Fire Hazards and Sprinkler Protection in Parking Structures: Results of Full-Scale Testing

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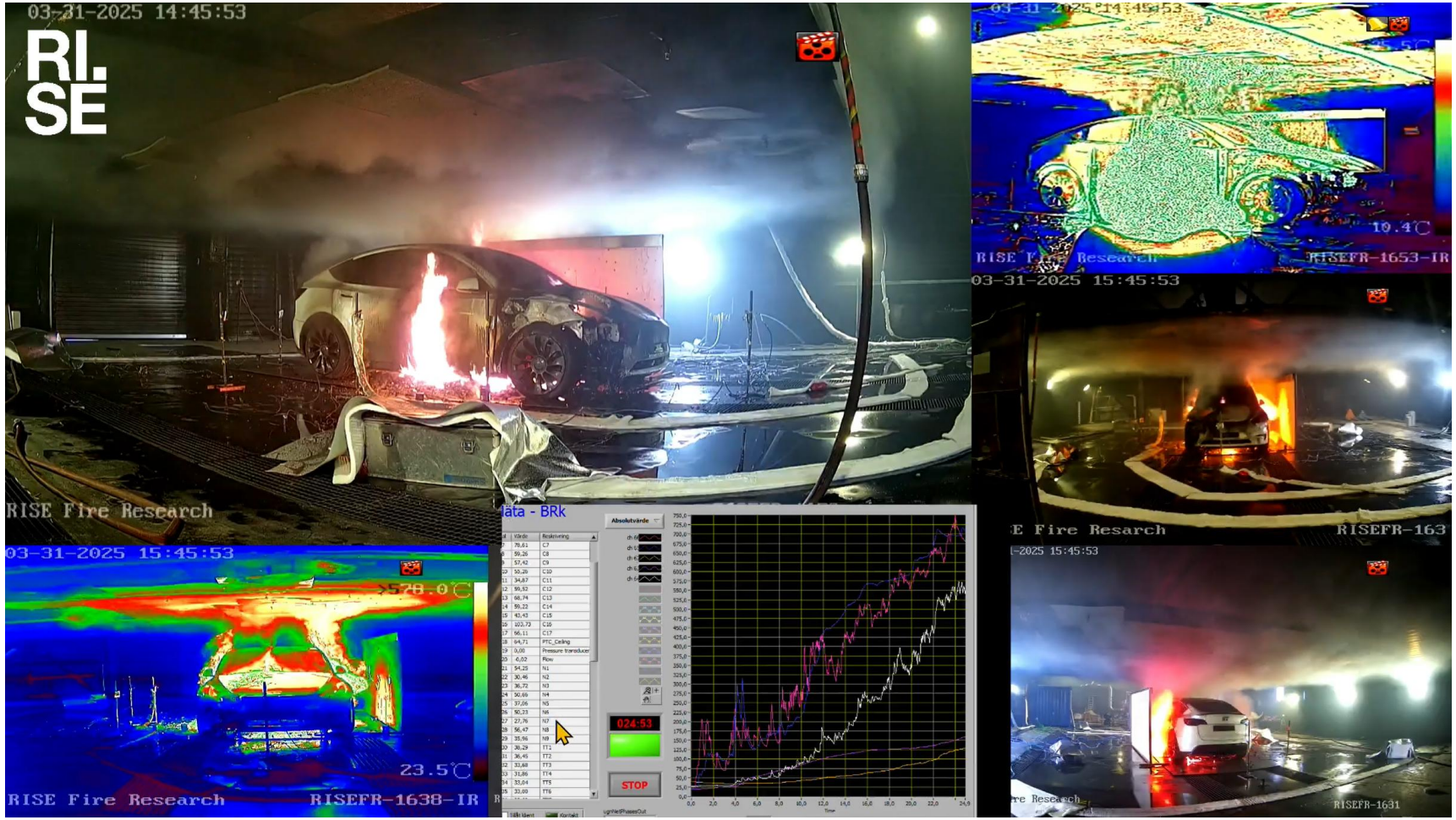
[3] RISE Research Institutes of Sweden, Sweden

[4] Fire Protection Research Foundation, USA

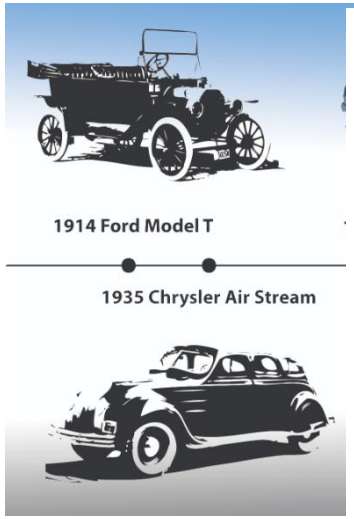
NFSD Nordic Fire & Safety Days

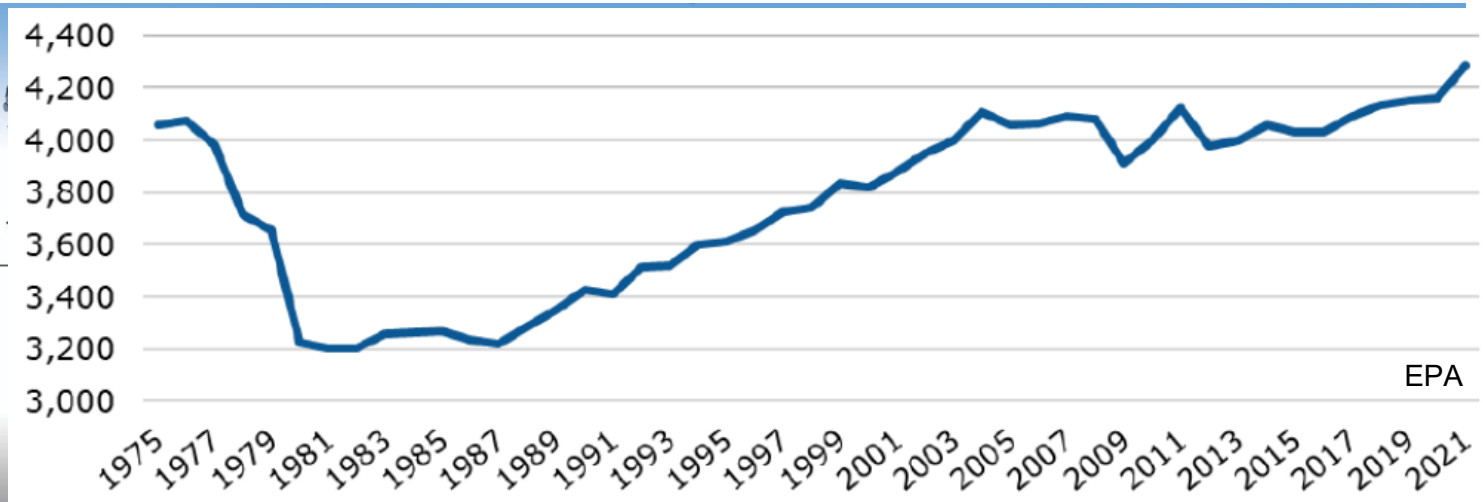
Outline

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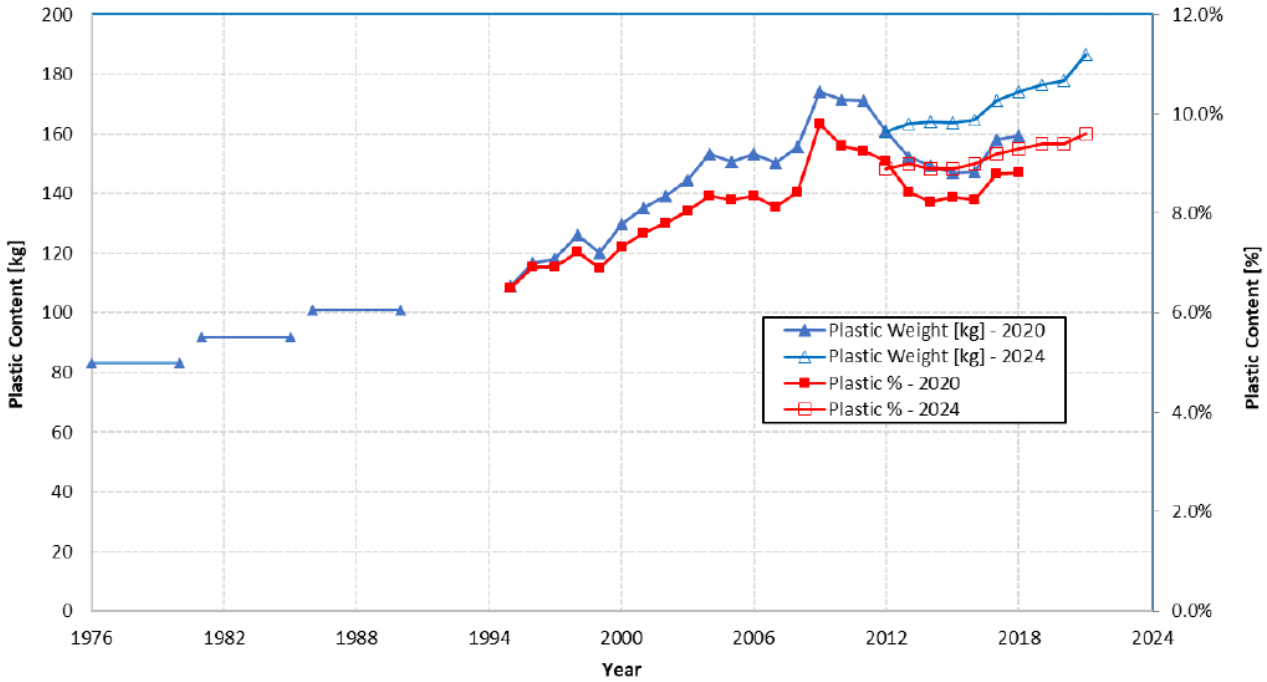
Background





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.

NFPA 88A (**Standard for Parking Structures**) 2019 states that all parking structures are required to have a sprinkler systems. The 2022 edition of NFPA 13 changed the hazard grouping for parking garages from OH1 to **OH2**.

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 (L/min/√bar)	Water Pressure (bar)	Water Flow Rate (L/min/nozzle)	Number of Activated Nozzles out of 9
1	BEV*	Burner	-	-	-	-
2	ICE	Pool Fire	80	1.5	100	7
3	BEV*	Burner	80	1.5	100	9
4	ICE	Pool Fire	160	0.5	113	6
5	BEV* , +	Burner	80	1.5 (0.6**)	100 (62**)	9

*Li-ion – 78 kWh

** Pressure drop at t= 40 min due to pump malfunction.

+ Fire extinguished before the battery got involved.

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]. The oxy-acetylene burner was operated for 10 min to promptly puncture a hole in the plastic and aluminium casing surrounding the battery, and then was turned off. A small propane burner with a capacity of 15.5 kW, pointing to the hole, continued to heat the battery cells until they reached a sustained thermal runway.
- **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.

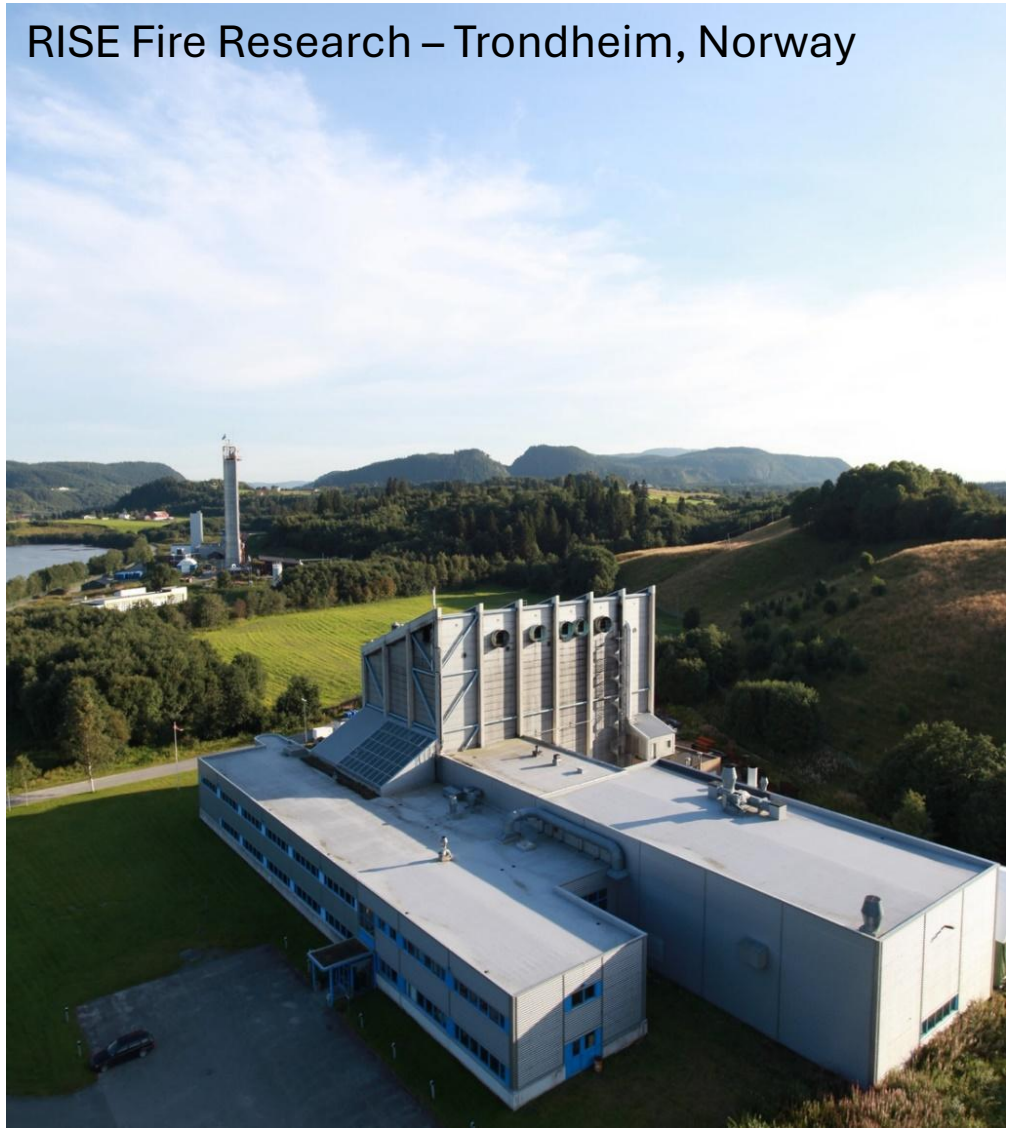
[1] S.M. Olenick, M.S. Klassen, N. Hussain, “Classification of Modern Vehicle Hazards in Parking Structures & Systems -Ph II Final Report”, 2024
[2] Jonna Hynynen, Ola Willstrand, Per Blomqvist, Petra Andersson, “Analysis of combustion gases from large-scale electric vehicle fire tests”, Fire Safety 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. 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.

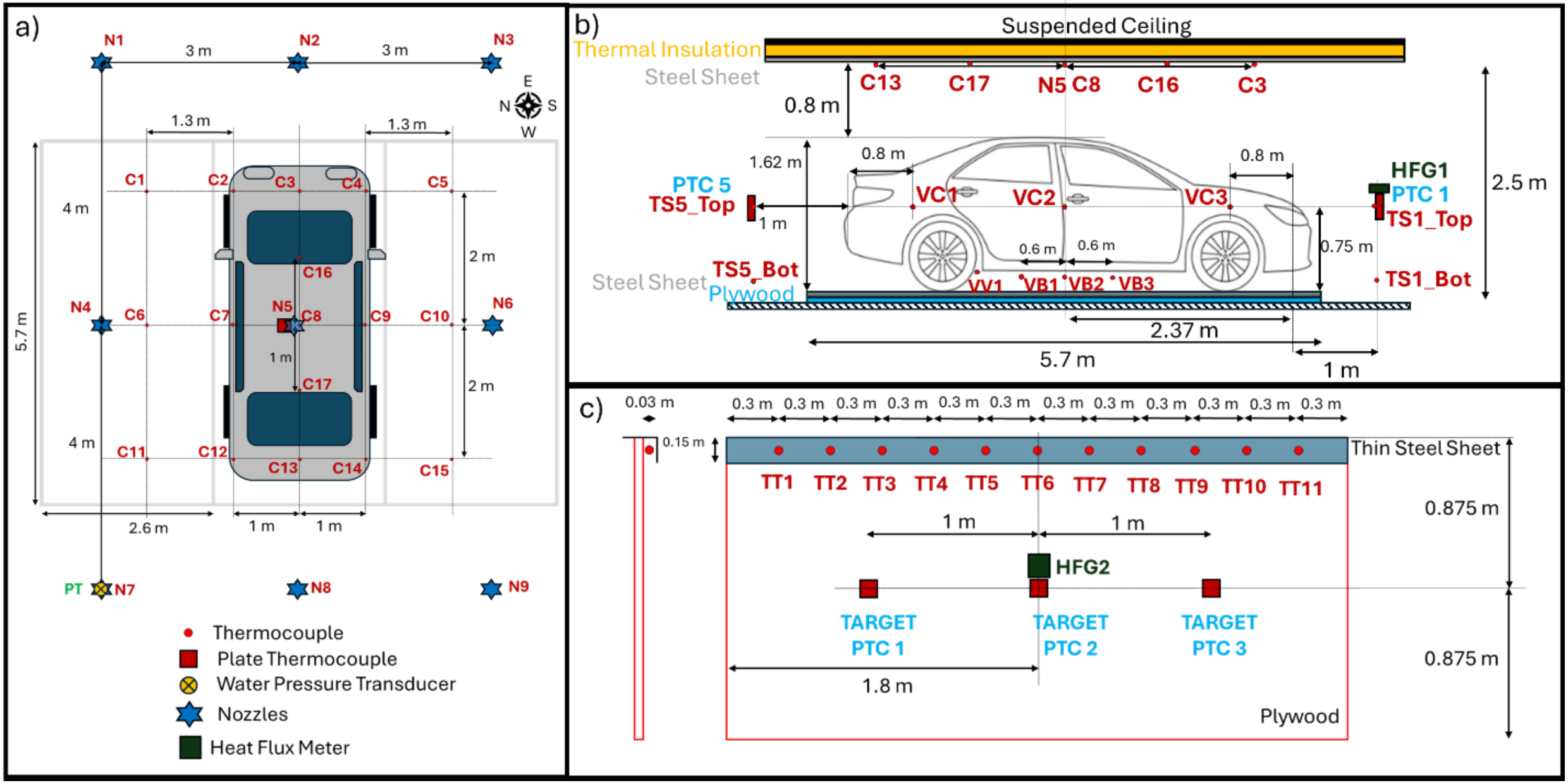
Experimental Setup



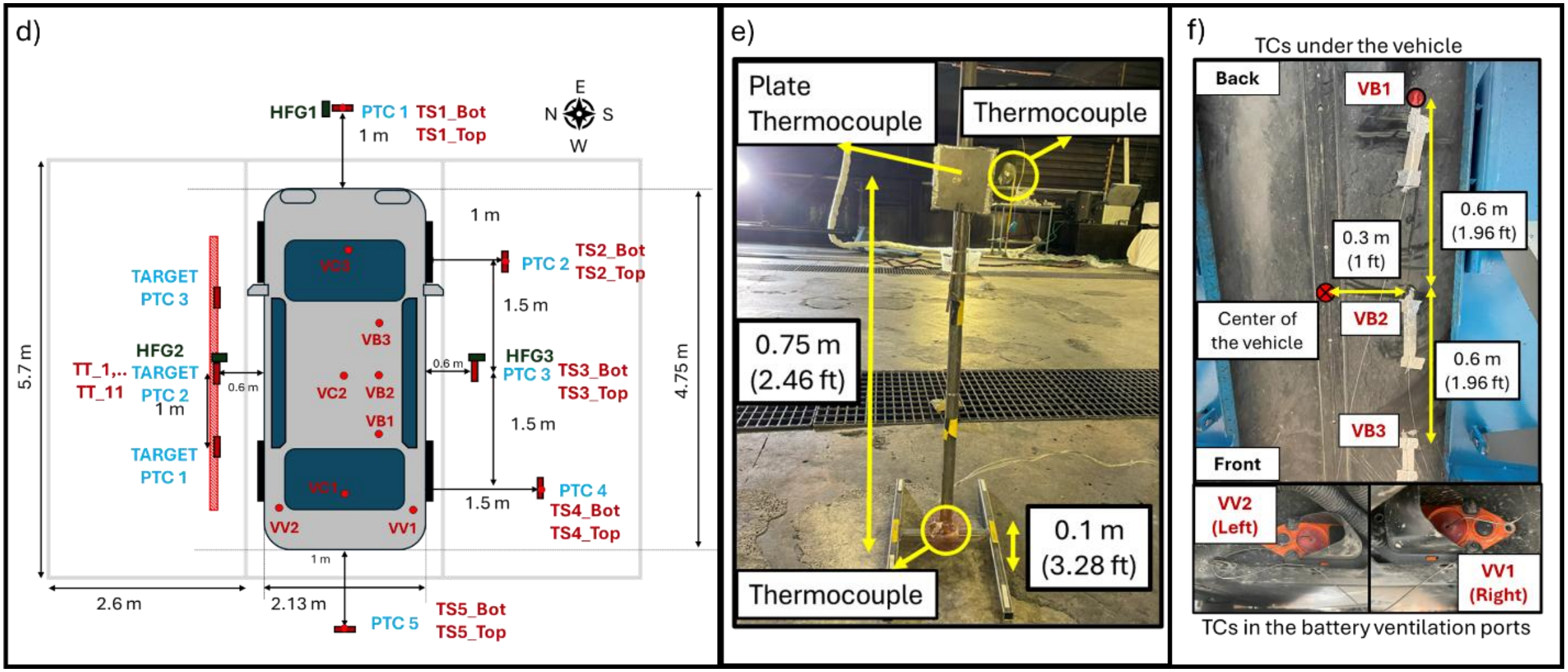


34 m × 17 m × 22 m indoor fire hall

Test Setup – Instrumentation



Test Setup – Instrumentation



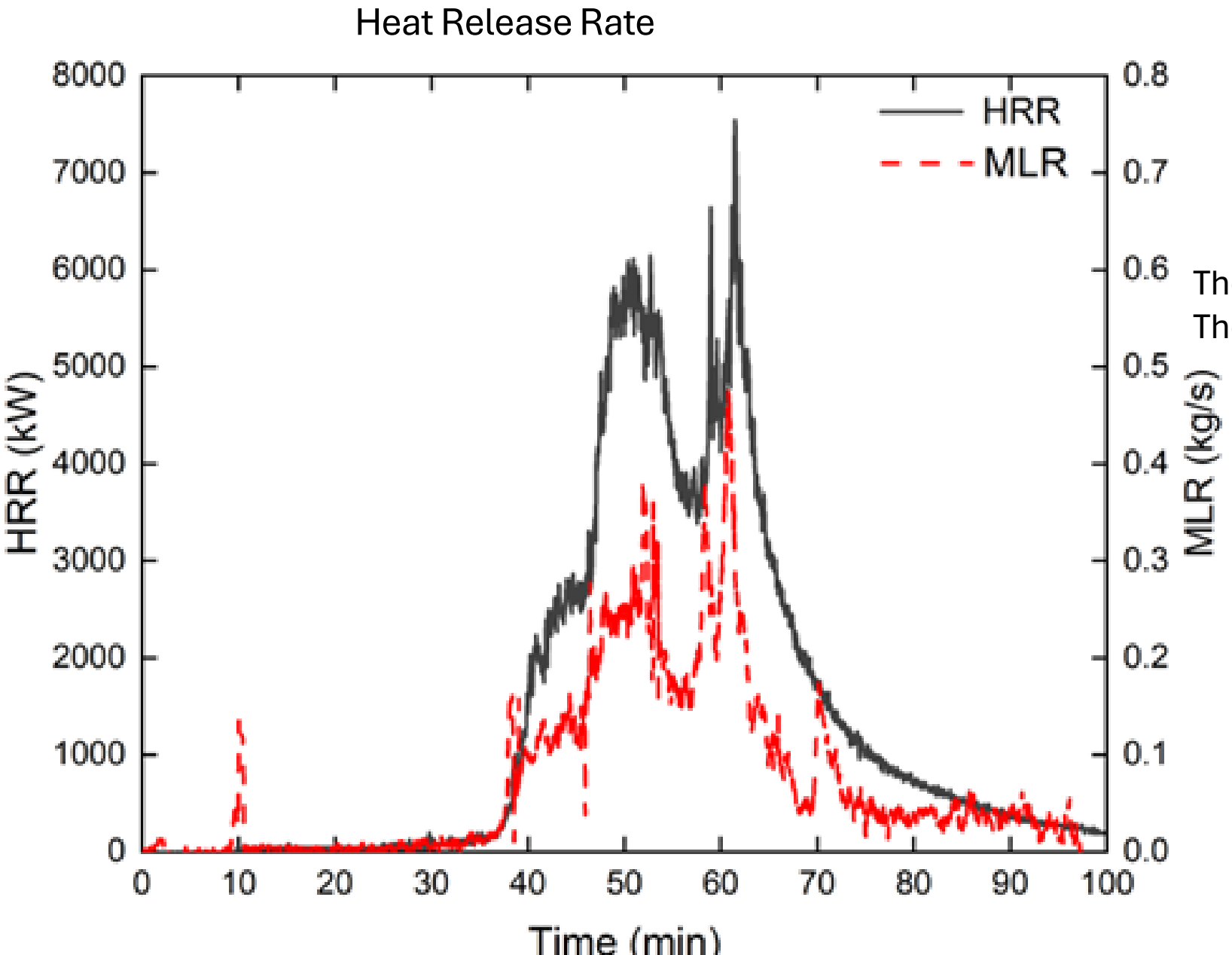
Results and Discussion – BEV Baseline

The state-of-the-art Battery Safety Lab at RISE in Borås, Sweden





Results and Discussion – BEV Baseline



The total mass loss was 435.5 kg.
The effective heat of combustion of 18.9 MJ/kg.

Results and Discussion – Suppression Tests

ICE – K80



ICE– K160

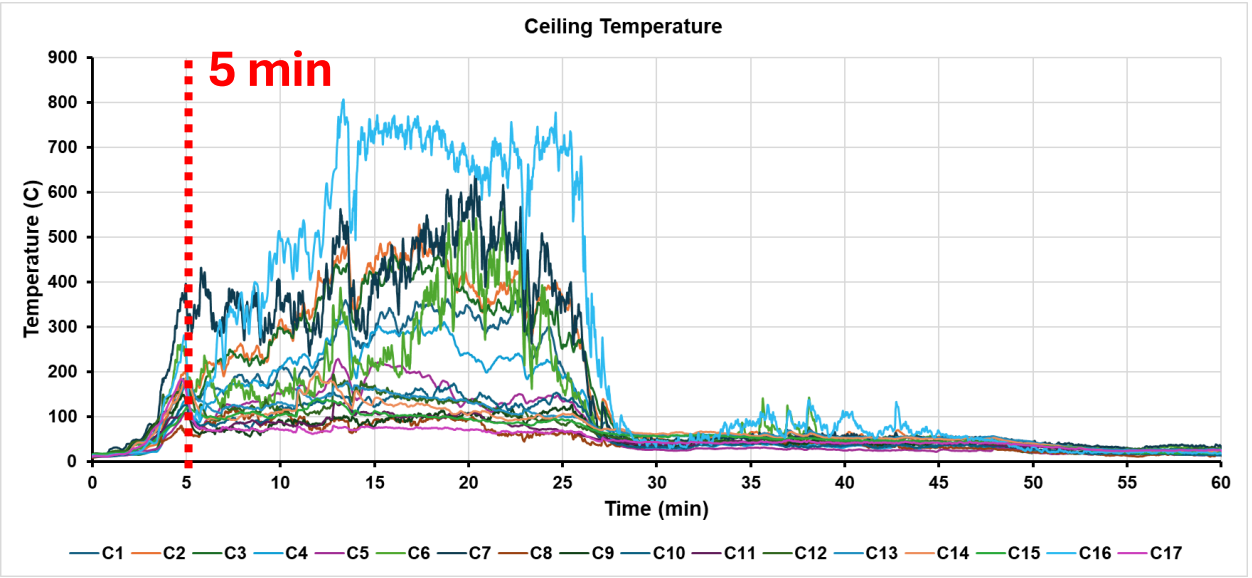


BEV– K80

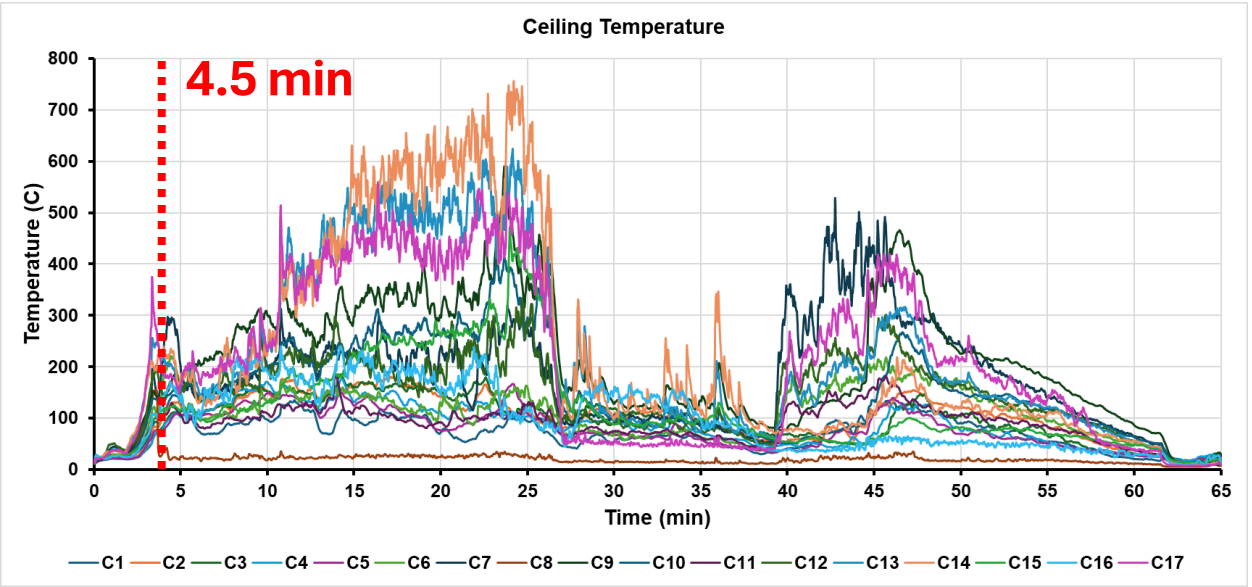


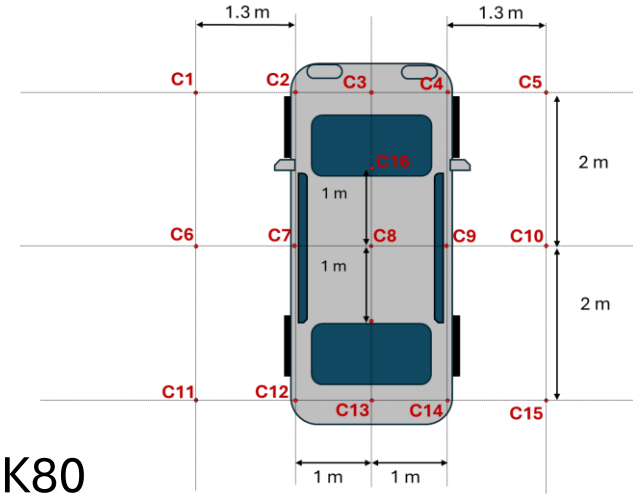
Results and Discussion – Suppression Tests – Ceiling Temperatures

ICE – K80

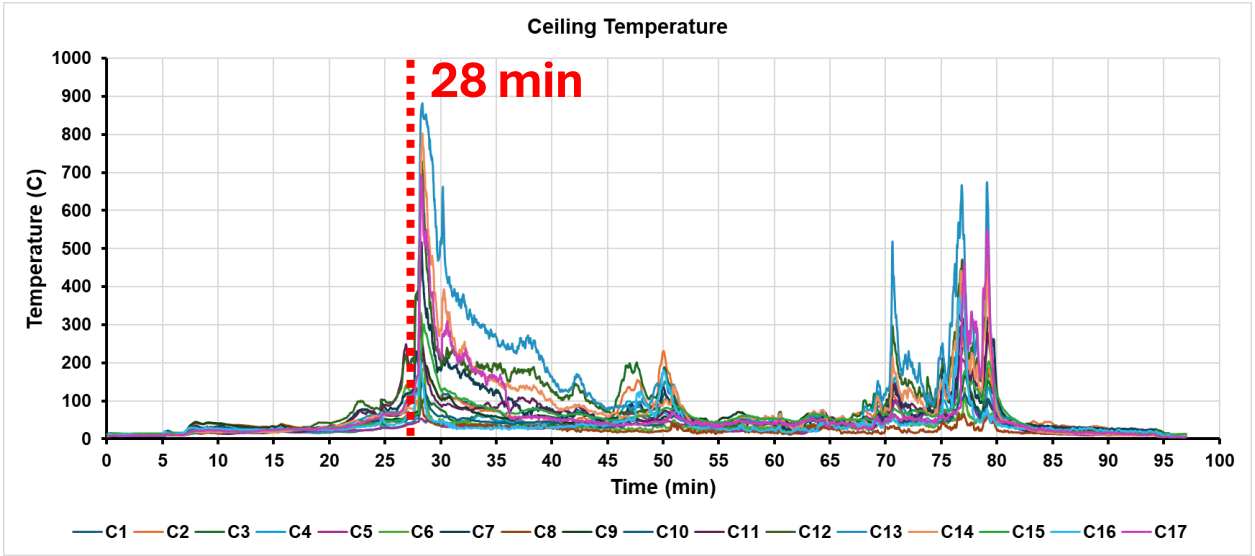


ICE– K160

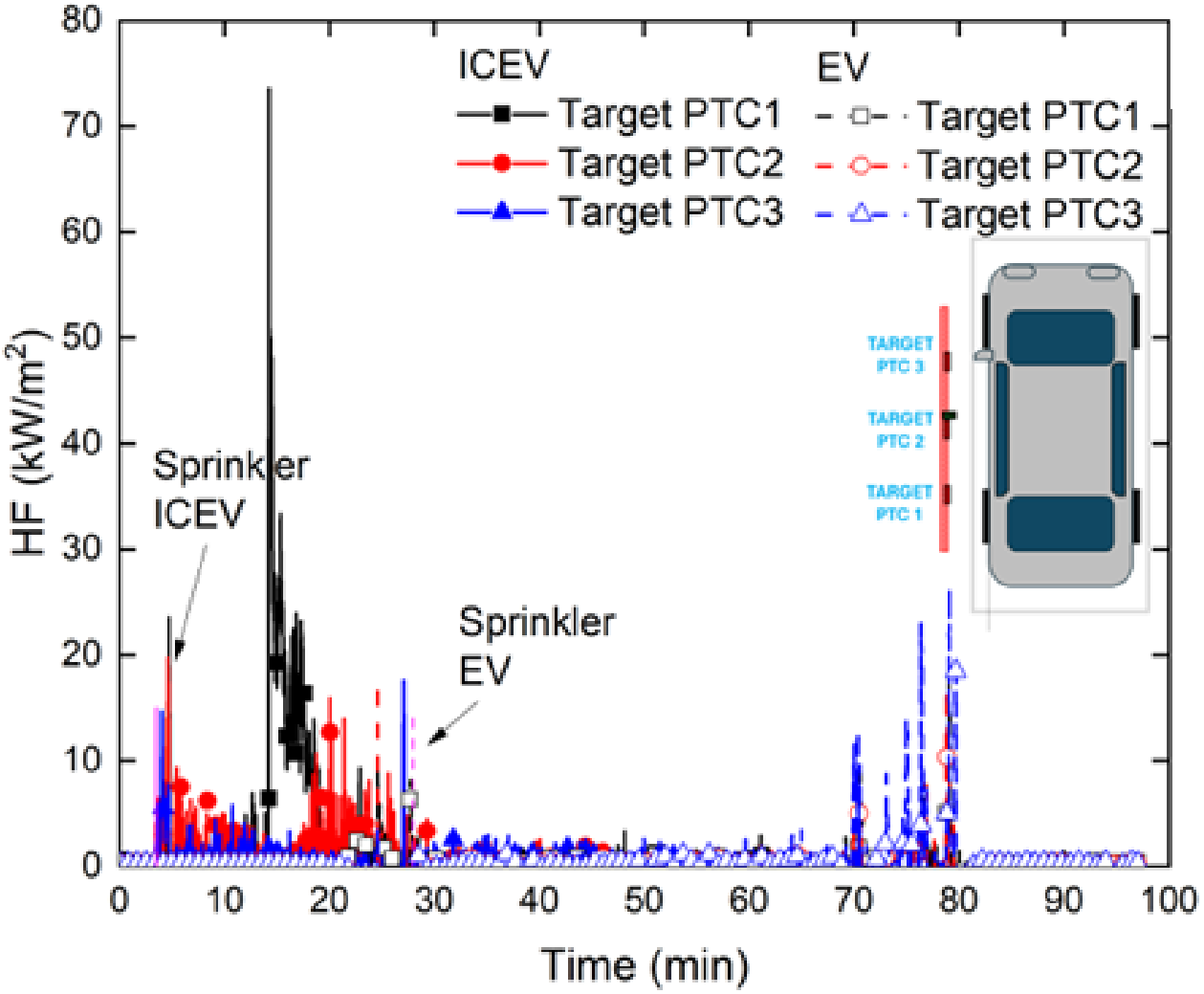


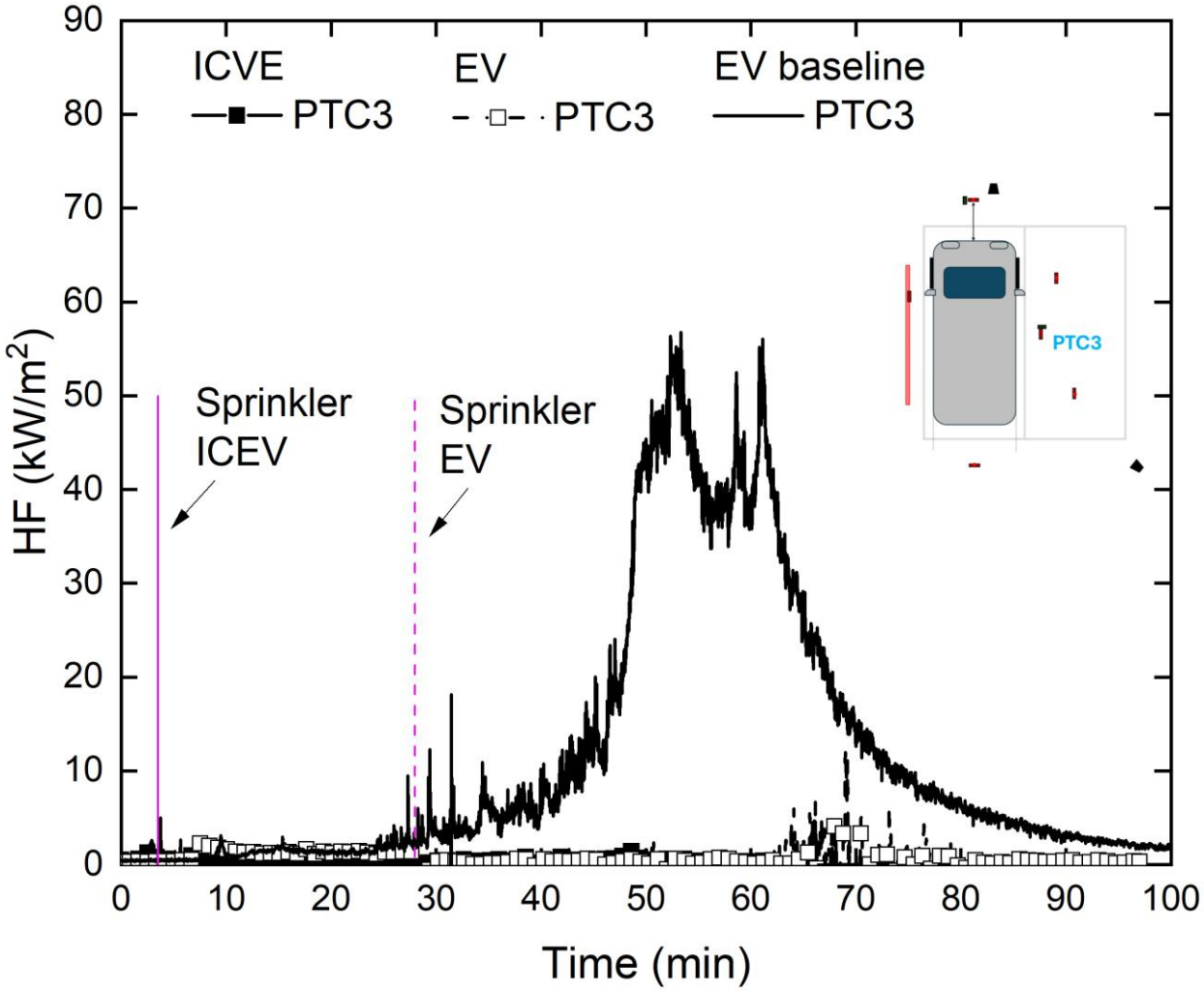


BEV– K80



Results and Discussion – Heat Flux Around the Vehicle



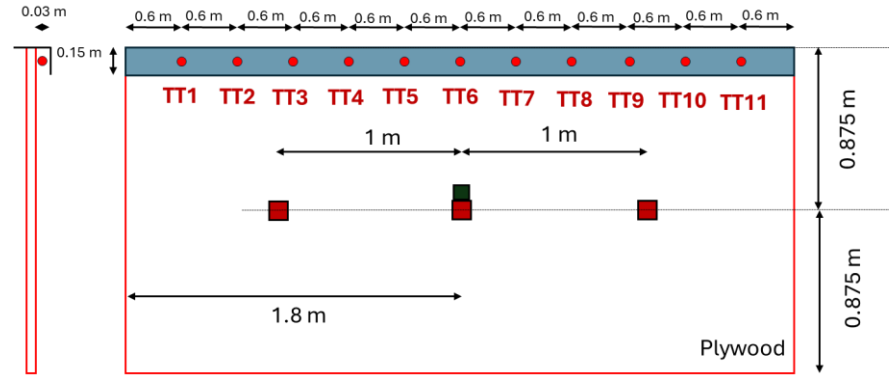


The critical ignition heat flux for many plastics is **25 kW/m²** (Olenick S et al, 2024). The BRE (2010) study suggested that a heat flux of **9 kW/m²** at the target location for over 1 min can be considered a condition that could ignite shielded (i.e., dry) plastics on neighbouring vehicles.

Results and Discussion – Suppression Tests – Target Temperatures

ICE – K80





ICE– K160



BEV– K80



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 max heat flux measured 0.6 m away from the BEV was **60 kW/m^2**

- Sprinkler:
  - The maximum heat flux measured 0.6 m away from the ICE was **5 kW/m^2**, while the BEV measured **12.6 kW/m^2**.
  - On the target size, the maximum heat flux for the ICE was **74 kW/m^2** and was **26 kW/m^2** for the BEV.

  - For the K80 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”

  - However, the target got heavily charred due to the jet flame impingement in the BEV test.

  - The risk of fire spread to nearby objects is high under the current experimental setup.

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

Thank You!

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