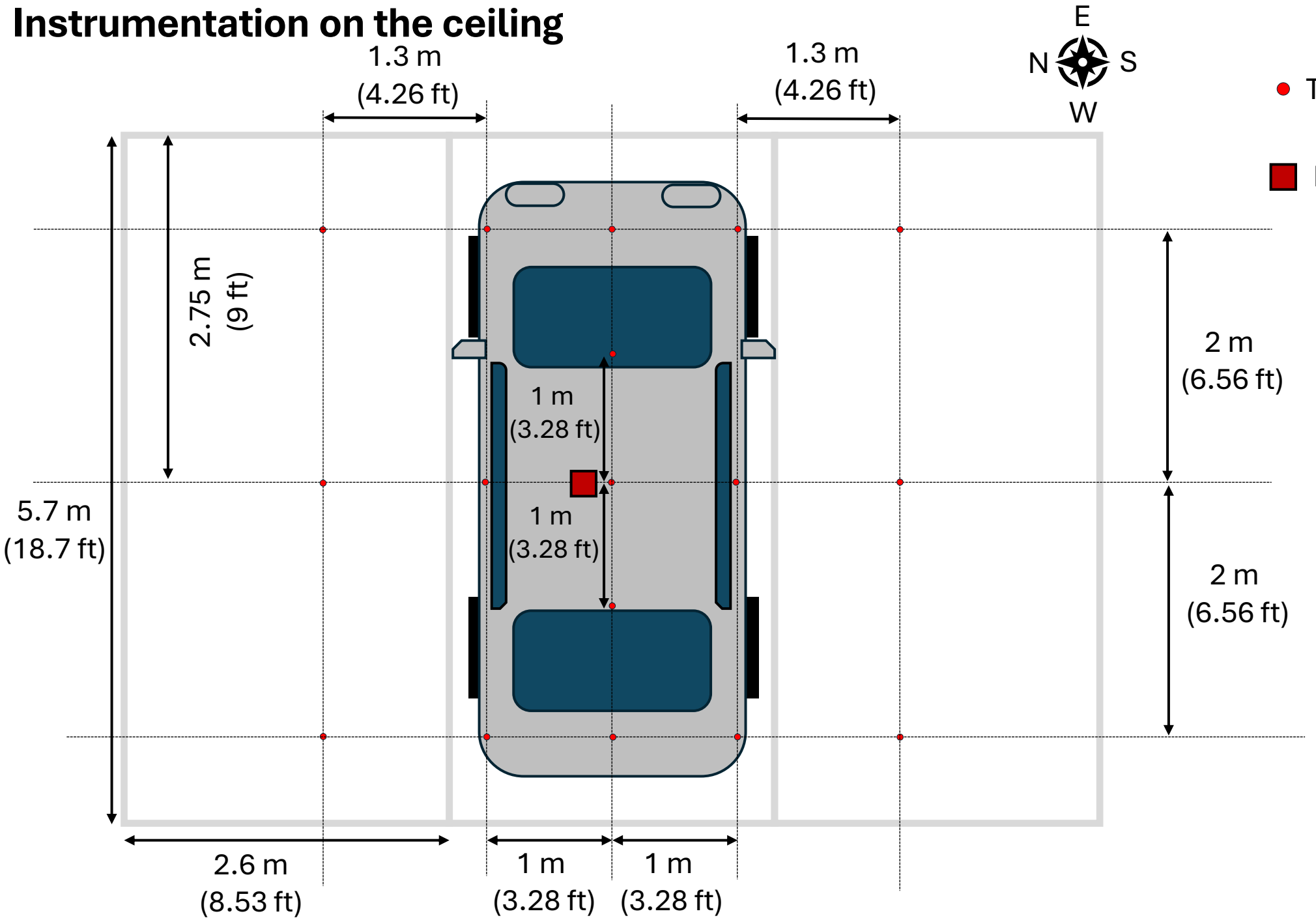


Test Setup – Nozzle Configuration





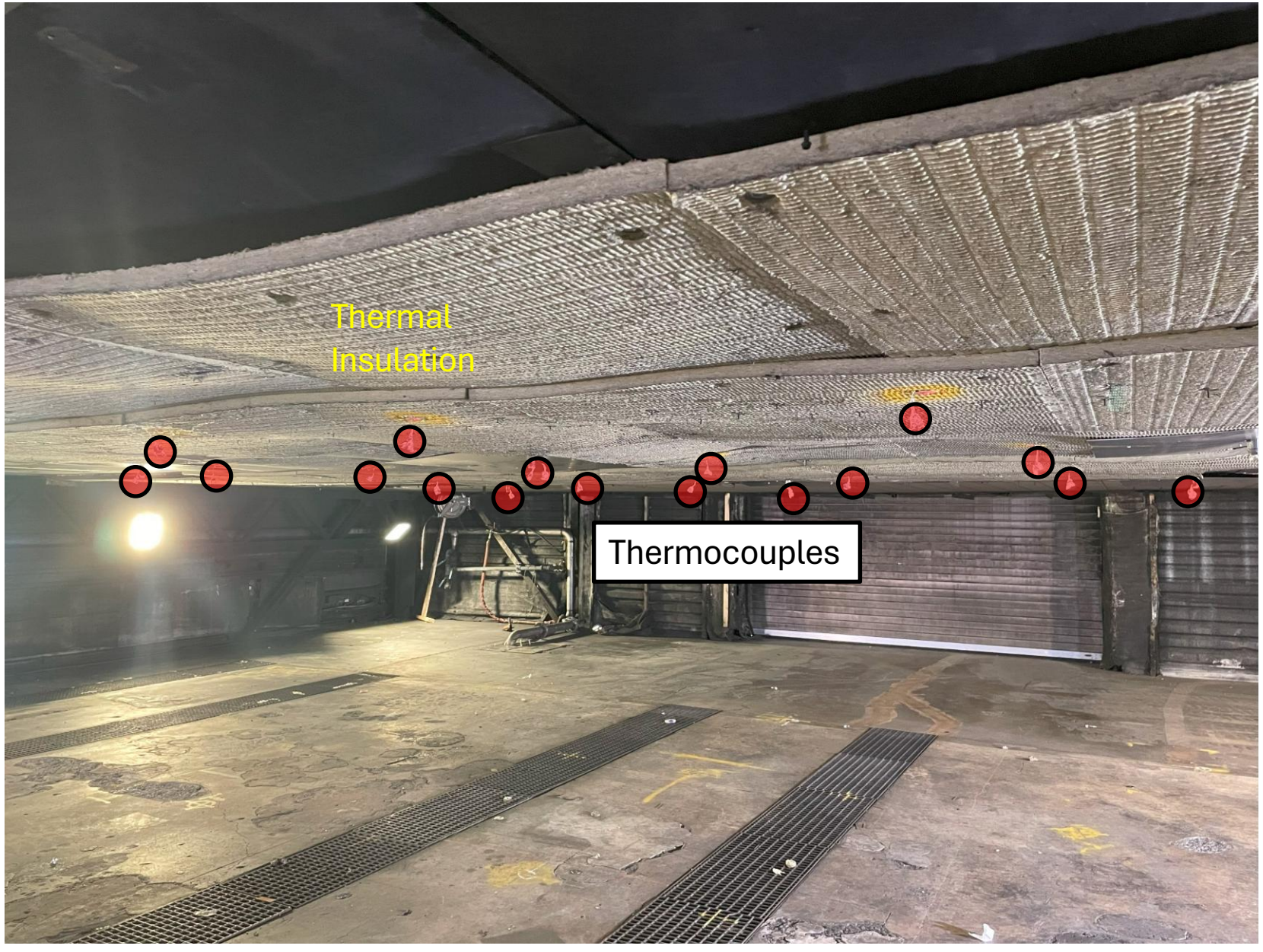
Instrumentation on the ceiling



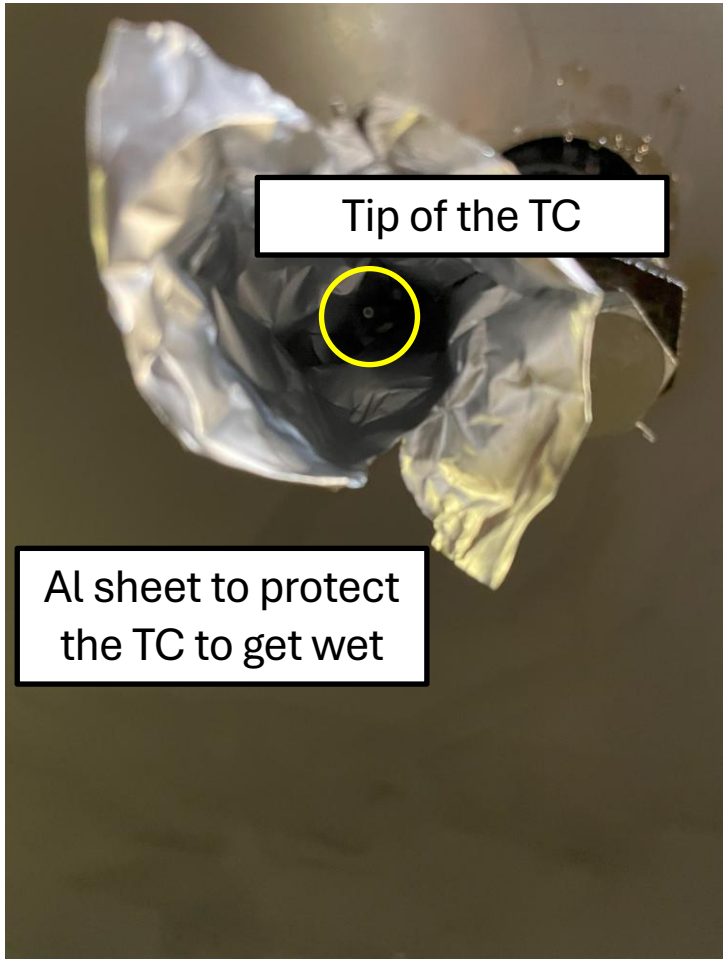
- TCs placed 7.5 cm (0.24 ft) below the ceiling
- Plate Thermocouple

17 TCs on the ceiling
9 on the nozzles
1 Plate Thermocouple

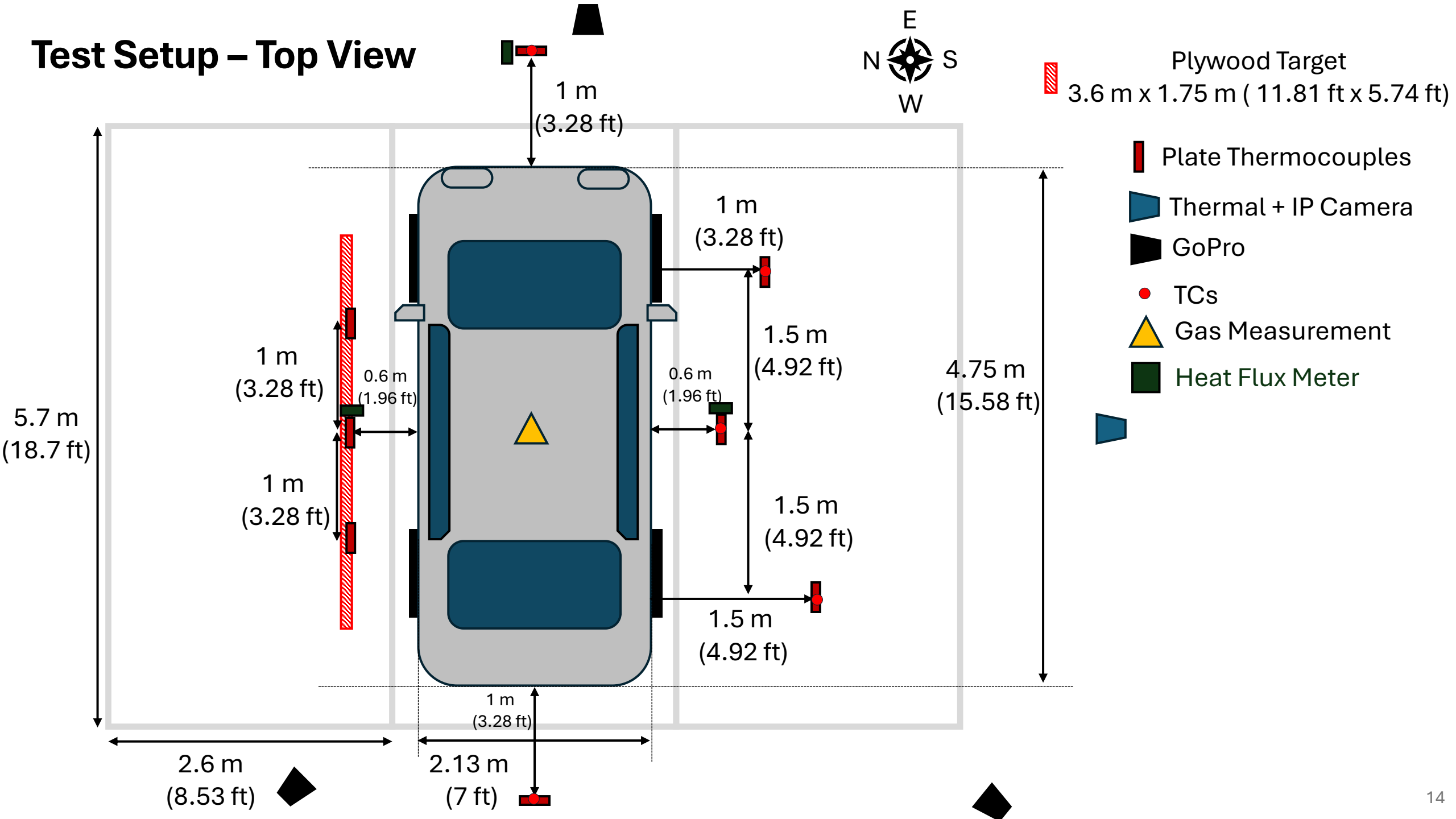
TC on the ceiling



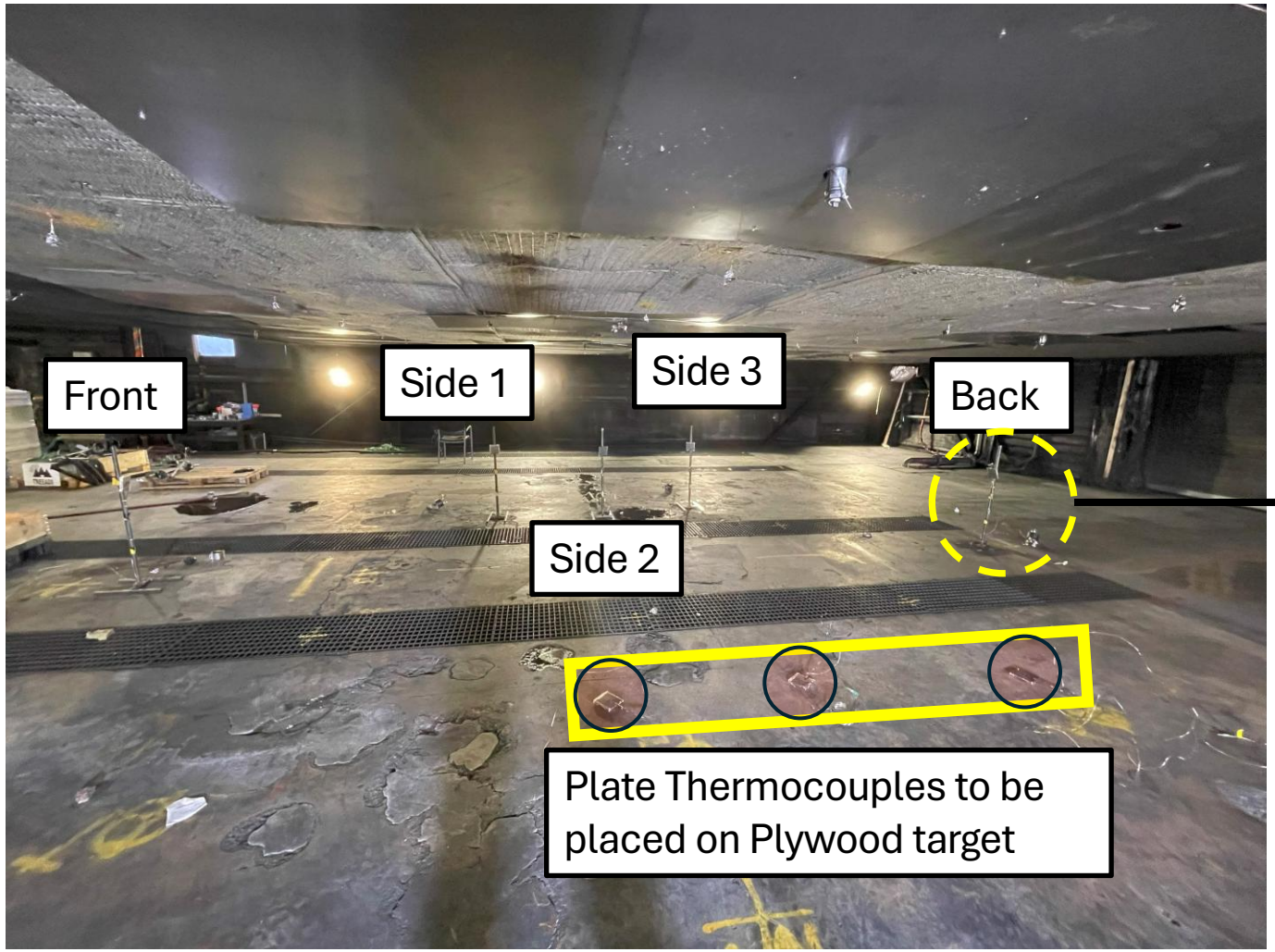
17 TCs on the ceiling
9 on the nozzles

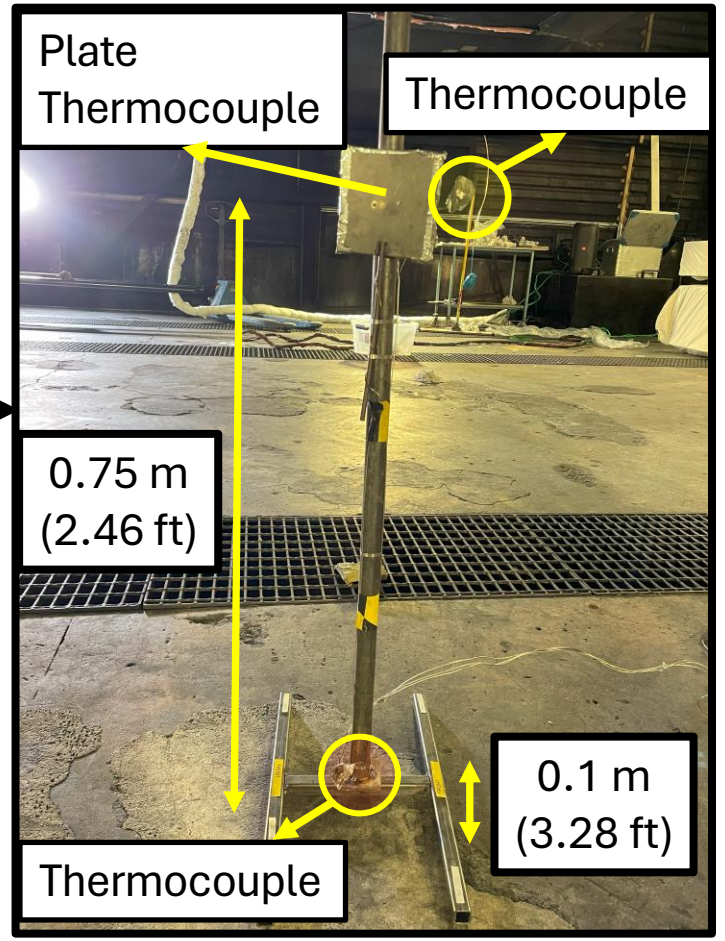


Test Setup – Top View



Instrumentation around the vehicle





Test Setup – Side View

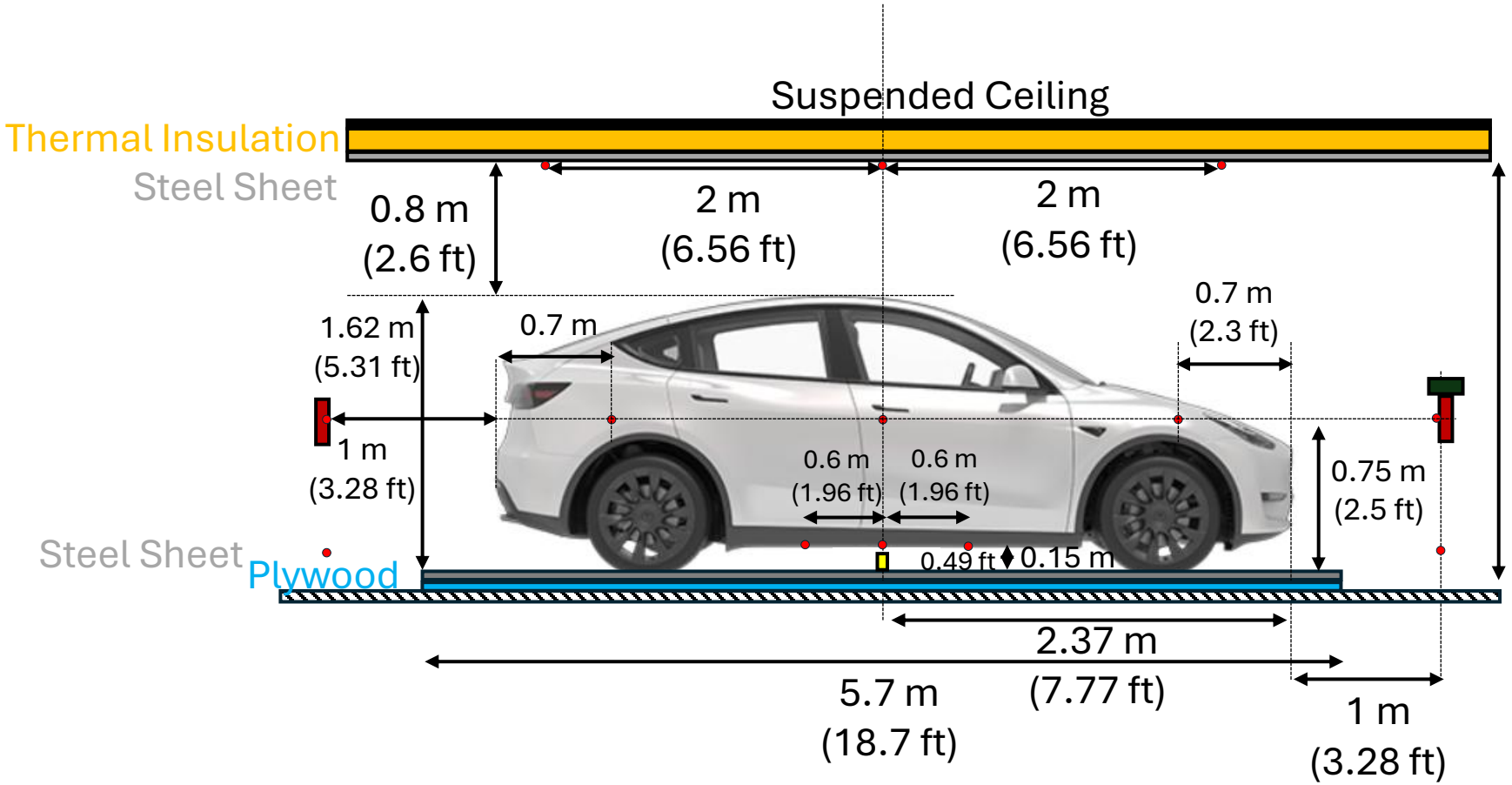


Plate Thermocouple

TCs

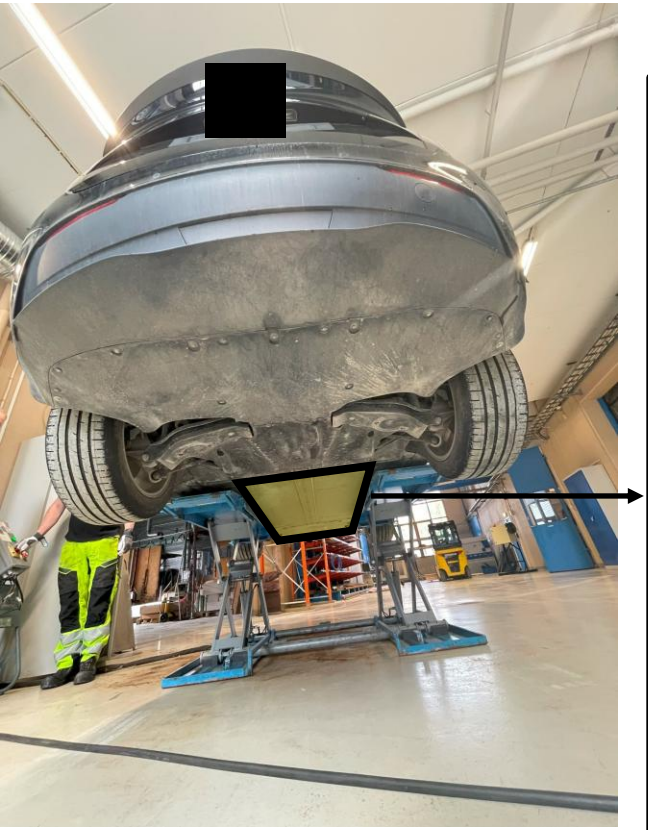
Gas Burner

Heat Flux Meter

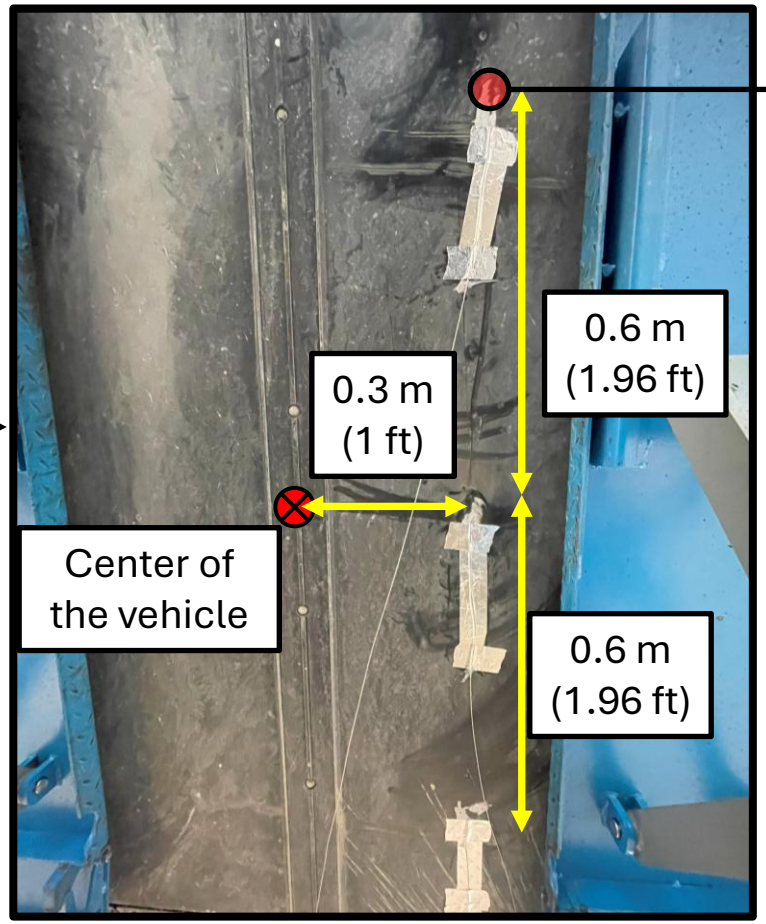
Instrumentation Summary

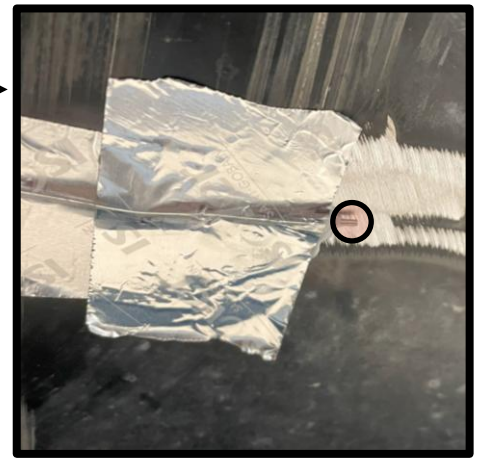
- 8 PTC surrounding the vehicle
- 10 TCs surrounding the vehicle
  - 1 PTC on the ceiling
- 17 TCs attached to the ceiling
  - 9 TCs on the nozzles
    - 8 TCs on vehicle
  - 11 TCs on the target
- 1 water pressure transducer placed on the furthest nozzle.

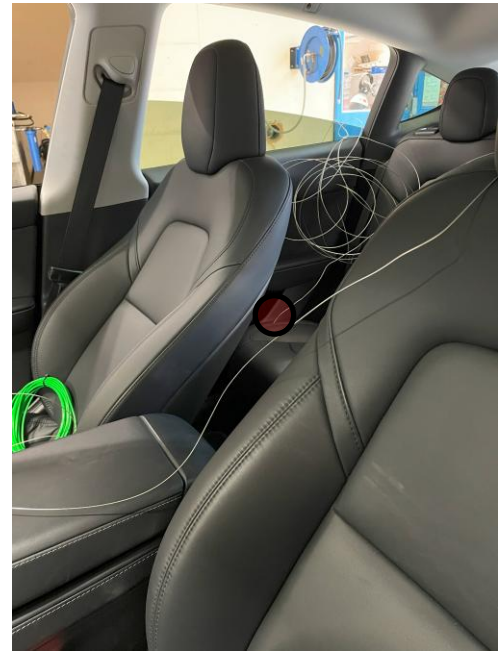
Instrumentation on the vehicle



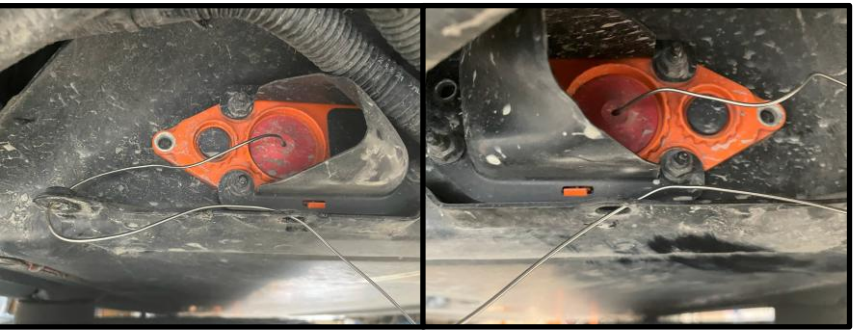
TCs under the vehicle







TCs in the vehicle

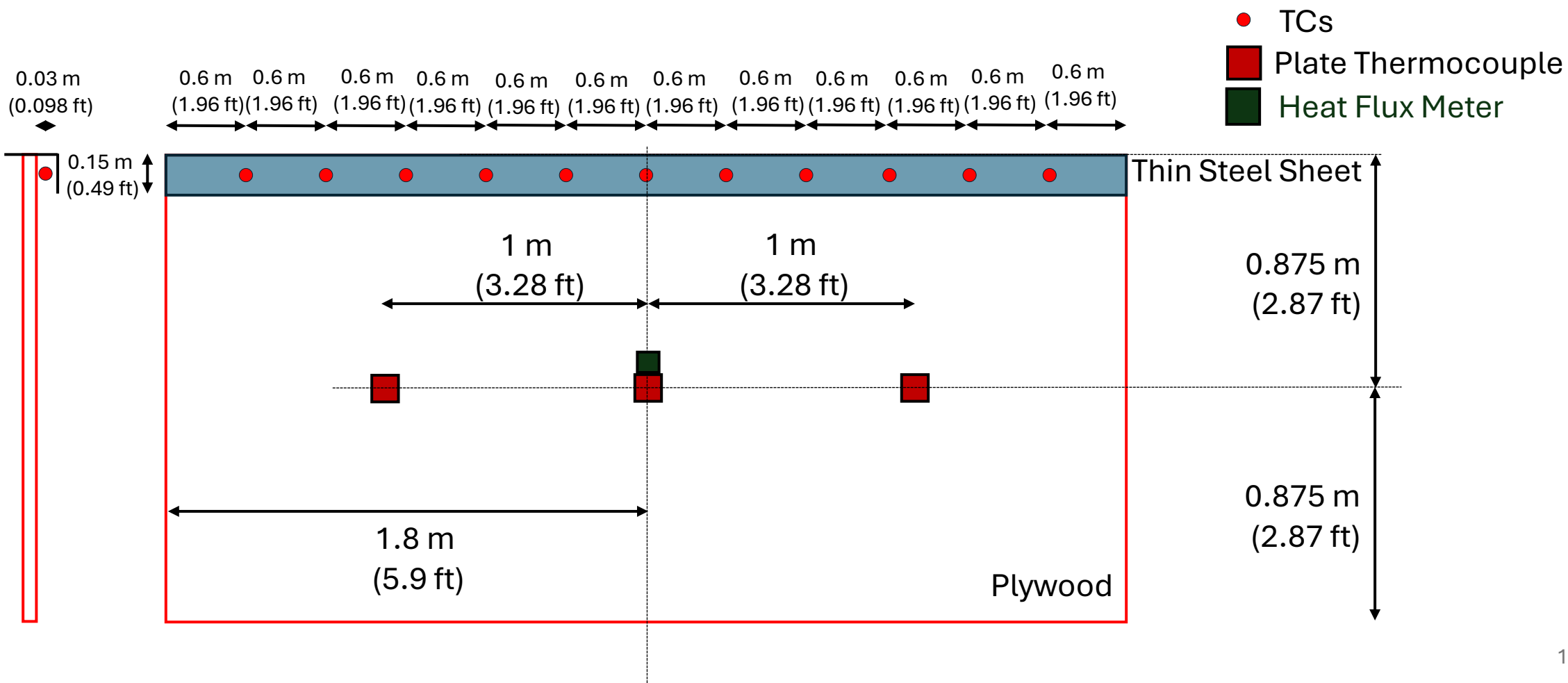


TCs in the battery ventilation ports

Target Properties for Single Vehicle Test

Targets will be manufactured according to IMO1430 guidelines, with a reduced height. Original height = 2.4 m , modified height = 1.75 m (5.74 ft).

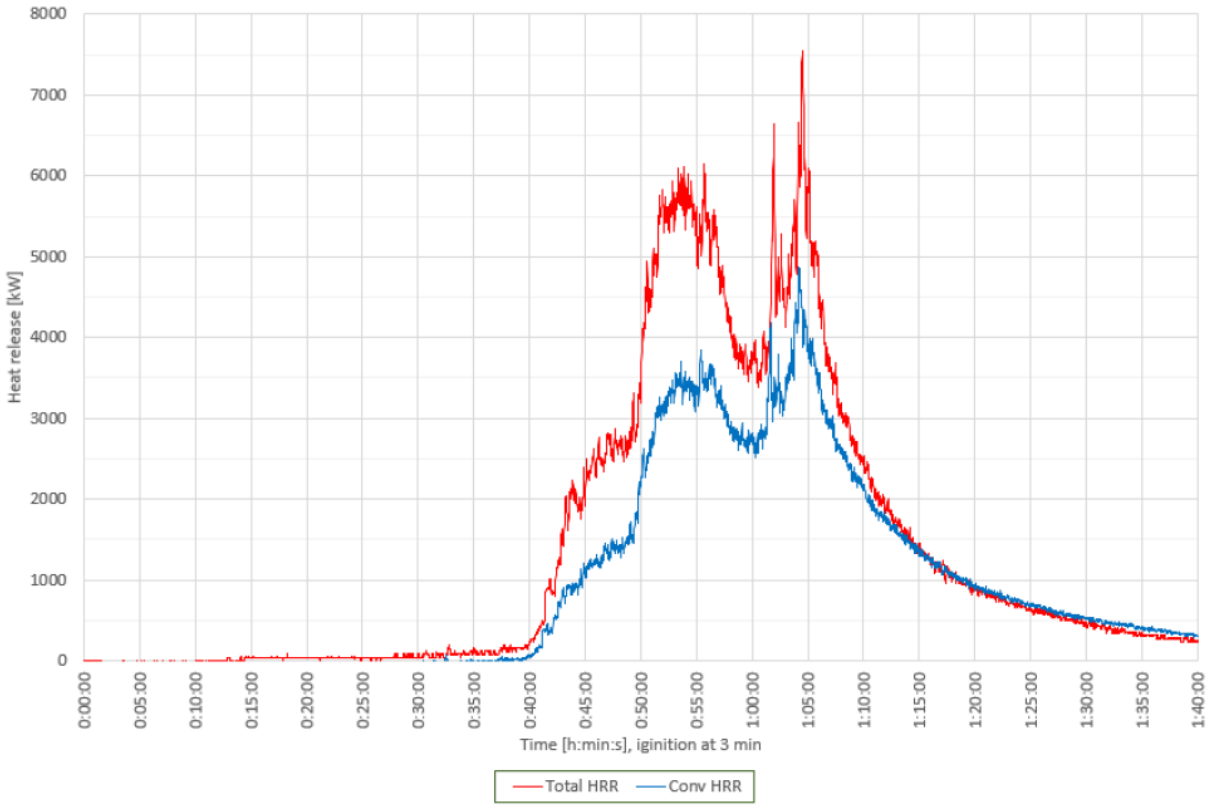
IMO1430 guideline: Plywood panels made of pine or spruce are used as targets. The panels should be approximately 12 mm (0.039 ft) thick.



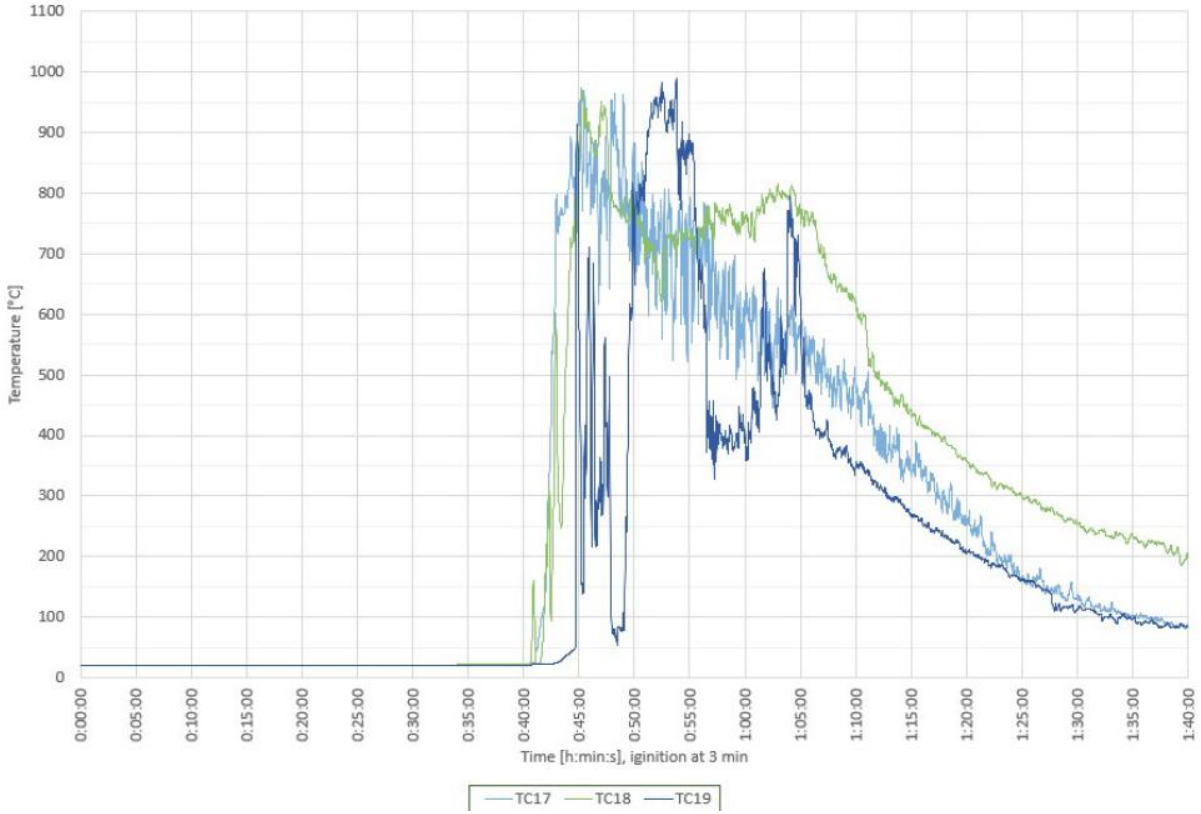
Results and Discussion – BEV Baseline

Results and Discussion – BEV Baseline

Heat Release Rate

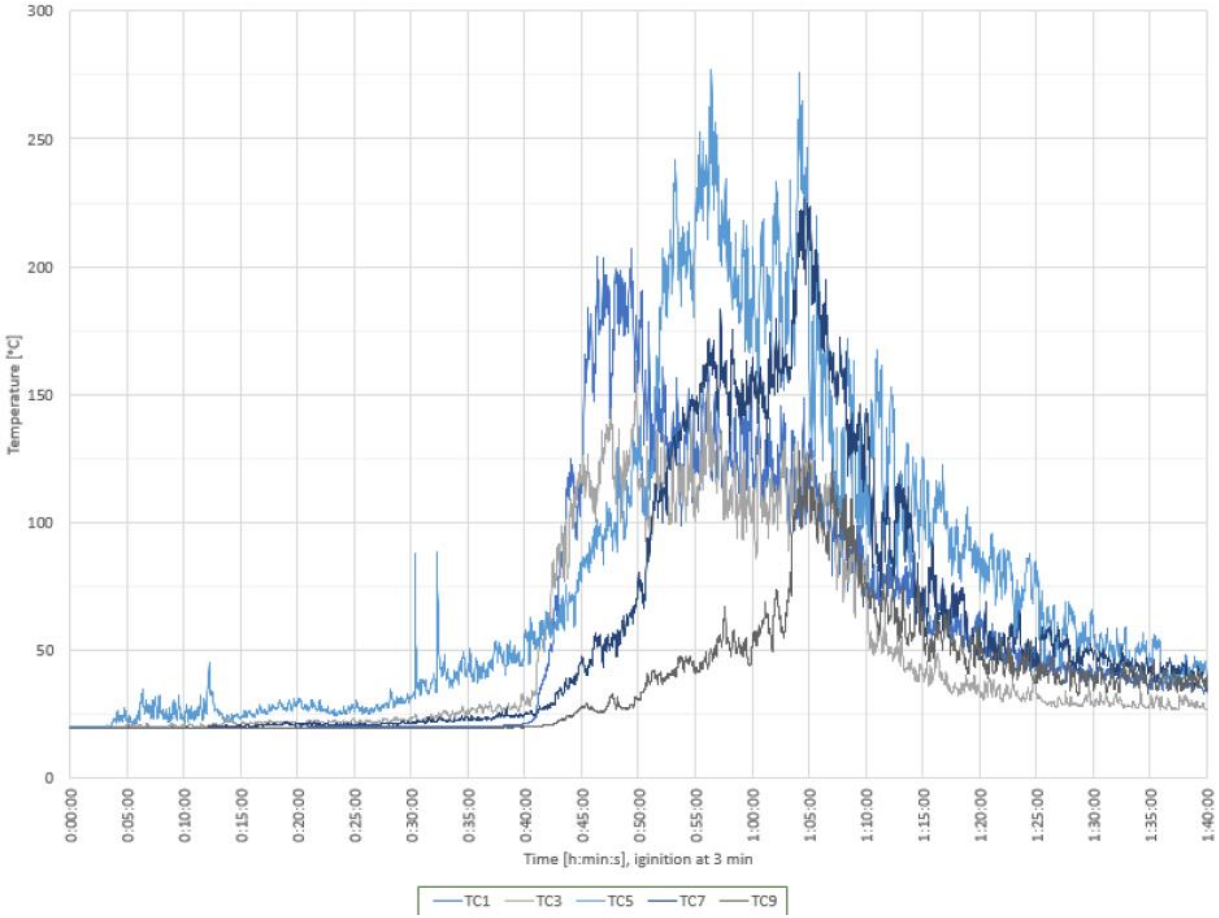


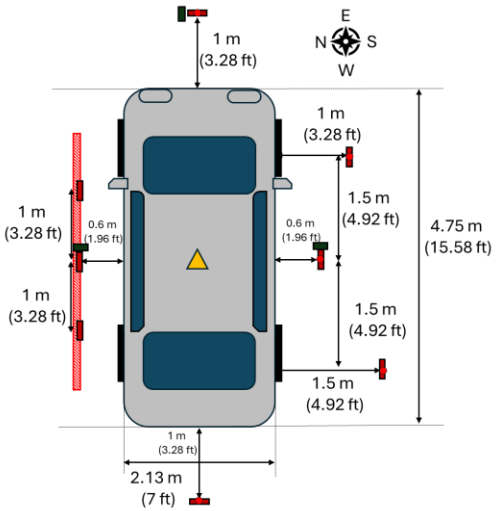
Temperature Inside the Vehicle



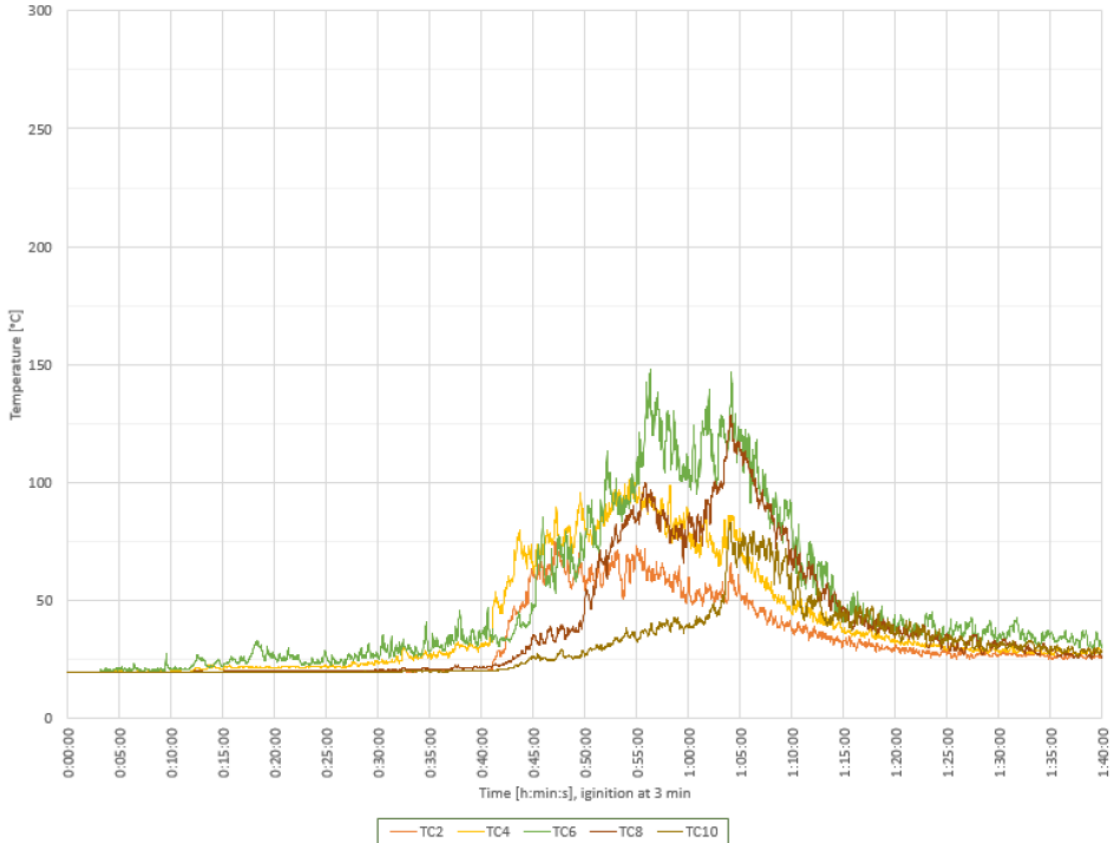
Results and Discussion – BEV Baseline

Temperatures Around the Vehicle – 75 cm



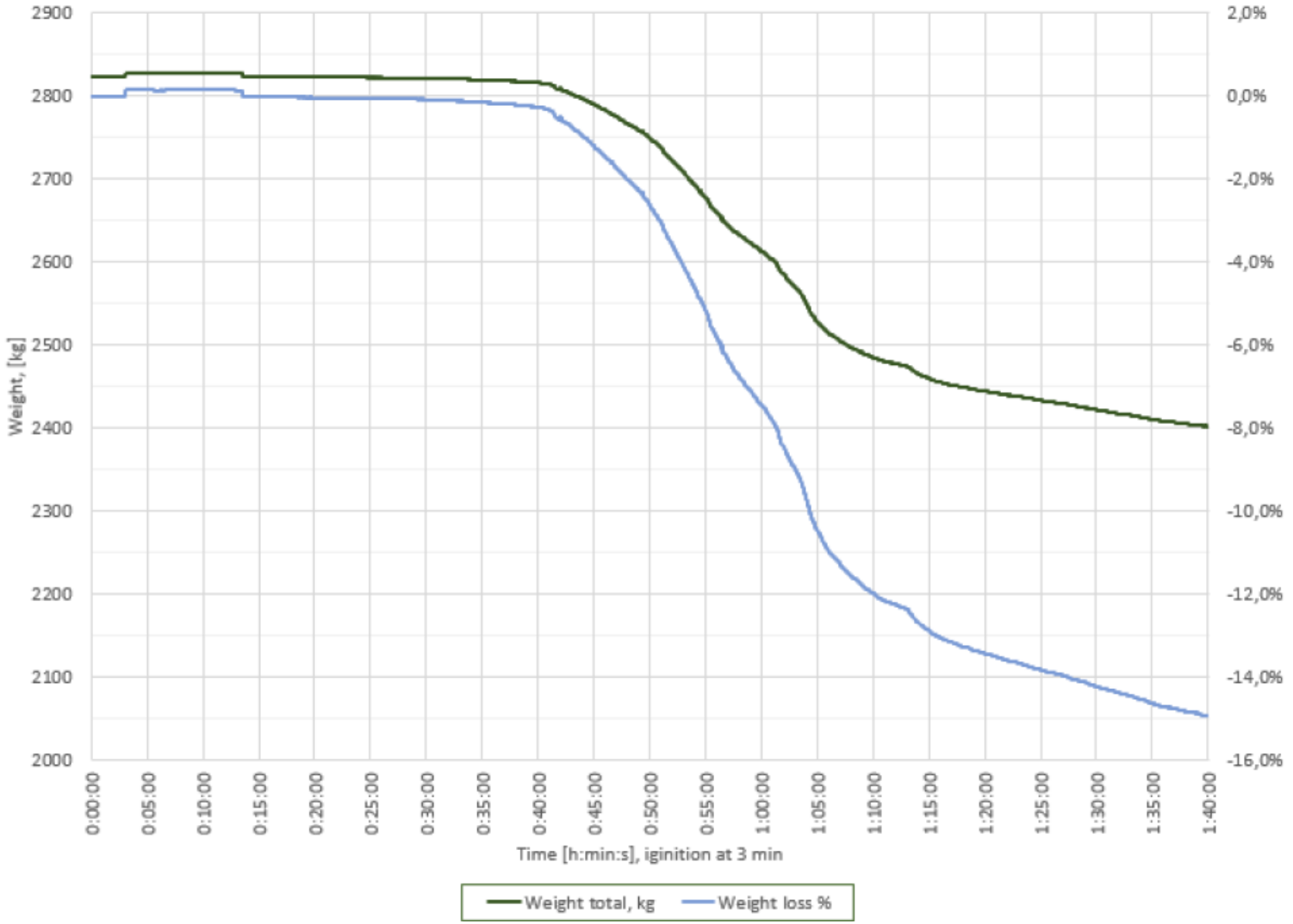


Temperatures Around the Vehicle – 10 cm

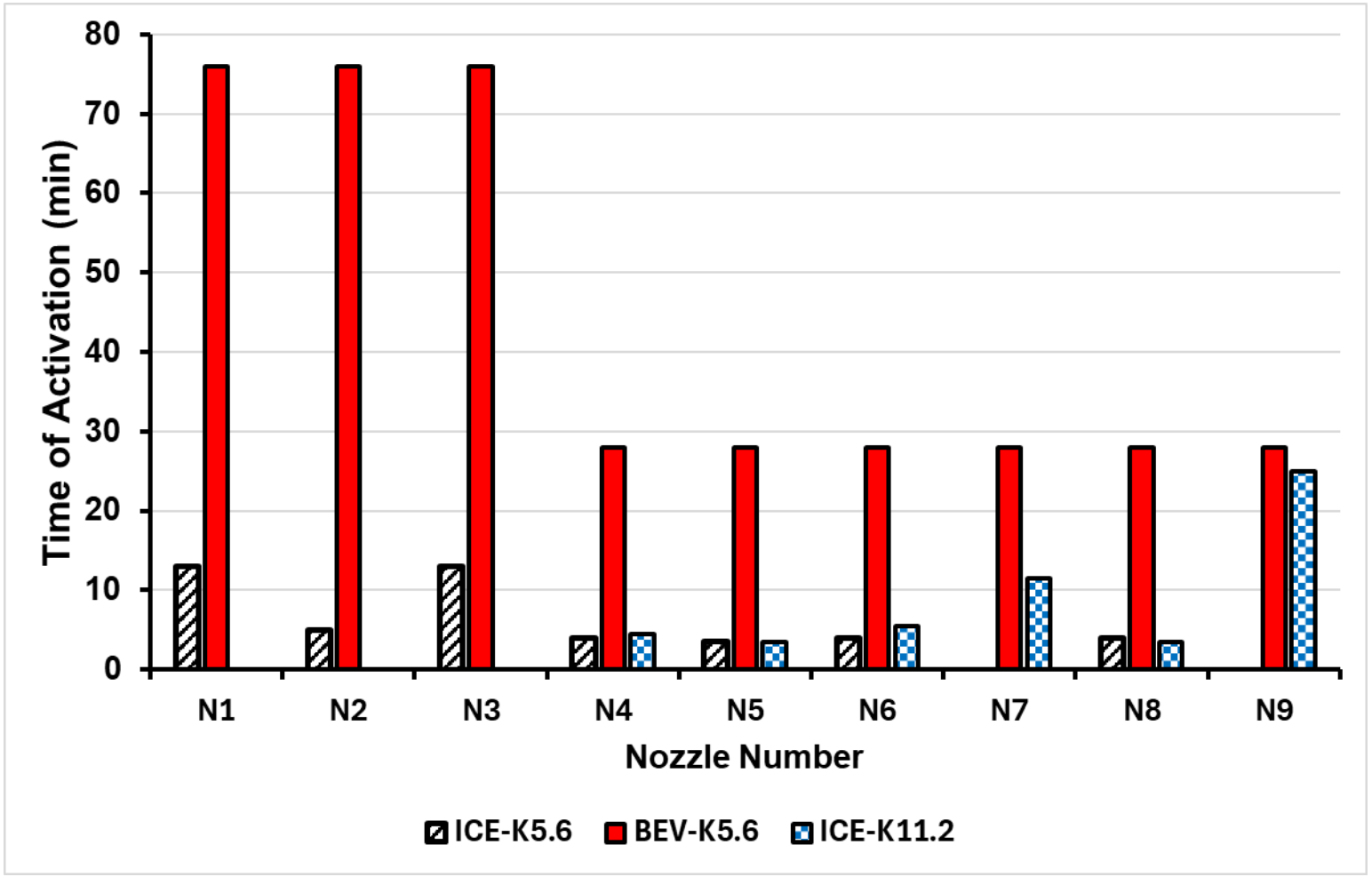


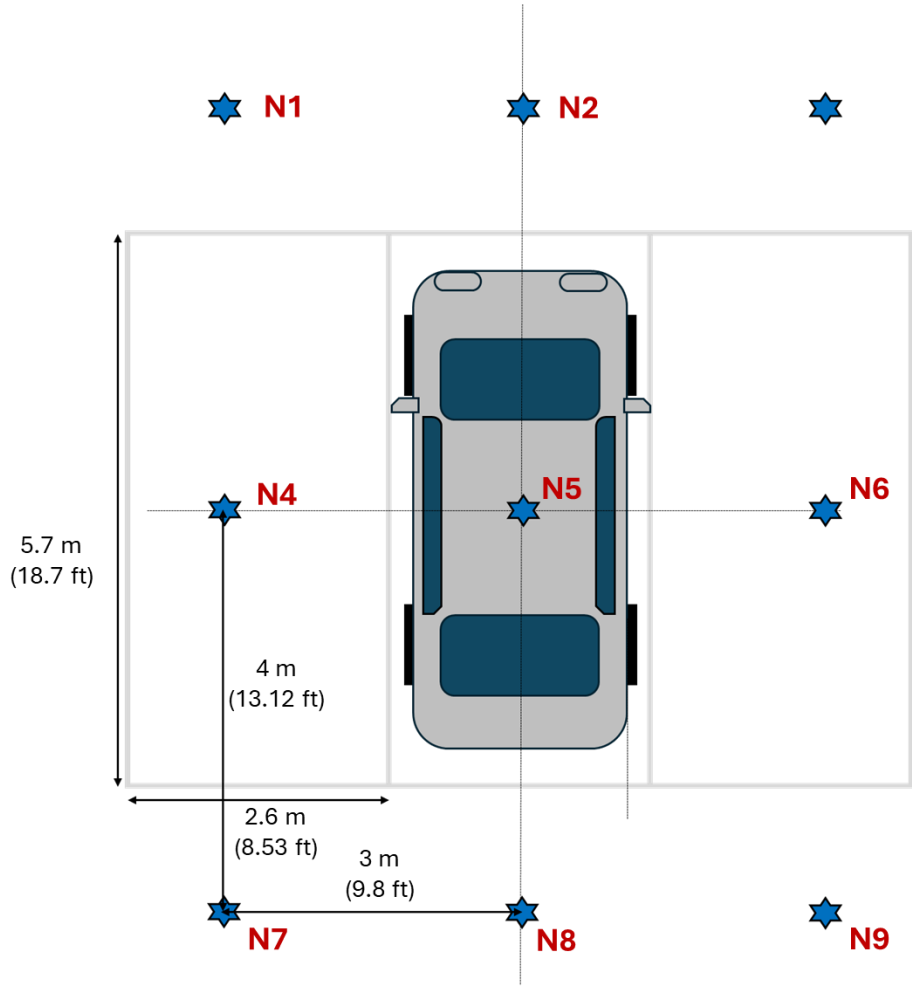
Results and Discussion – BEV Baseline

Mass Loss and Mass Loss Rate



Results and Discussion – Suppression Tests – Activation Times





Results and Discussion – Suppression Tests

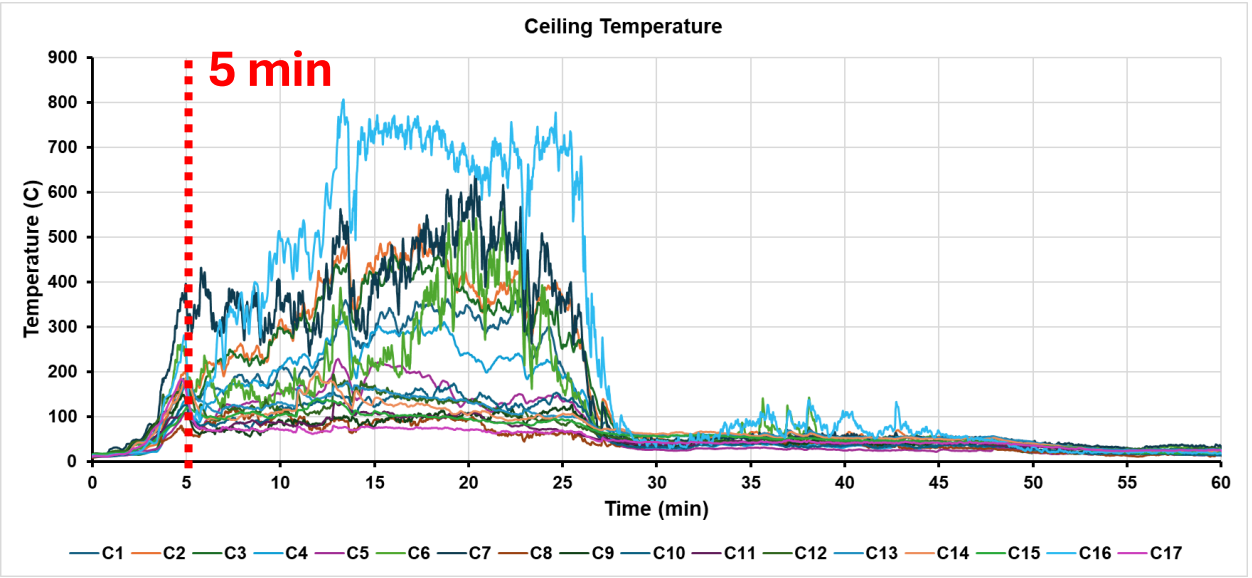
ICE – K5.6

ICE– K11.2

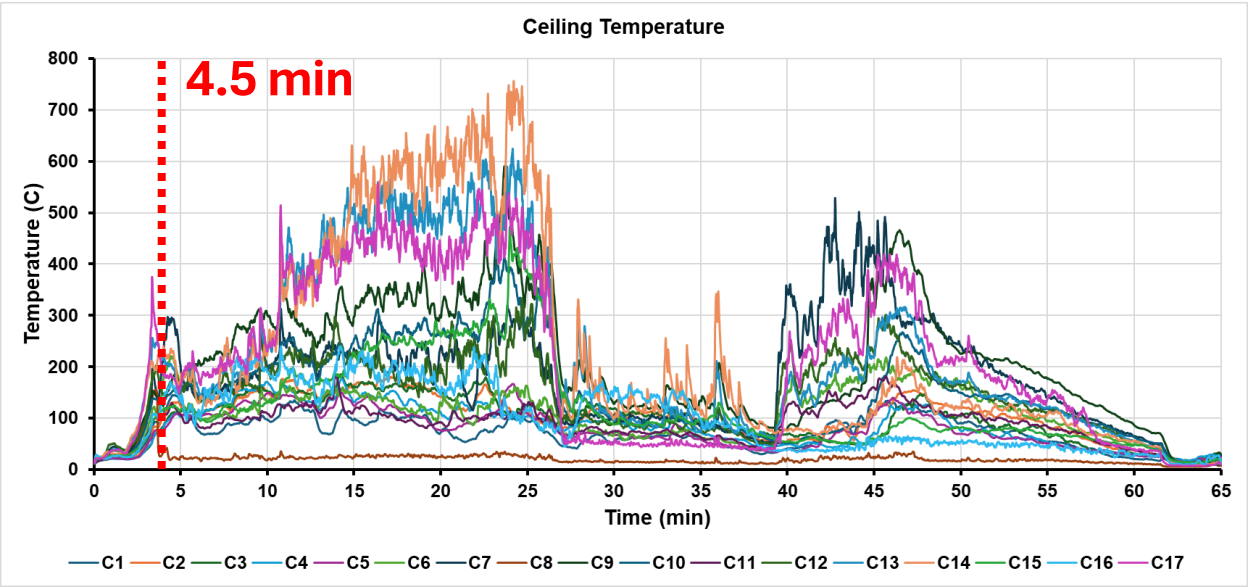
BEV– K5.6

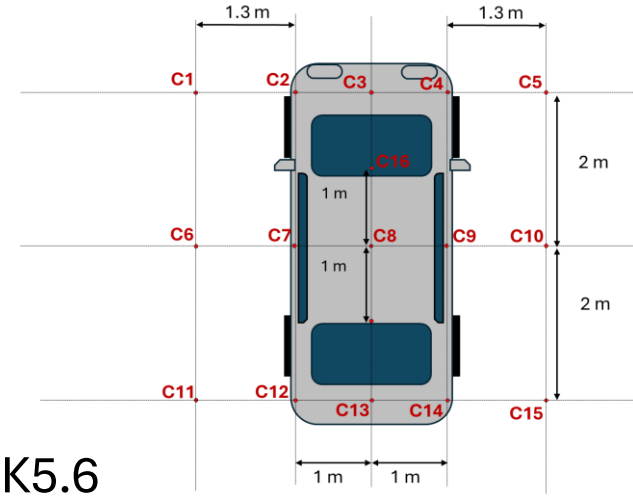
Results and Discussion – Suppression Tests – Ceiling Temperatures

ICE – K5.6

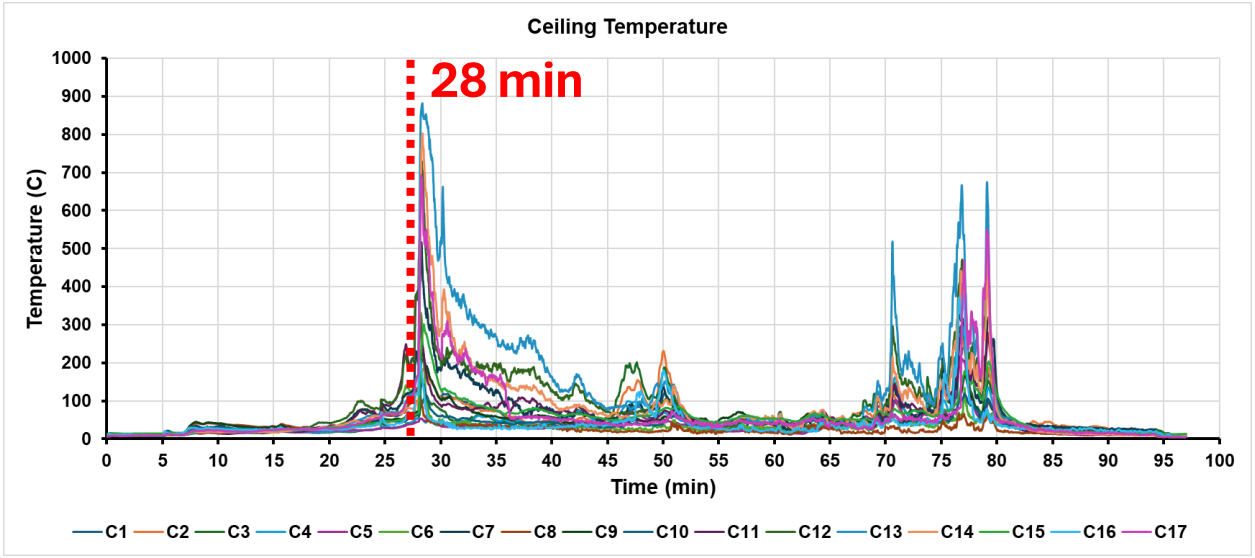


ICE– K11.2



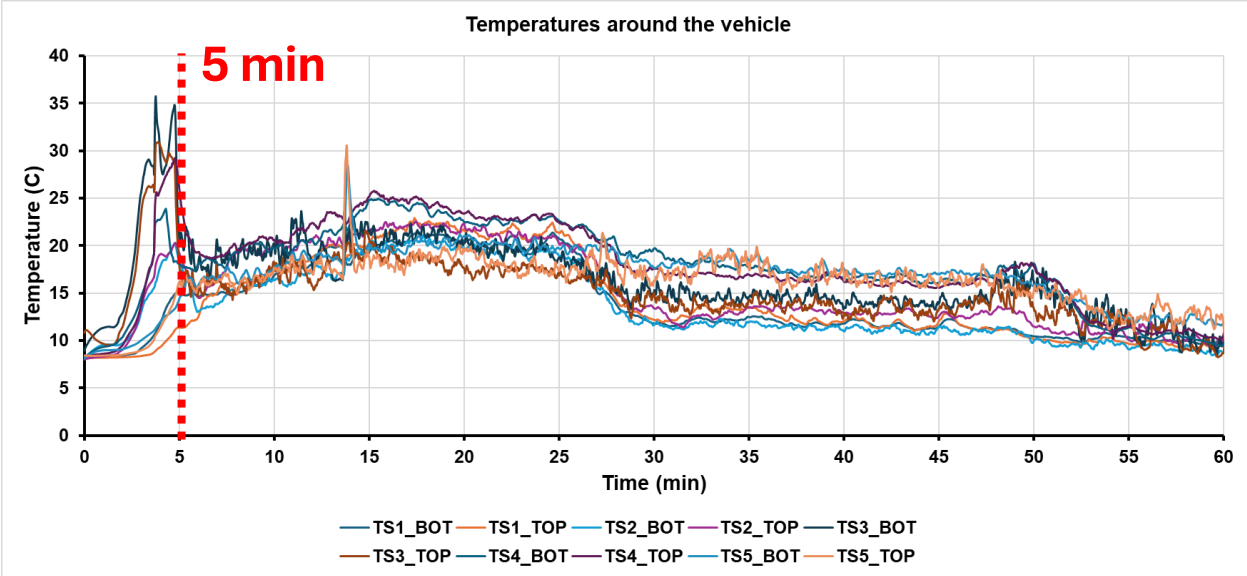


BEV– K5.6

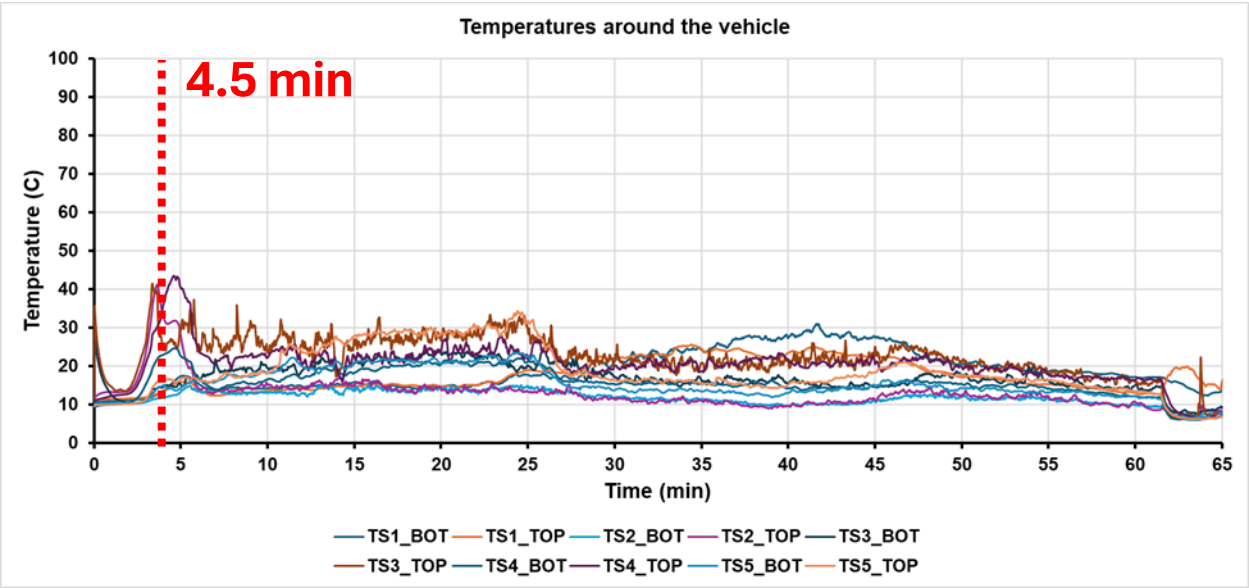


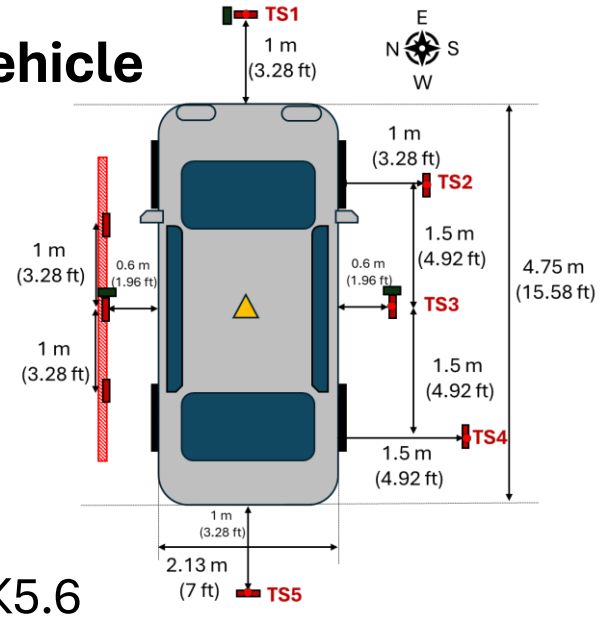
Results and Discussion – Suppression Tests – Temperatures Around the Vehicle

ICE – K5.6

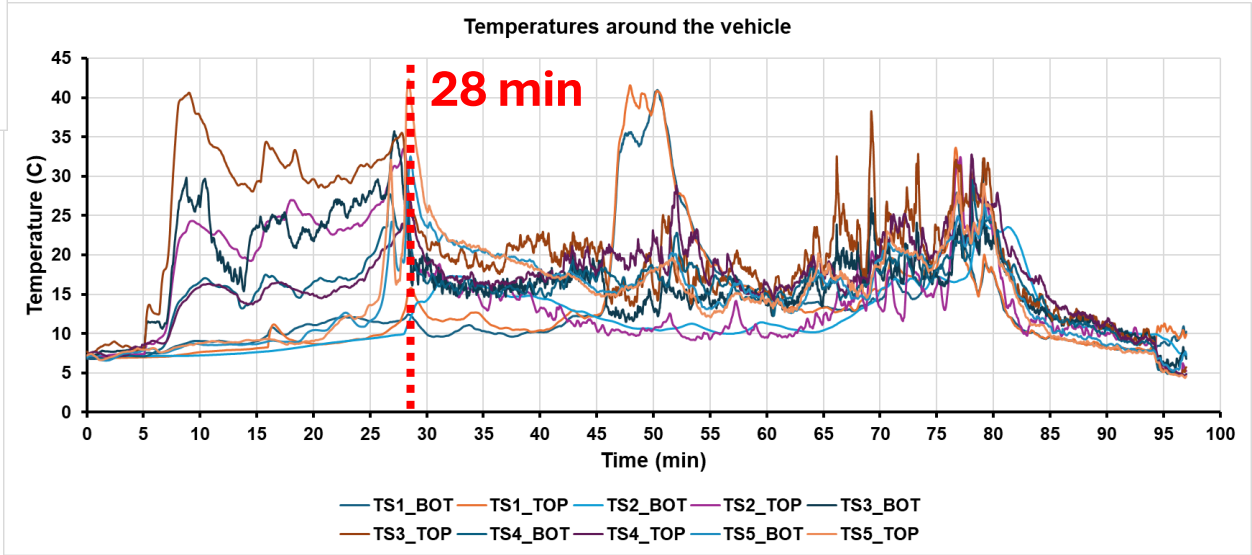


ICE– K11.2



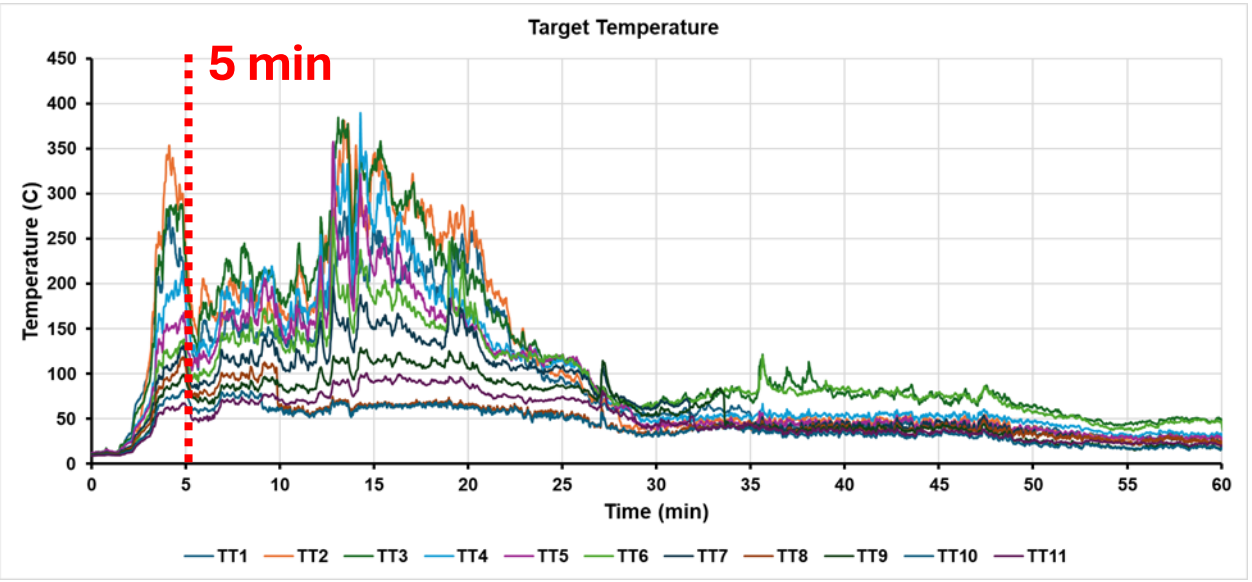


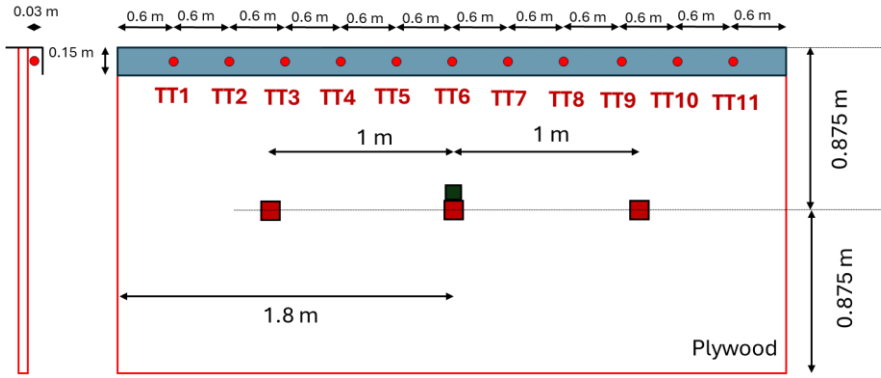
BEV– K5.6



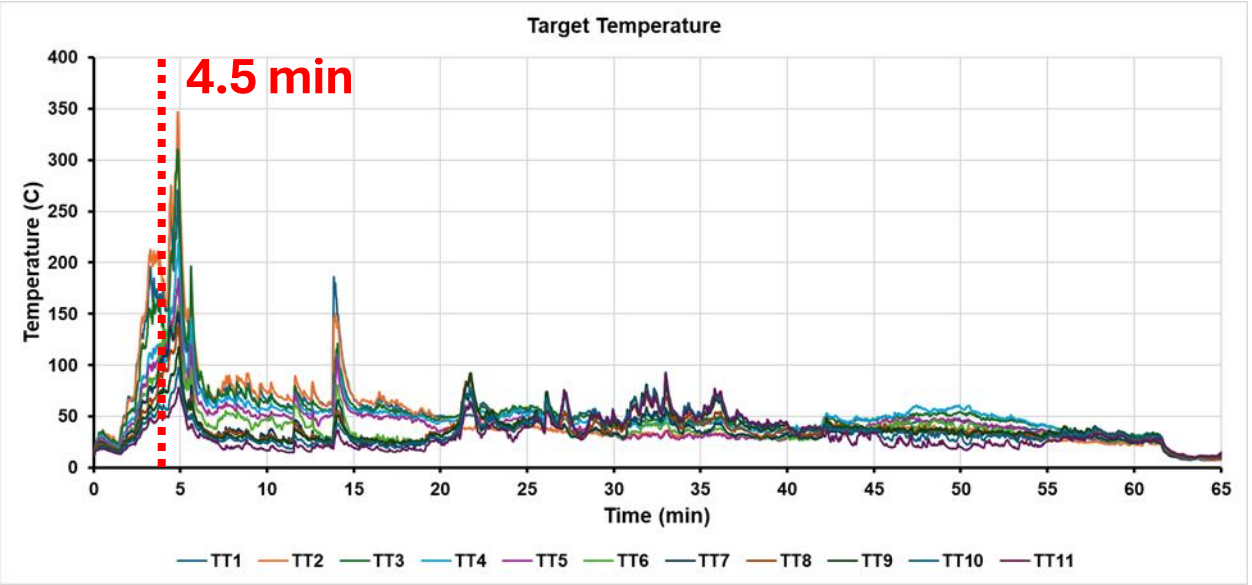
Results and Discussion – Suppression Tests – Target Temperatures

ICE – K5.6

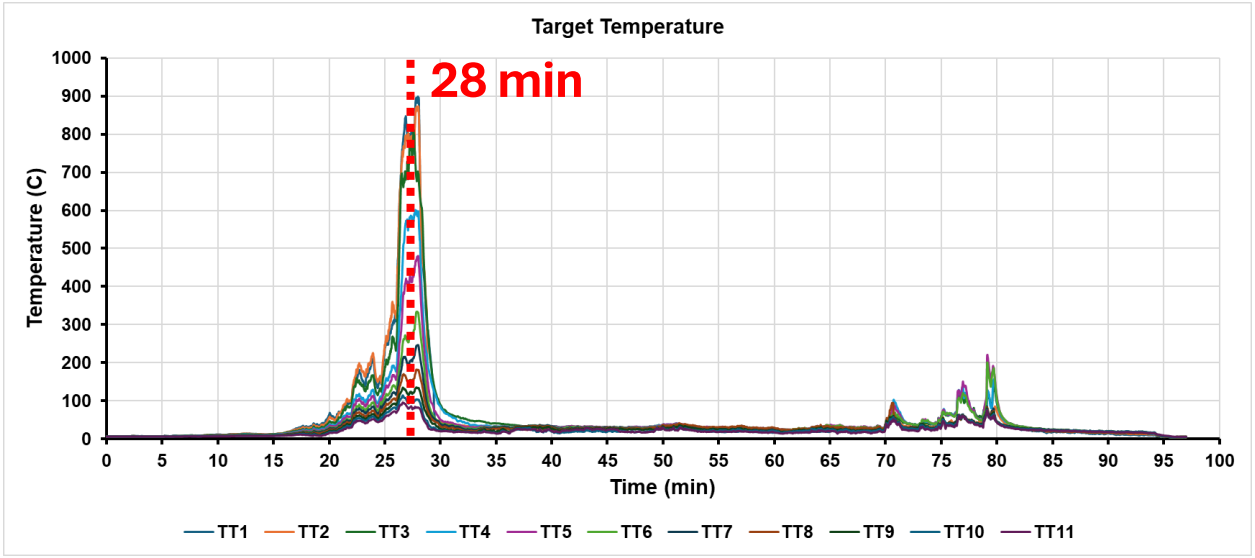




ICE– K11.2

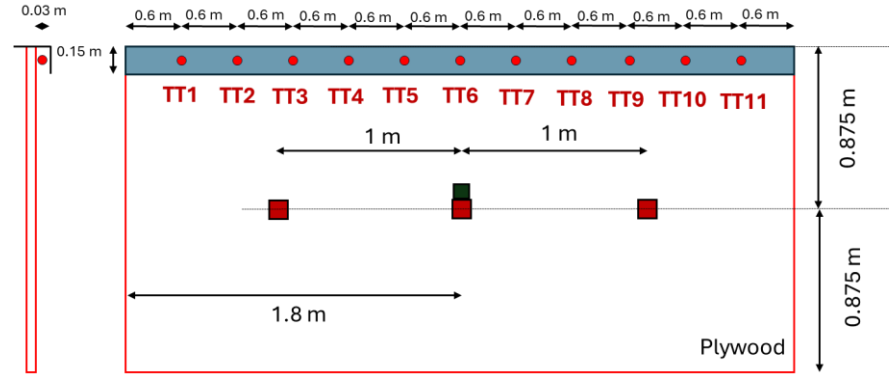


BEV– K5.6



Results and Discussion – Suppression Tests – Target Temperatures

ICE – K5.6



ICE– K11.2

BEV– K5.6

Conclusions

- This study examined the impact of sprinkler systems on ICE and BEV fires in parking garages, focusing on heat release, gas temperatures, fire development, and fire propagation.

- Baseline:
  - The maximum HRR was 7.5 MW.
  - The temperatures around the vehicle ranged between 150 and 250 C.
  - Temperatures inside the vehicle were around 900 C.

- Sprinkler:
  - The max temperature around the vehicle was around 40 C.
  - Temperatures inside the vehicle were around 900 C. But the fire development was slower.
  - For the K5.6 sprinklers, in both the ICE and BEV tests, the target temperature measurements meet the criteria specified in the IMO 1430 Guidelines."

  “after system activation the maximum five minute average at any of the four measurement location should not exceed 350 C”

- Further studies are required to study the impact of water mist on the BEV parking garage fires.

- Further studies are required to study the effectiveness of sprinkler systems on stacked car configurations.

Thank You!

NFPA®

RI. SE

Combustion Science & Engineering Inc