Electric Vehicle Fire Testing

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Outline

A. Introduction

- Objectives
- Test Setup
- Vehicles Under Test

B. Comparison Graphs

C. Conclusions and Take away messages

Introduction and Objectives

- To perform comparative fire testing on internal combustion (ICE) and electric vehicles (EV). Vehicles and battery packs were equipped with multiple thermocouples, voltage sensors, heat flux meters, smoke detectors and gas sampling lines.

- The objective was a comparative study on the effects of a REESS with respect to a gasoline fuel tank in comparable vehicles and to identify what, if any, are the potential safety issues with respect to the REESS.

- Two gasoline and five electric vehicles were tested.

EV Battery Pack Burn – Test Setup

- Tests were performed indoors, unheated under a test calorimeter, which measures heat released and rate.

- Vehicles were suspended over a propane sand burner, previously calibrated with gasoline to simulate a gasoline pool fire.

- Guideline for test :

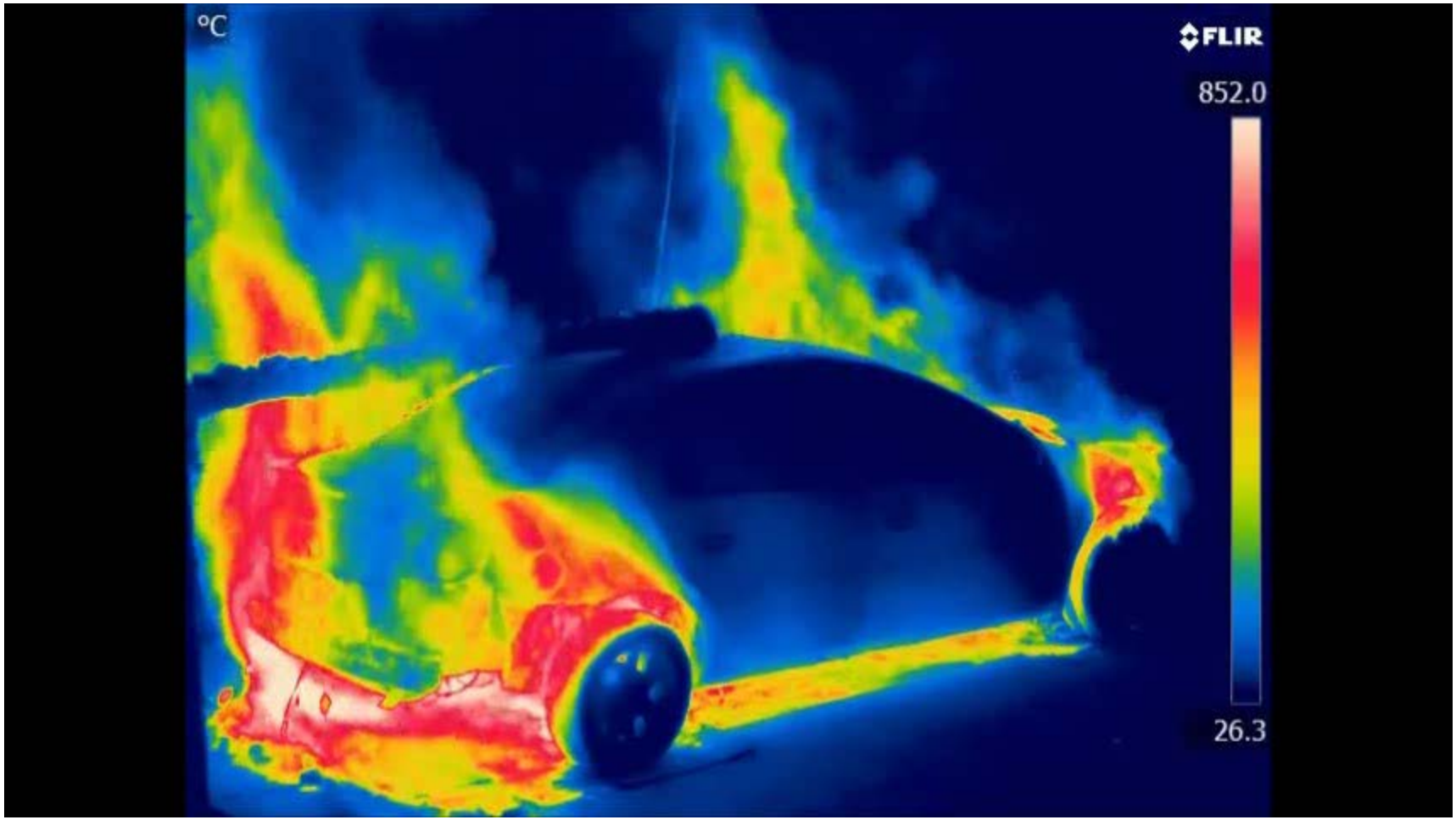
UL 2580 : **Minimum** 590°C

in 5 min, burn for 20 min

No explosions

Filled with pebbles prior to test

Vehicle Testing – A Sample

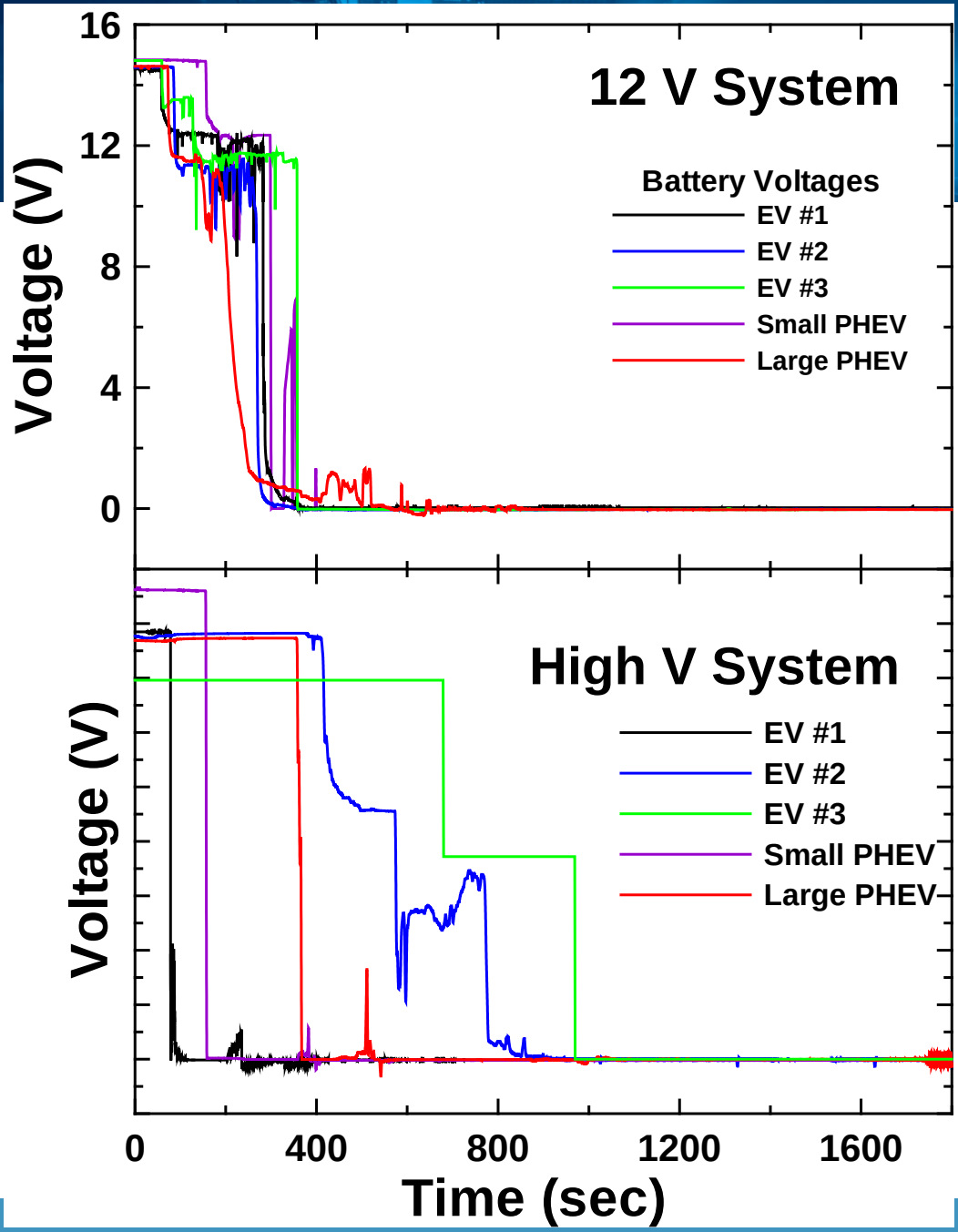


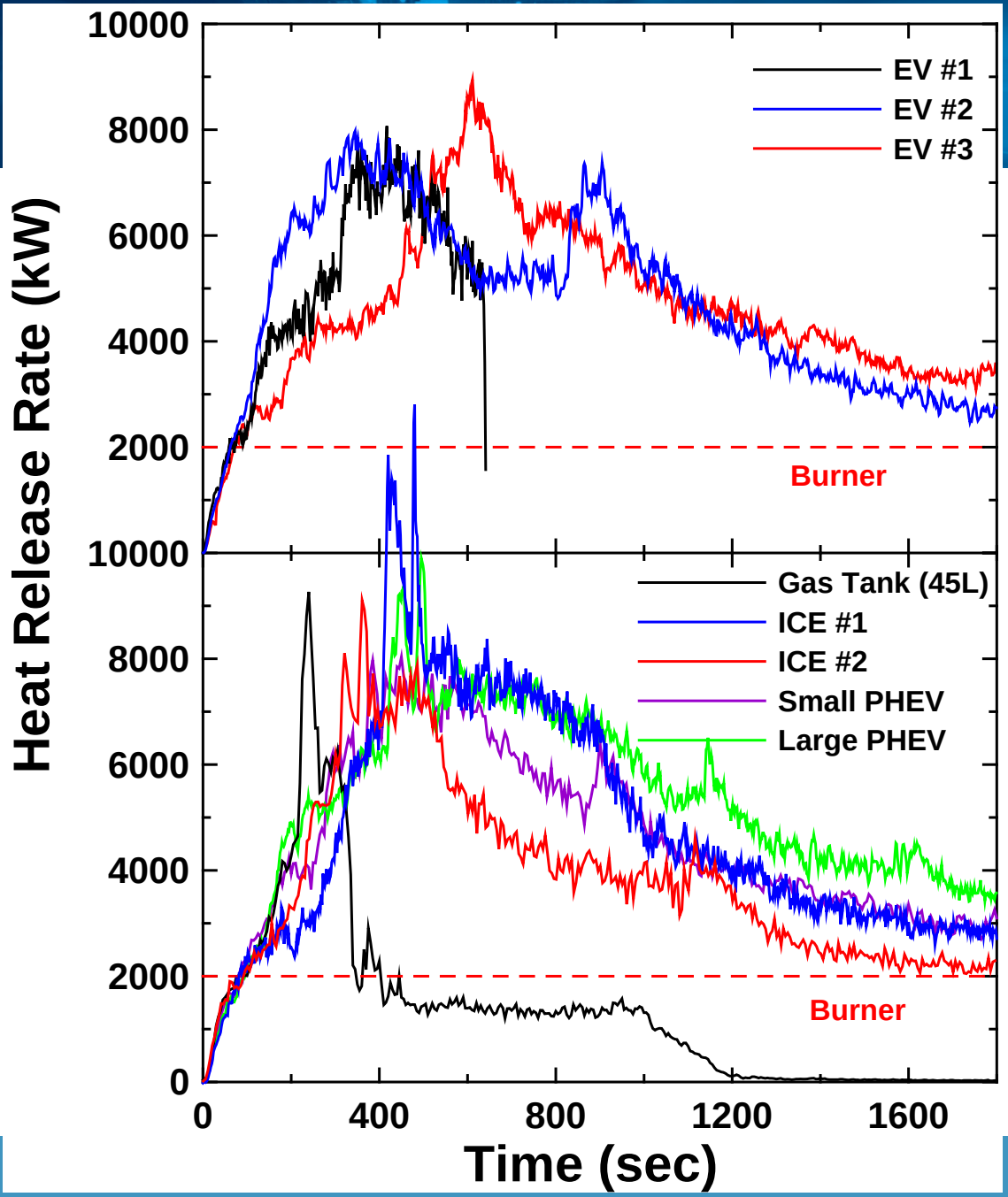
List of vehicles under test

Vehicles under test

- Gas Tank (45L)
- Two Baseline ICE vehicle (between 40 and 50L of Gasoline)
- Small PHEV
- Large PHEV
- BEV x 3 (100 and 85% SOC - vehicle 1A and 1B, 100% - vehicle 2)

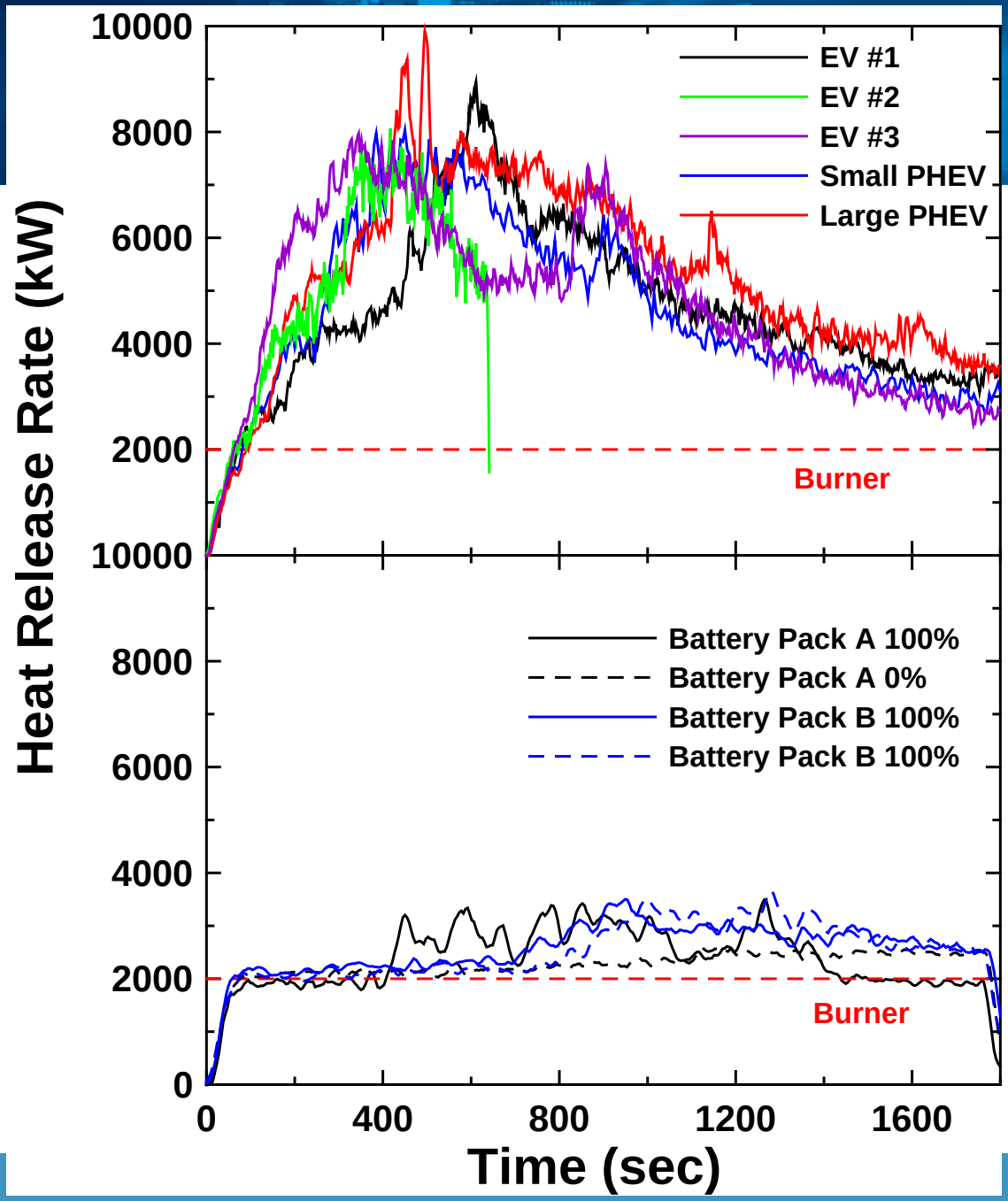
- Some comparisons to EV Battery Pack testing from 2 different EVs


12 V System
Battery Voltages
EV #1
EV #2
EV #3
Small PHEV
Large PHEV
Voltage (V)
16
12
8
4
0
High V System
EV #1
EV #2
EV #3
Small PHEV
Large PHEV
Voltage (V)
0
400
800
1200
1600
Time (sec)



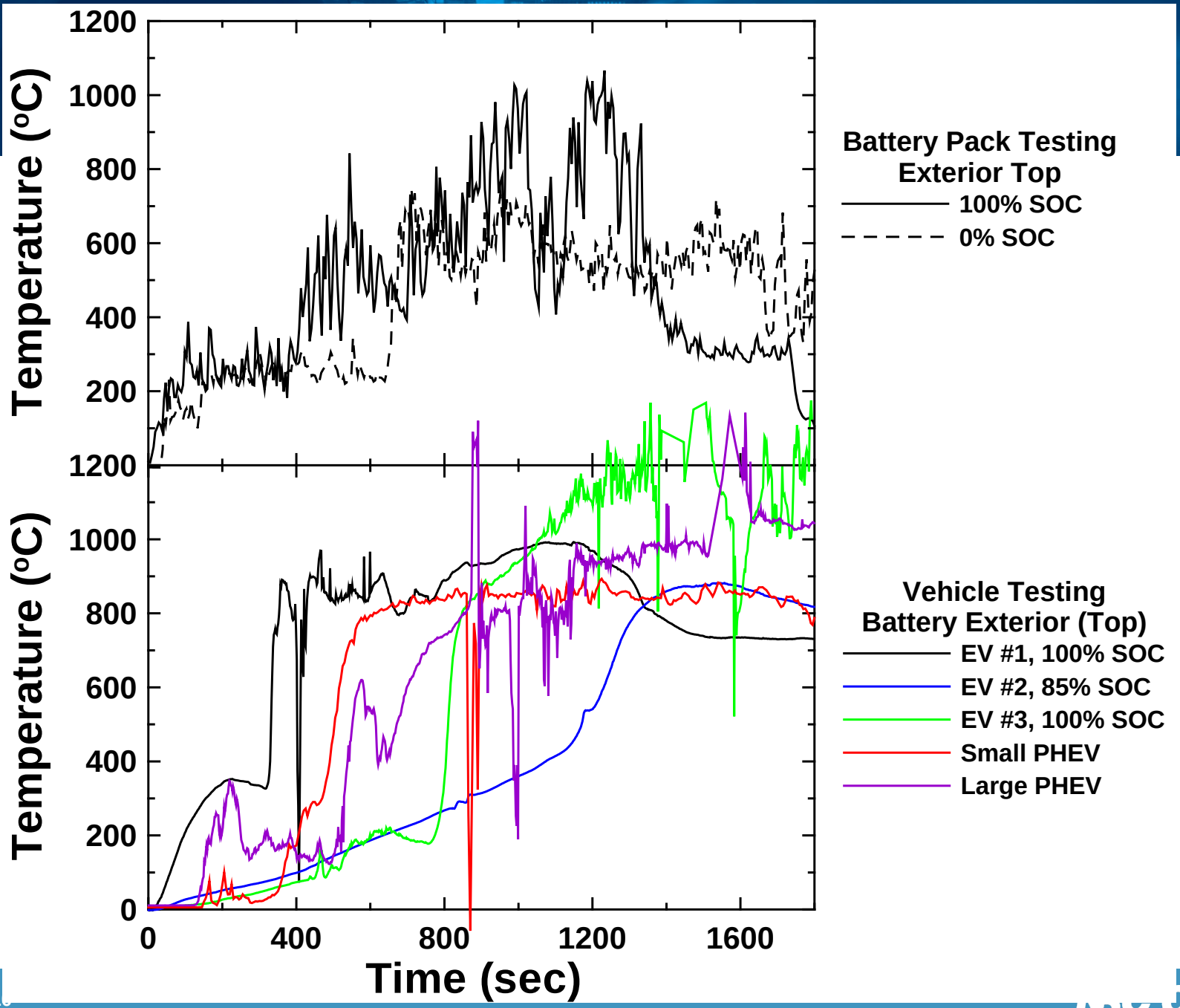
BEVs

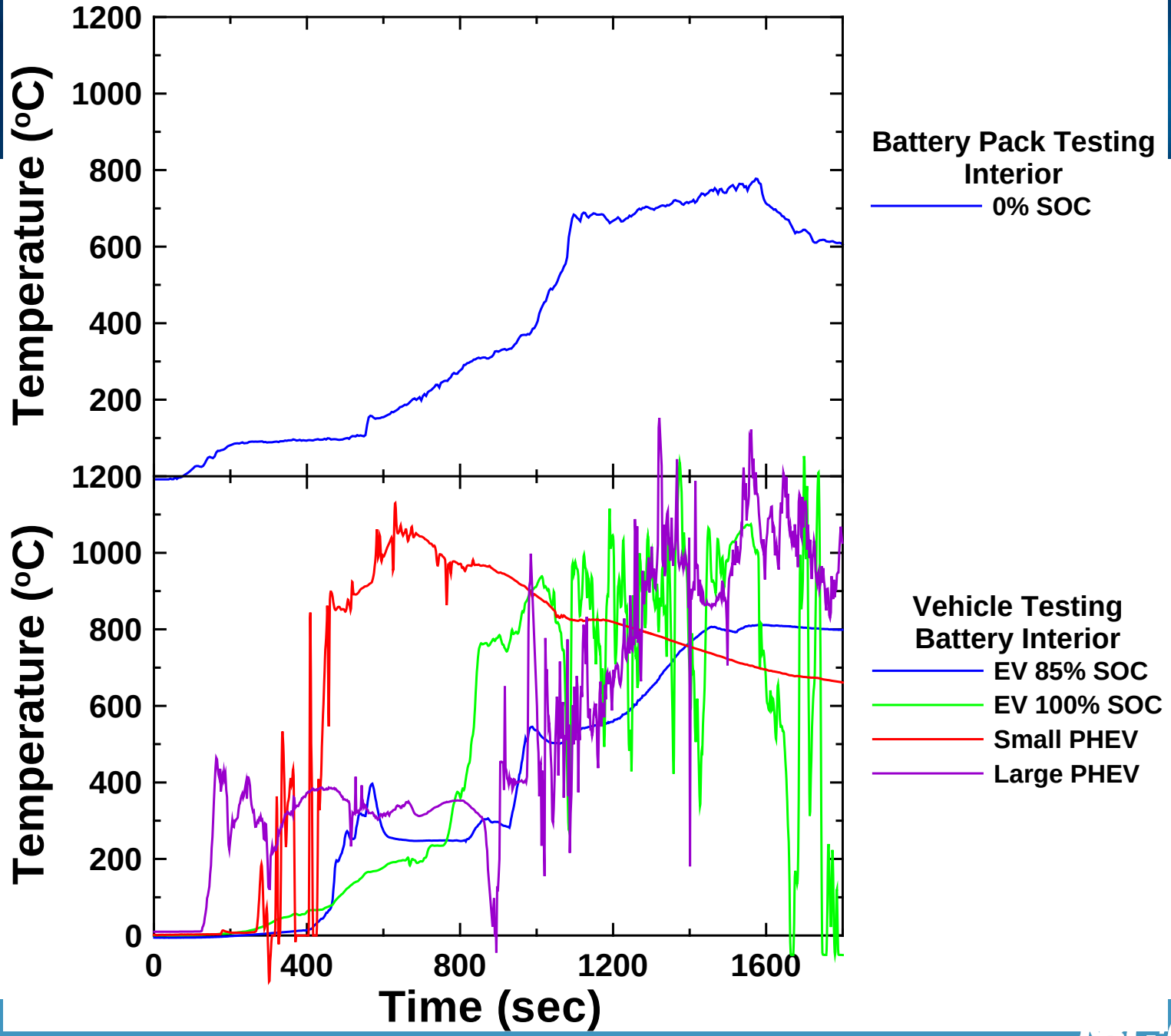
Gasoline Containing



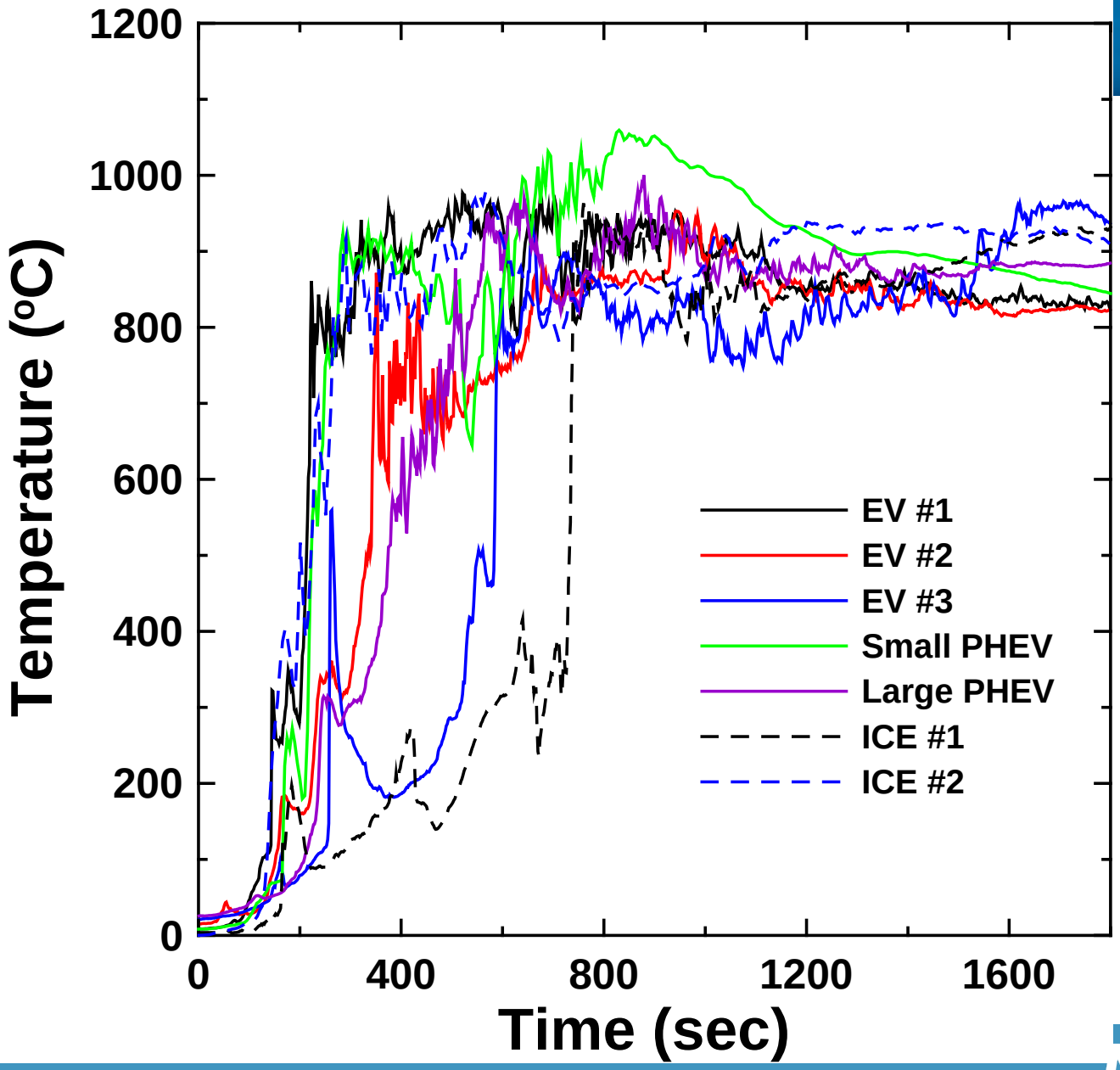
Full Vehicle

BEV Battery Packs


Temperature (°C)
1200
1000
800
600
400
200
0
0
400
800
1200
1600
Time (sec)
Battery Pack Testing
Exterior Top
100% SOC
0% SOC
Vehicle Testing
Battery Exterior (Top)
EV #1, 100% SOC
EV #2, 85% SOC
EV #3, 100% SOC
Small PHEV
Large PHEV


Temperature (°C)
1200
1000
800
600
400
200
1200
Temperature (°C)
1000
800
600
400
200
0
0
400
800
1200
1600
Time (sec)
Battery Pack Testing
Interior
0% SOC
Vehicle Testing
Battery Interior
EV 85% SOC
EV 100% SOC
Small PHEV
Large PHEV

Cabin Temperature at Head Height



Conclusions and Take away message

- No vehicle showed a catastrophic explosion, although numerous pops, flares and fire jets were expelled during the test indicative of a reactive fire, which includes tires, shocks and air bags.

Transport Canada proposal:

- No test at the vehicle level

If a fire testing is to be performed at the component level;

- SOC should be at highest level that the vehicle can charge the REESS
- 2 minutes is not sufficient to initiate reactions within the REESS
- A suggestion is to follow/perform a test similar to the UL 2580 (min 590°C; 20 minutes; pass criteria: no explosion) or a test similar to the one specified in GTR 13 to assure that the REESS case can contain cell venting and explosion without affecting its structure.

Acknowledgements

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Thank you for your kind attention!

Any Questions or Comments

6.2.4.3. Localized gas leak test (pneumatic)

A bubble test may be used to fulfil this requirement. The following procedure is used when conducting the bubble test:

(a) The exhaust of the shutoff valve (and other internal connections to hydrogen systems) shall be capped for this test (as the test is focused at external leakage).

At the discretion of the tester, the test article may be immersed in the leak-test fluid or leak-test fluid applied to the test article when resting in open air. Bubbles can vary greatly in size, depending on conditions. The tester estimates the gas leakage based on the size and rate of bubble formation.

(b) *Note*: For a localized rate of 0.005 mg/sec (3.6 NmL/min), the resultant allowable rate of bubble generation is about 2,030 bubbles per minute for a typical bubble size of 1.5 mm in diameter. Even if much larger bubbles are formed, the leak should be readily detectable. For an unusually large bubble size of 6 mm in diameter, the allowable bubble rate would be approximately 32 bubbles per minute.

6.2.5. Test procedures for service terminating performance in fire (para. 5.1.4.)

6.2.5.1. Fire test

The hydrogen container assembly consists of the compressed hydrogen storage system with additional relevant features, including the venting system (such as the vent line and vent line covering) and any shielding affixed directly to the container (such as thermal wraps of the container(s) and/or coverings/barriers over the TPRD(s)).

Either one of the following two methods are used to identify the position of the system over the initial (localized) fire source:

6.2.5.1.1. Method 1: Qualification for a generic (non-Specific) vehicle installation

If a vehicle installation configuration is not specified (and the qualification of the system is not limited to a specific vehicle installation configuration) then the localized fire exposure area is the area on the test article farthest from the TPRD(s). The test article, as specified above, only includes thermal shielding or other mitigation devices affixed directly to the container that are used in all vehicle applications. Venting system(s) (such as the vent line and vent line covering) and/or coverings/barriers over the TPRD(s) are included in the container assembly if they are anticipated for use in any application. If a system is tested without representative components, retesting of that system is required if a vehicle application specifies the use of these type of components.

6.2.5.1.2. Method 2: Qualification for a specific vehicle installation

If a specific vehicle installation configuration is specified and the qualification of the system is limited to that specific vehicle installation configuration, then the test setup may also include other vehicle components in addition to the hydrogen storage system. These vehicle components (such as shielding or barriers, which are permanently attached to the vehicle's structure by means of welding or bolts and not affixed to the storage system) shall be included in the test setup in the vehicle-installed configuration relative to the hydrogen storage system. This localized fire test is conducted

on the worst case localized fire exposure areas based on the four fire orientations: fires originating from the direction of the passenger compartment, cargo/luggage compartment, wheel wells or ground-pooled gasoline.

The container may be subjected to engulfing fire without any shielding components, as described in paragraph 6.2.5.2.

The following test requirements apply whether Method 1 or 2 (above) is used:

(a) The container assembly is filled with compressed hydrogen gas at 100 per cent of NWP. The container assembly is positioned horizontally approximately 100 mm above the fire source. (Note: as stated in para. 5.1.4., contracting parties under the 1998 Agreement may choose to use compressed air as an alternative test gas for certification of the container for use in their countries or regions.) ;

Localized portion of the fire test

(b) The localized fire exposure area is located on the test article furthest from the TPRD(s). If Method 2 is selected and more vulnerable areas are identified for a specific vehicle installation configuration, the more vulnerable area that is furthest from the TPRD(s) is positioned directly over the initial fire source;

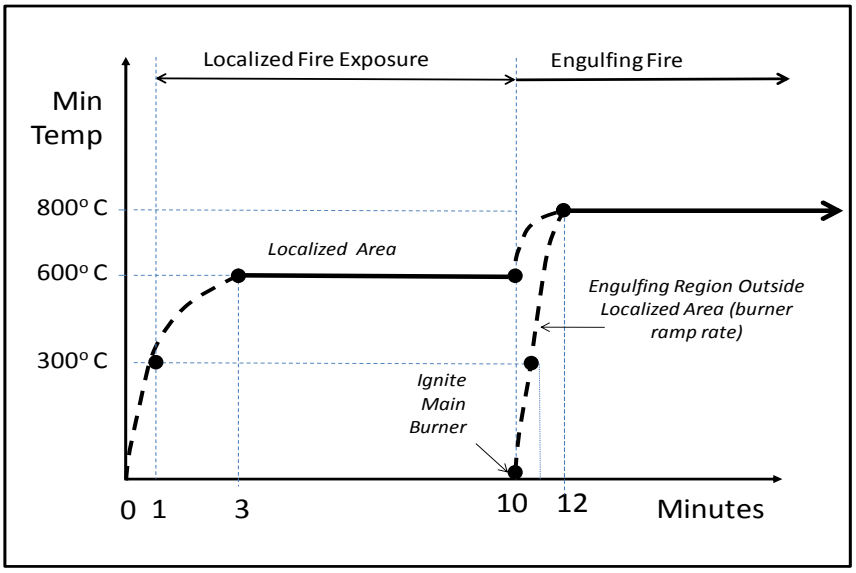
(c) The fire source consists of LPG burners configured to produce a uniform minimum temperature on the test article measured with a minimum 5 thermocouples covering the length of the test article up to 1.65 m maximum (at least 2 thermocouples within the localized fire area, and at least 3 thermocouples equally spaced and no more than 0.5 m apart in the remaining area) located 25 mm ± 10mm from the outside surface of the test article along its longitudinal axis. At the option of the manufacturer or testing facility, additional thermocouples may be located at TPRD sensing points or any other locations for optional diagnostic purposes;

(d) Wind shields are applied to ensure uniform heating;

(e) The fire source initiates within a 250 mm ±50 mm longitudinal expanse positioned under the localized exposure area of the test article. The width of the fire source encompasses the entire diameter (width) of the storage system. If Method 2 is selected, the length and width shall be reduced, if necessary, to account for vehicle-specific features;

(f) As shown in Figure 7 the temperature of the thermocouples in the localized fire area has increased continuously to at least 300 °C within 1 minute of ignition, to at least 600 °C within 3 minutes of ignition, and a temperature of at least 600 °C is maintained for the next 7 minutes. The temperature in the localized fire area shall not exceed 900 °C during this period. Compliance to the thermal requirements begins 1 minute after entering the period with minimum and maximum limits and is based on a 1-minute rolling average of each thermocouple in the region of interest. (Note: The temperature outside the region of the initial fire source is not specified during these initial 10 minutes from the time of ignition.).

Figure 7
Temperature profile of fire test



Engulfing portion of the fire test

Within the next 2-minute interval, the temperature along the entire surface of the test article shall be increased to at least 800 °C and the fire source is extended to produce a uniform temperature along the entire length up to 1.65 meters and the entire width of the test article (engulfing fire). The minimum temperature is held at 800°C, and the maximum temperature shall not exceed 1100 °C. Compliance to thermal requirements begins 1 minute after entering the period with constant minimum and maximum limits and is based on a 1-minute rolling average of each thermocouple.

The test article is held at temperature (engulfing fire condition) until the system vents through the TPRD and the pressure falls to less than 1 MPa. The venting shall be continuous (without interruption), and the storage system shall not rupture. An additional release through leakage (not including release through the TPRD) that results in a flame with length greater than 0.5 m beyond the perimeter of the applied flame shall not occur.

Table 2
Summary of fire test protocol

	Localized fire region	*Time period*	*Engulfing fire region (Outside the localized fire region)*
Action	Ignite Burners	0-1 minute	No Burner Operation
Minimum temperature	Not specified		Not specified
Maximum temperature	Less than 900°C		Not specified
Action	Increase temperature and stabilize fire for start of localized fire exposure	1-3 minutes	No Burner Operation
Minimum temperature	Greater than 300°C		Not specified
Maximum temperature	Less than 900°C		Not specified
Action	Localized fire exposure continues	3-10 minutes	No Burner Operation
Minimum temperature	1-minute rolling average greater than 600°C		Not specified
Maximum temperature	1-minute rolling average less than 900°C		Not specified
Action	Increase temperature	10-11 minutes	Main Burner Ignited at 10 minutes
Minimum Temperature	1-minute rolling average greater than 600°C		Not specified
Maximum temperature	1-minute rolling average less than 1,100°C		Less than 1,100°C
Action	Increase temperature and stabilize fire for start of engulfing fire exposure	11-12 minutes	Increase temperature and stabilize fire for start of engulfing fire exposure
Minimum temperature	1-minute rolling average greater than 600°C		Greater than 300°C
Maximum temperature	1 minute rolling average less than 1,100°C		Less than 1,100°C
Action	Engulfing fire exposure continues	12 minutes - end of test	Engulfing fire exposure continues
Minimum temperature	1-minute rolling average greater than 800°C		1-minute rolling average greater than 800°C
Maximum temperature	1 minute rolling average less than 1,100°C		1-minute rolling average less than 1,100°C

Documenting results of the fire test

The arrangement of the fire is recorded in sufficient detail to ensure the rate of heat input to the test article is reproducible. The results include the elapsed time from ignition of the fire to the start of venting through the TPRD(s), and the maximum pressure and time of evacuation until a pressure of less than 1 MPa is reached. Thermocouple temperatures and container pressure are recorded at intervals of every 10 sec or less during the test. Any failure to maintain specified minimum temperature requirements based on the 1-minute rolling averages invalidates the test result. Any failure to maintain specified maximum temperature requirements based on the 1-minute rolling averages invalidates the test result only if the test article failed during the test.

6.2.5.2. Engulfing fire test:

The test unit is the compressed hydrogen storage system. The storage system is filled with compressed hydrogen gas at 100 per cent NWP. The container is positioned horizontally with the container bottom approximately 100 mm above the fire source. Metallic shielding is used to prevent direct flame impingement on container valves, fittings, and/or pressure relief devices. The metallic shielding is not in direct contact with the specified fire protection system (pressure relief devices or container valve).

A uniform fire source of 1.65 m length provides direct flame impingement on the container surface across its entire diameter. The test shall continue until the container fully vents (until the container pressure falls below 0.7 MPa (100 psi)). Any failure or inconsistency of the fire source during a test shall invalidate the result.

Flame temperatures shall be monitored by at least three thermocouples suspended in the flame approximately 25 mm below the bottom of the container. Thermocouples may be attached to steel cubes up to 25 mm on a side. Thermocouple temperature and the container pressure shall be recorded every 30 seconds during the test.

Within five minutes after the fire is ignited, an average flame temperature of not less than 590°C (as determined by the average of the two thermocouples recording the highest temperatures over a 60 second interval) is attained and maintained for the duration of the test.

If the container is less than 1.65 m in length, the centre of the container shall be positioned over the centre of the fire source. If the container is greater than 1.65 m in length, then if the container is fitted with a pressure relief device at one end, the fire source shall commence at the opposite end of the container. If the container is greater than 1.65 m in length and is fitted with pressure relief devices at both ends, or at more than one location along the length of the container, the centre of the fire source shall be centred midway between the pressure relief devices that are separated by the greatest horizontal distance.

The container shall vent through a pressure relief device without bursting.

6.2.6. Test Procedures for performance durability of primary closures (para. 5.1.5. requirement).

6.2.6.1. Compressed hydrogen storage TPRD qualification performance tests

Testing is performed with hydrogen gas having gas quality compliant with ISO 14687-2/SAE J2719. All tests are performed at ambient temperature 20