Full-Scale Lithium-Ion Battery Electric Vehicle Fire Testing

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Outline

- Introduction
- Methods: General Test Setup
- Results
  - Test Overview
  - Vehicle Ignition
  - First Suppression Period
  - Post Initial Suppression “Battery Fire”
  - Second Suppression Period
- Analysis
  - Heat Release Rate
  - Hose Stream
- Recommendations

Introduction

- Driving Questions

  What happens when a BEV catches fire?

  How is the fire characterized?

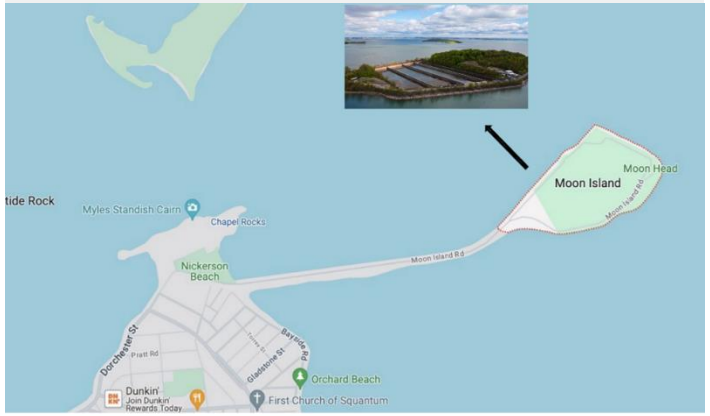
  How much water is needed?

  Can you put the fire out? Do you need to?

- Goals
  - Instrument an intact BEV
  - Induce thermal runaway through thermal heating
  - Observe and measure firefighter interactions during suppression efforts
- Outcome
  - Better understanding for BEV fires
  - Improve the methodology for subsequent BEV testing

Methods: General Test Setup

Moon Island Training Academy (MITA), Boston harbor.

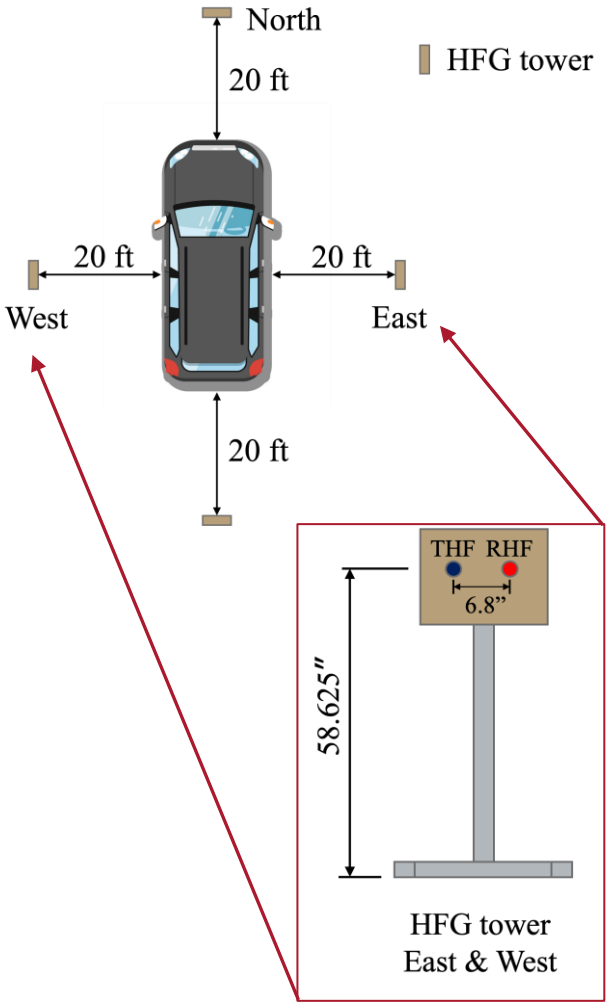


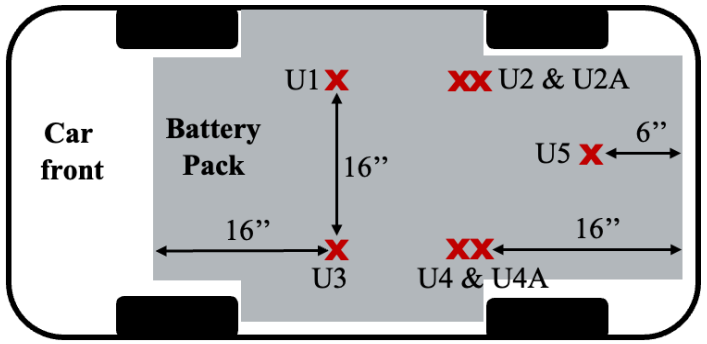
59°F, overcast

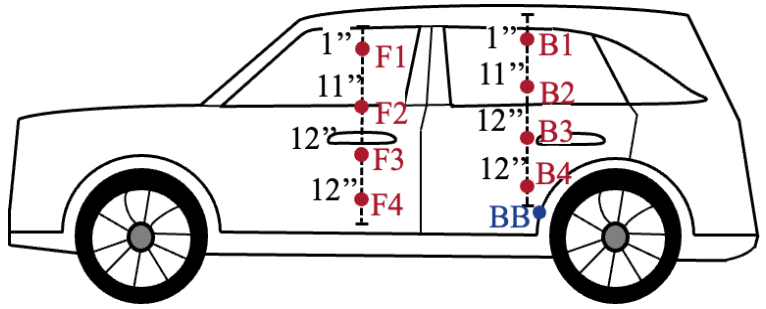
Make	Hyundai Kona [1]
Engine capacity	Motor - 150 kW
Engine type	Electric
Battery type	lithium-ion
Size (length, width, height) [inches]	164, 70.9, 61 approximately
Weight	Approximately 3715 lbs
Typical combustible materials	Engine cover, batteries, seats, plastic parts, tires

[1] "*VINDECODERZ*". Available at https://www.vindecoderz.com/EN/check-lookup/KM8K33AG1LU064666.

Methods: Instrumentation

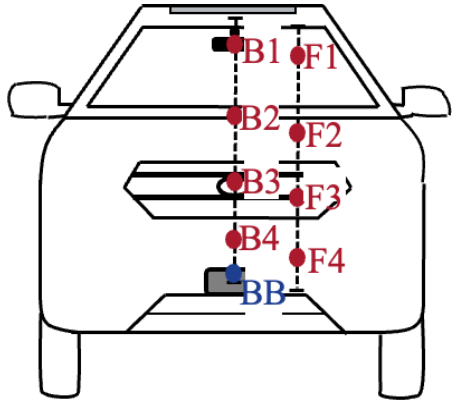




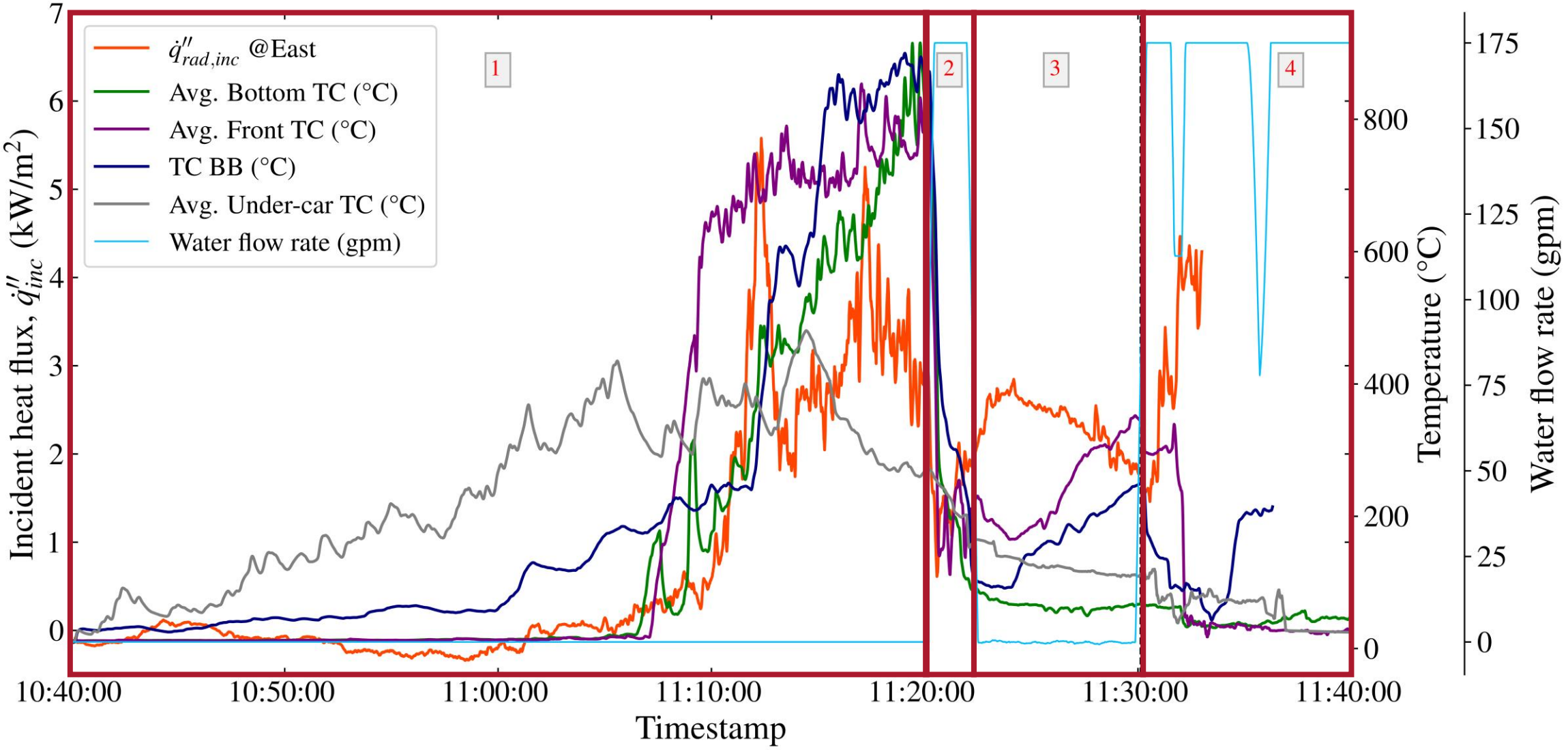


U2A, U4A
(armored)

U1 – U5
(unarmored)

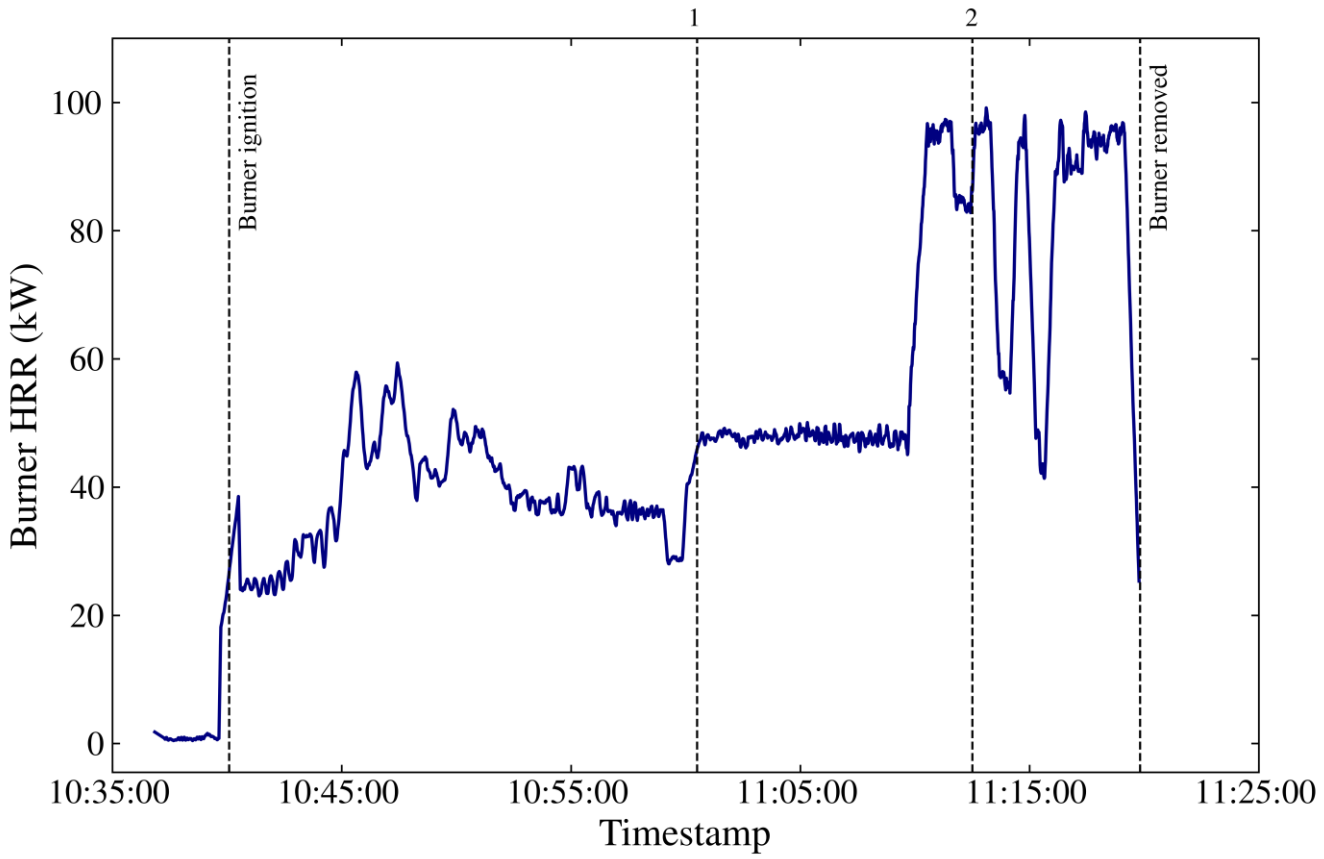


Results: Test Overview



Vehicle Ignition

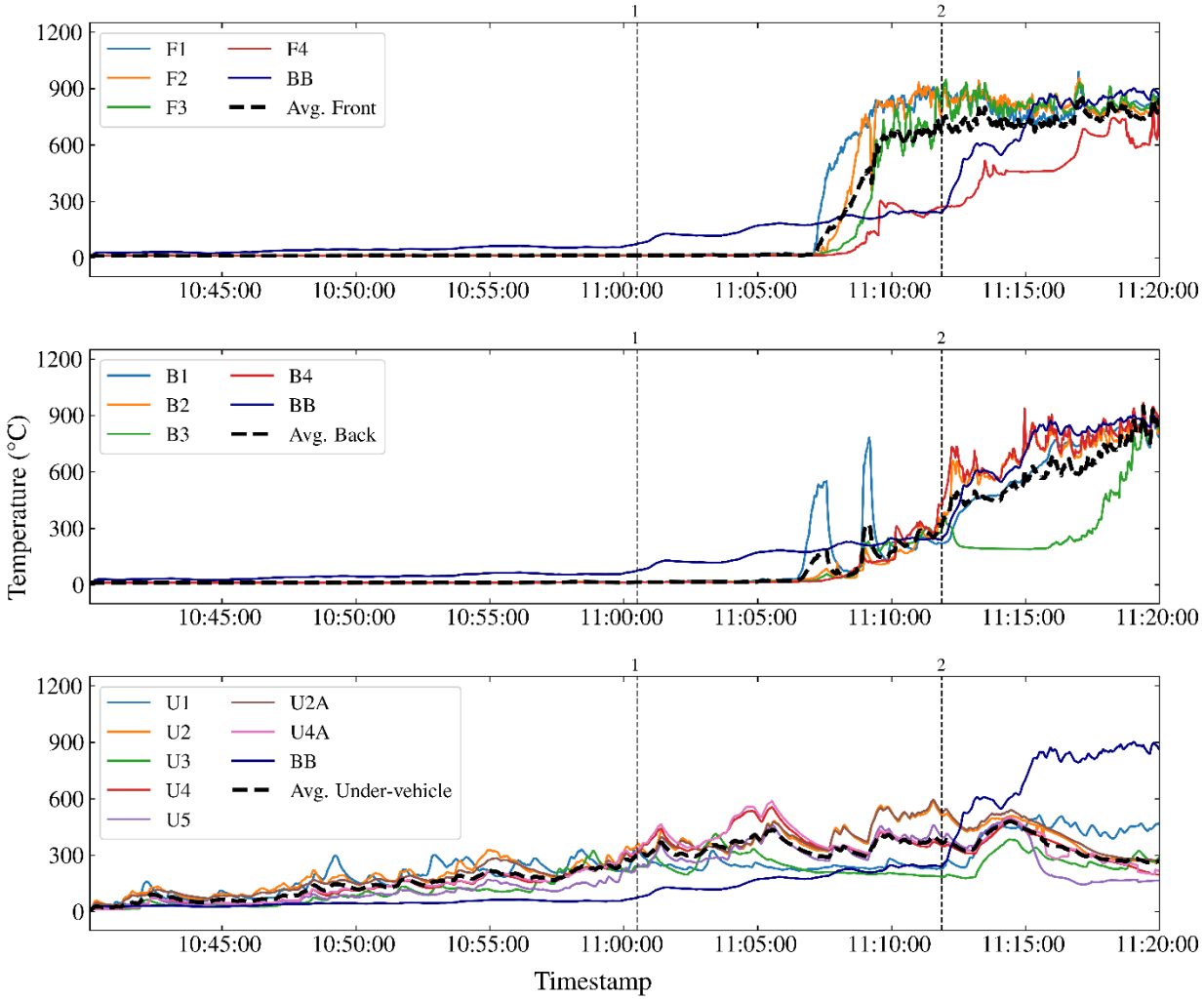
(10:40:04 – 11:20:15)

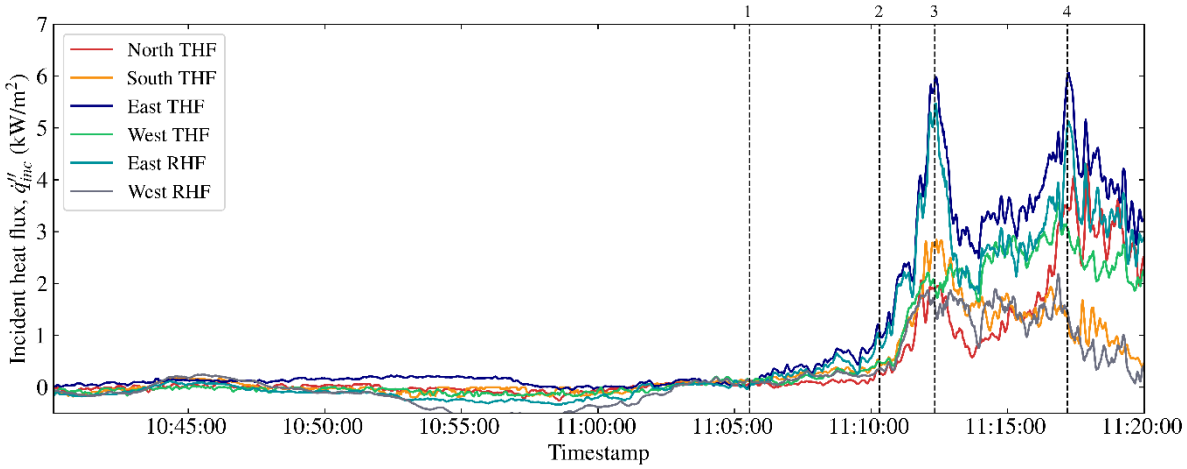


- Timings:
  - Burner starts at 10:40:04
  1. Car fire starts at 11:00:30 (W)
  2. Highest $\dot{q}''_{rad,inc}$ at 11:12:20 (E)

Vehicle Ignition

(10:40:04 – 11:20:15)

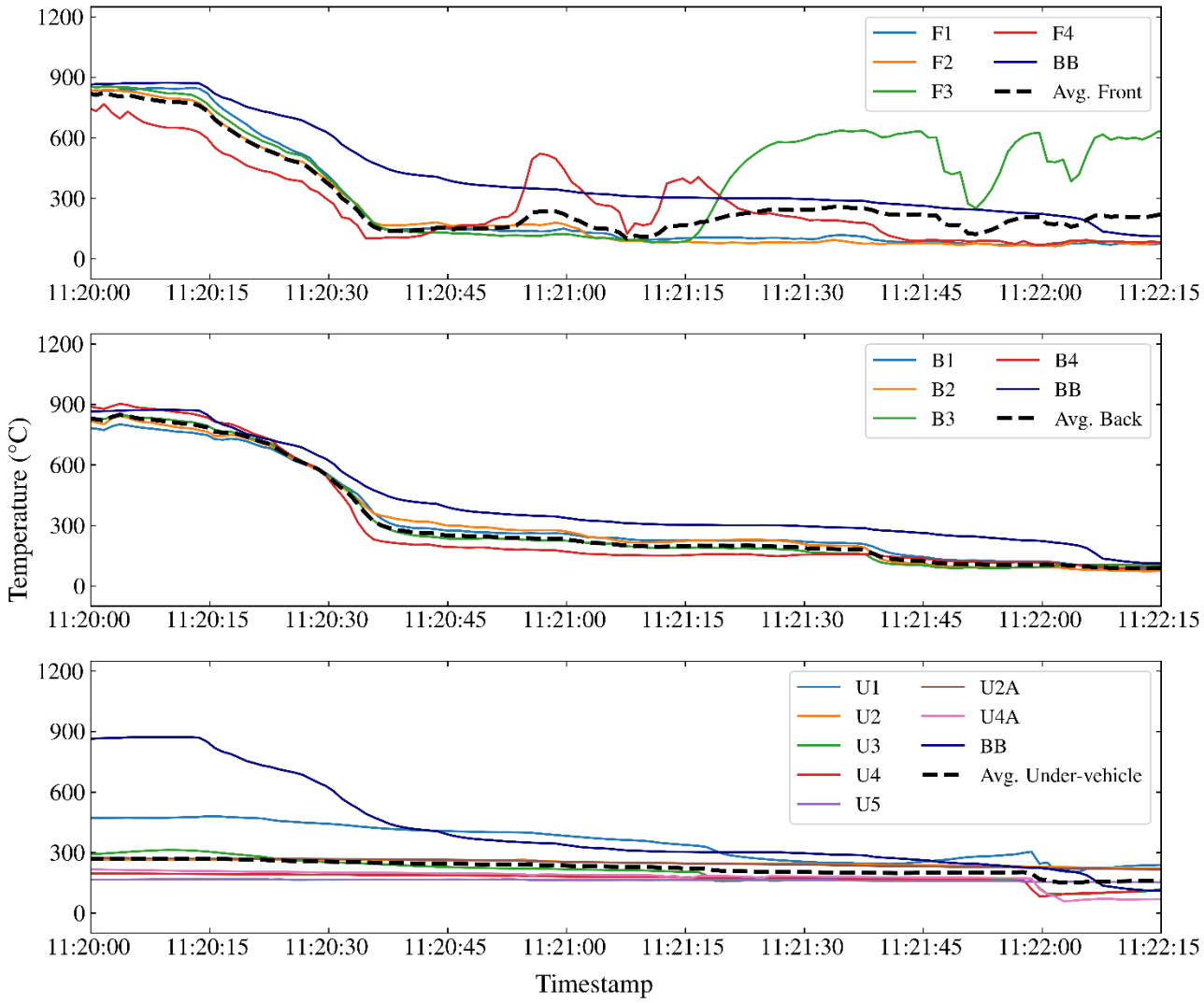




- At **3** (11:12:20) was the highest incident RHF from the vehicle fire,
  - $\dot{q}''_{inc,3,rad} = 5.95\ \mathrm{kW/m^2}$

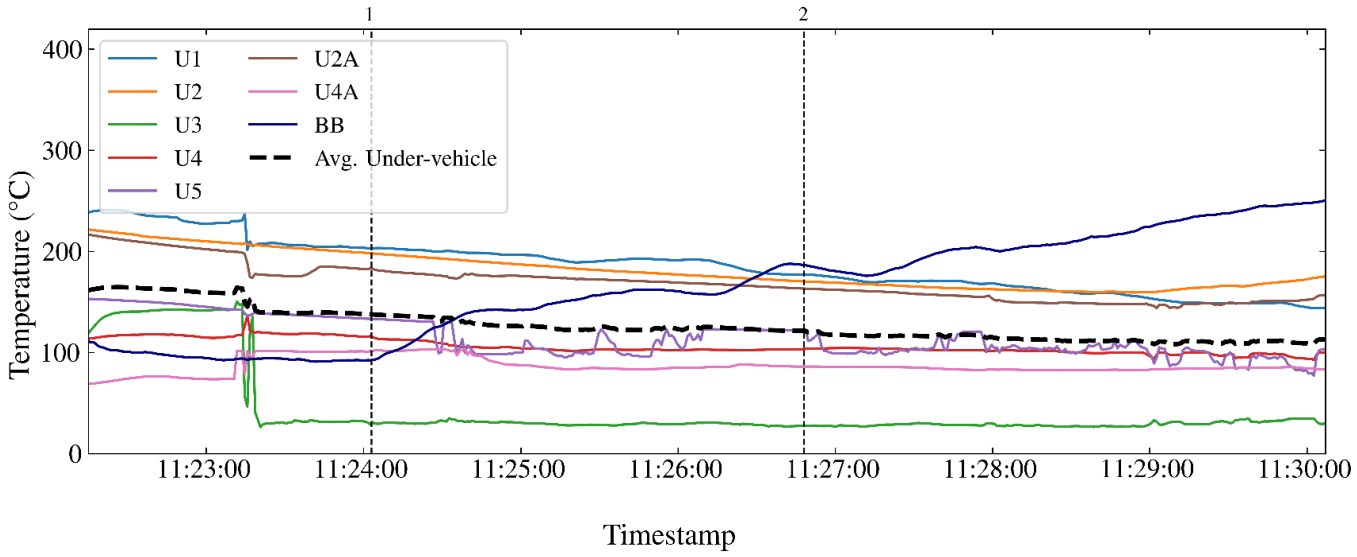
First Suppression Period

(11:20:15 – 11:22:14)



Post Initial Suppression “Battery Fire”

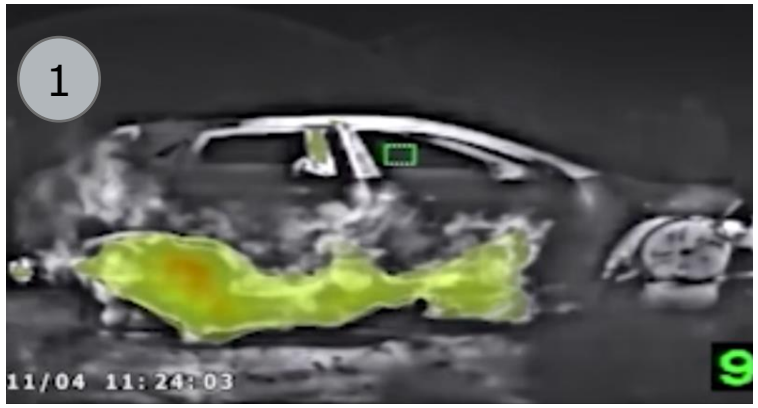
(11:22:14 – 11:30:07)



- Timings:
  1. Under-car fire, E @11:24:03
  2. First ‘jet flames’, NW @11:26:48

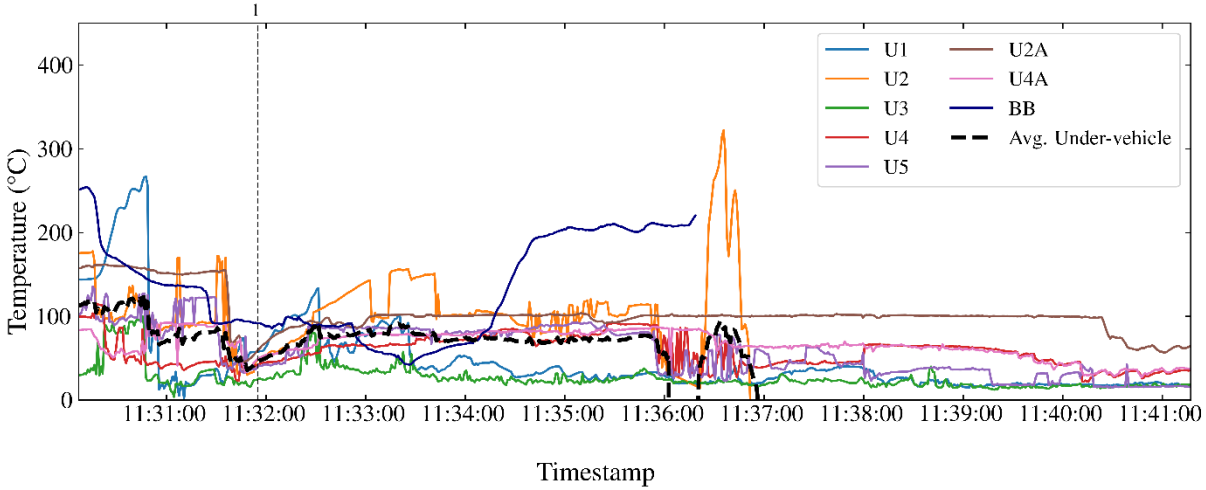
Temperature measurements (Unit: °C or °C/s)

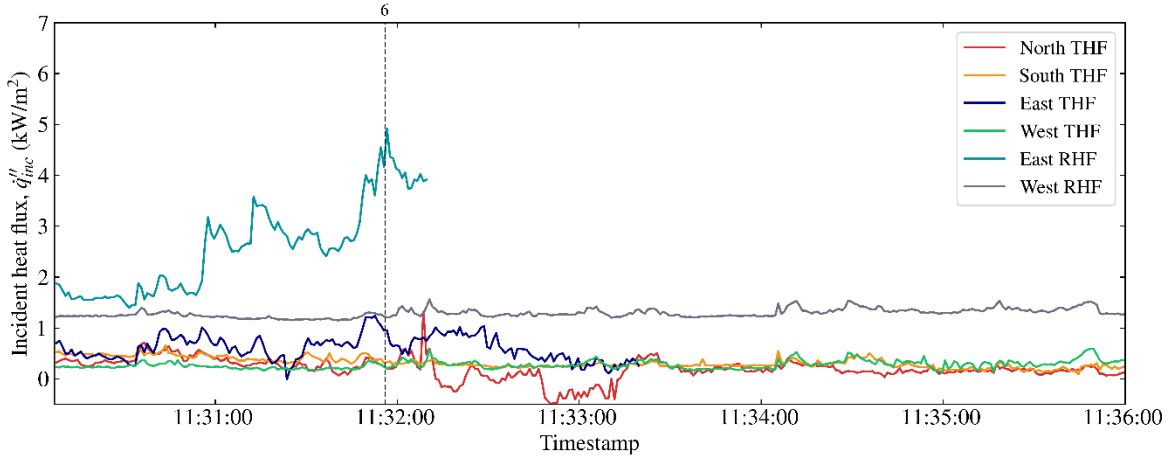
Time	U1	U2	U2A	U3	U4	U4A	U5
11:20:14	477	264	271	308	194	20	167
11:30:07	144	175	157	30	100	84	103
ΔT/time	0.7	0.2	0.2	0.6	0.20	0.3	0.1



Second Suppression Period

(11:30:07 – 11:41:15)



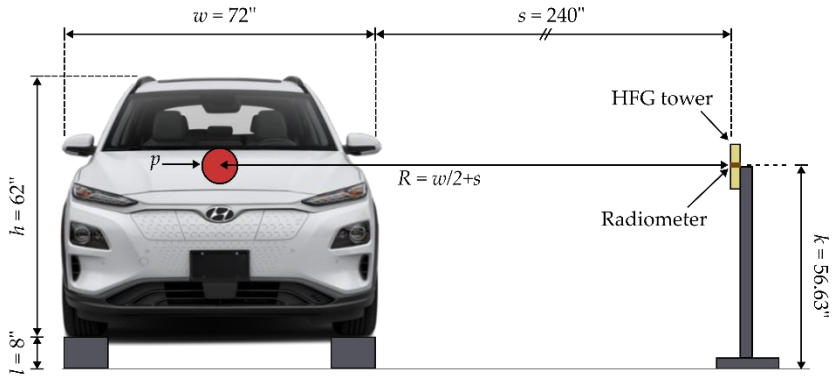


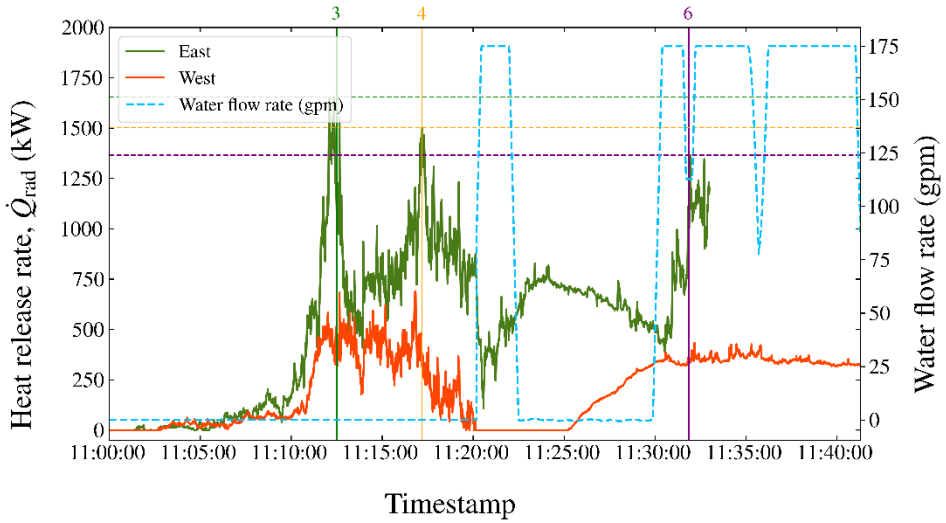
Analysis: Heat Release Rate

- Assuming:
  1. The radiative heat release rate originates from a point source, *p* [1].
  2. The radiative fraction is $\chi_r = 0.45$ [2]

$$\dot{q}''_{inc,rad} = \frac{\dot{Q}\chi_r}{4\pi R^2}$$

$$\dot{Q}\chi_r = \dot{q}''_{inc,rad} 4\pi R^2$$





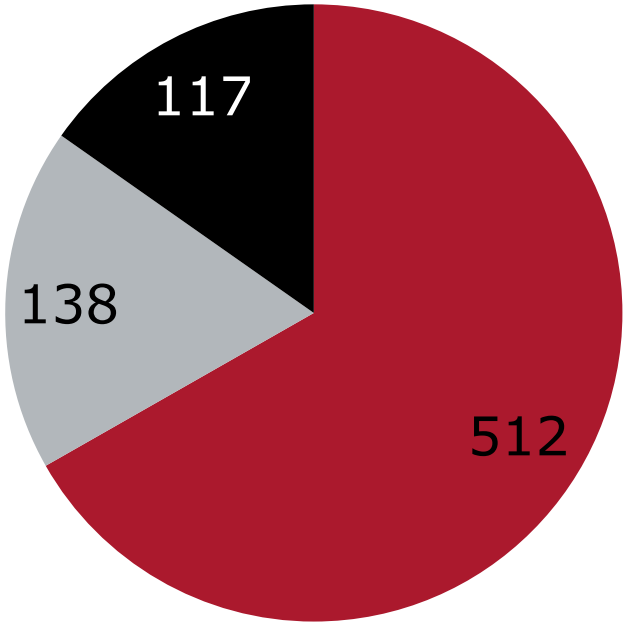
- At **3** (11:12:20) was the highest incident RHF from the vehicle fire,
  - $\dot{Q}_3 = 1.65$ MW
- At **6** (11:31:56) was the highest incident RHF from the battery fire
  - $\dot{Q}_6 = 1.37$ MW

[1] Drysdale, D. (2011). An introduction to fire dynamics. John Wiley & Sons.
[2] Hu, Y., Zhou, X., Cao, J., Zhang, L., Wu, G., & Yang, L. (2020). Interpretation of fire safety distances of a minivan passenger car by burning behaviors analysis. Fire Technol, 56, 1527-1553.

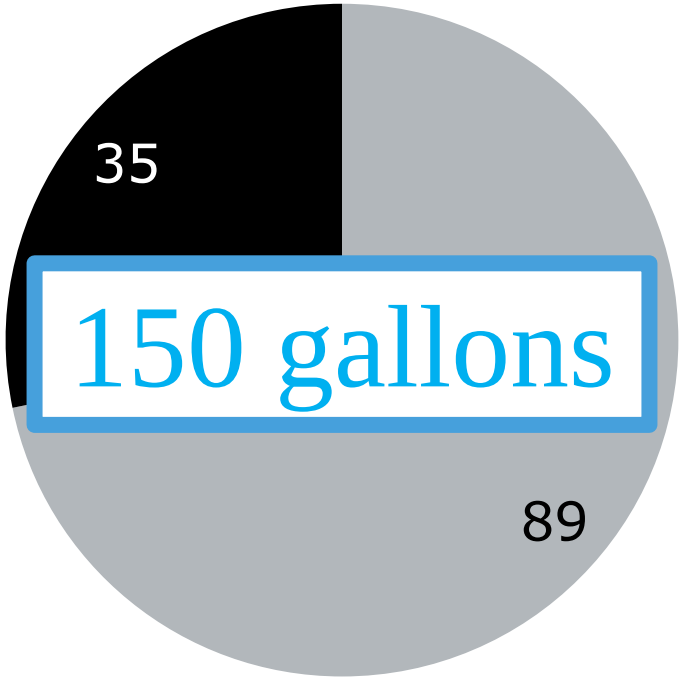
Analysis: Hose Stream

(recorded data only)

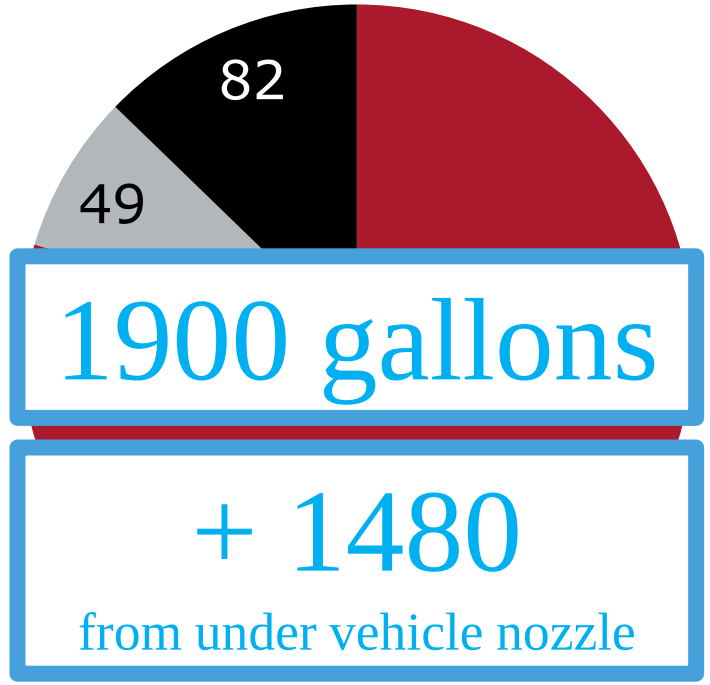
Firefight Hose Stream
(All Data)



Firefight Hose Stream
(First Suppression)



Firefight Hose Stream
(Second Suppression)



■ Exterior Ground ■ Exterior Car ■ Inside car

(Time in seconds)

Recommendations: Instrumentation

- Heat flux gages and thermocouples within and under the car help tell the vehicle fire story but additional instrumentation would be beneficial
- Data collected on the exterior of the battery pack turns the batteries into a “black box”
- Any data acquisition in the car interior becomes unreliable as soon as water is applied into the vehicle and possibly before
- The means to measure the burning or mass loss rate is lacking and would add clarity to observed phenomena and provide insights about the total heat release rate

Recommendations: Future Testing

- Thermal runaway should ignite the rest of the vehicle
  - Does the battery management system need to be on?
  - What other ways can thermal runaway be induced?
- Means of validating thermal runaway for needs to be clarified
- When should suppression start?
  - At some assessed response time to reach the vehicle?
  - At the time of peak HRR (worst-case scenario)?
  - Once the vehicle becomes fully involved?
  - Once the battery reaches a certain temperature?
- Tests should be conducted indoors to control environmental parameters better
- Multiple data sets need to be obtained for a variety of vehicles

Conclusions

- There is a great need for additional data and testing
- A battery electric vehicle was instrumented, ignited, brought to thermal runaway, and burnt completely
- The firefighter interactions for this test created 5 distinct periods
  - Ignition, First Suppression, Battery Fire, Second Suppression, Test Runout
- The two fire suppression periods represent two distinct threats
  - A fully involved BEV fire with a compromised battery pack
  - An EV battery pack fire

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