

Battery Electric Vehicle firefighting tests with Outside Air High Expansion Foam

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1. Background

- Battery electric vehicles (BEVs) powered by a Lithium-ion battery (LIB) have gradually increased their proportion in the total number of vehicles carried by Pure Car and Truck Carriers (PCTCs).
- Not a few PCTCs now have adopted the fixed high expansion foam fire-extinguishing system for their cargo holds, of which effectiveness on BEV fires needs to be verified.

2. Purpose

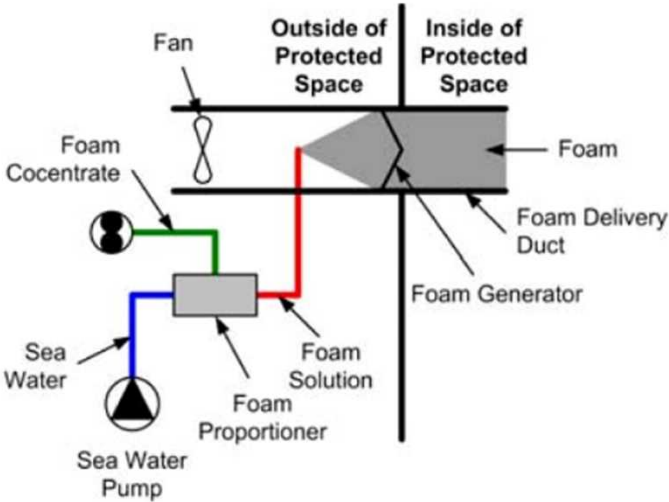
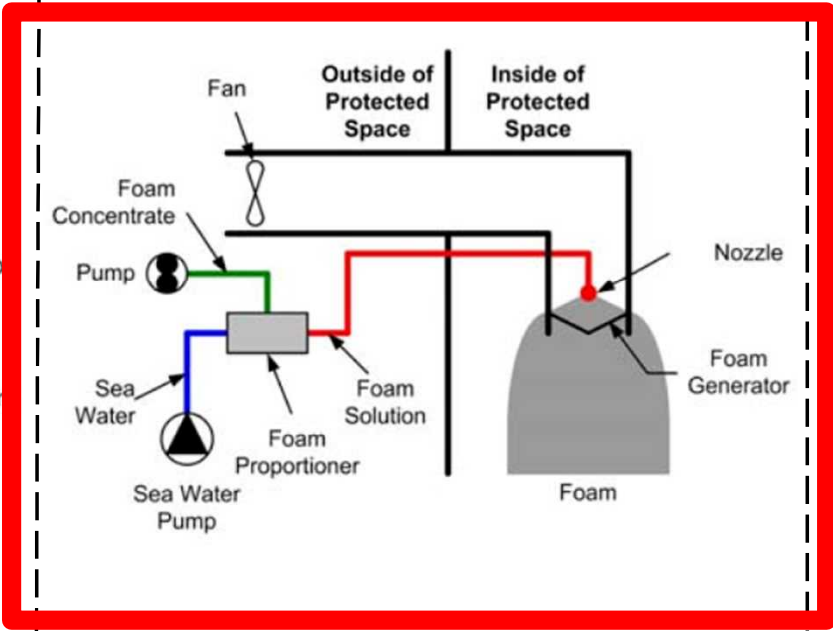
- To confirm the effectiveness of high-expansion foam fire-extinguishing system to fire of BEVs.

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3. Fixed High Expansion Foam Fire-extinguishing Systems on Ships

Inside Air Type

Outside Air Type



Generators installed **inside the protected space**

Generators installed **outside the protected space**

Quote : IMO FP 54-3-4 (Korea) (19Feb2010)

Foam Discharge from Outside Air High Expansion Foam Fire-extinguishing System



Absence of obstacles



Presence of obstacles

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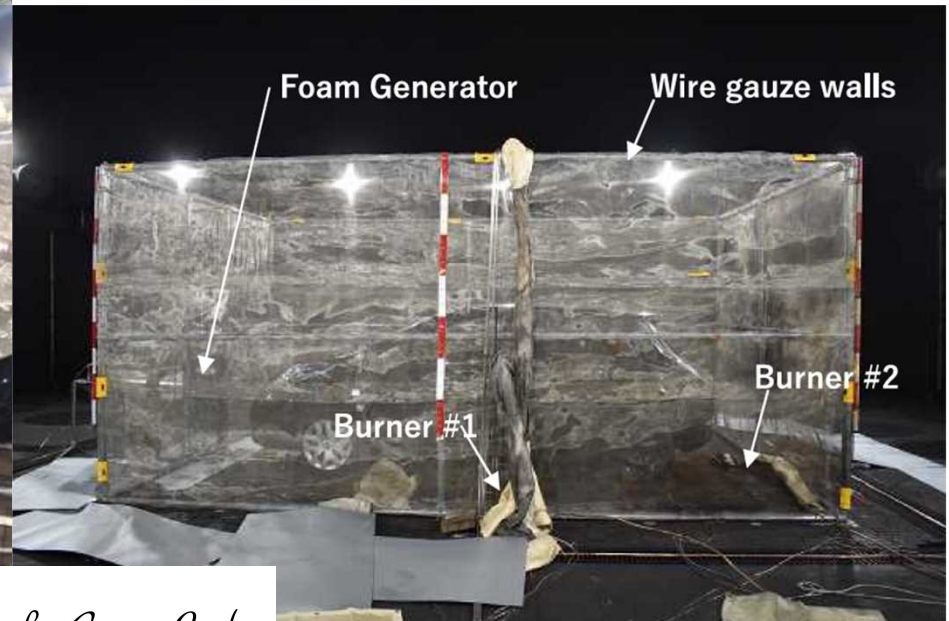
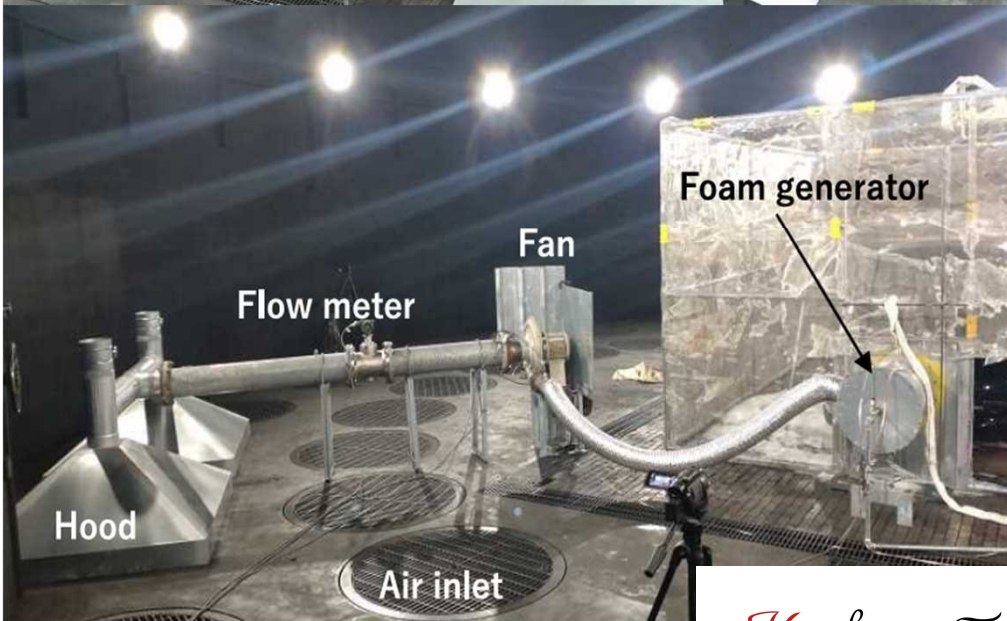
- FSS code CHAPTER 6
FIXED FOAM FIRE-EXTINGUISHING SYSTEM
- MSC.1 / Circ.1384
GUIDELINES FOR THE TESTING AND APPROVAL
OF FIXED HIGH-EXPANSION FOAM SYSTEMS

| | |
|------------------------|---|
| Type | Outside air (Foam expansion with air supplied from outside of the protected space) |
| Expansion ratio | 900 times (of the volume of the foam concentrate) |
| Filling rate | 1 m/min or higher (in an empty hold) |

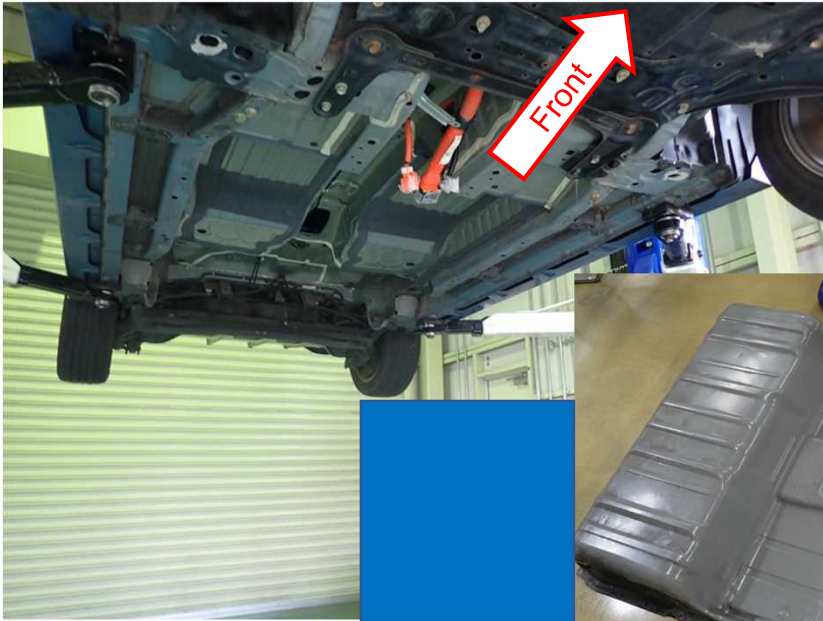
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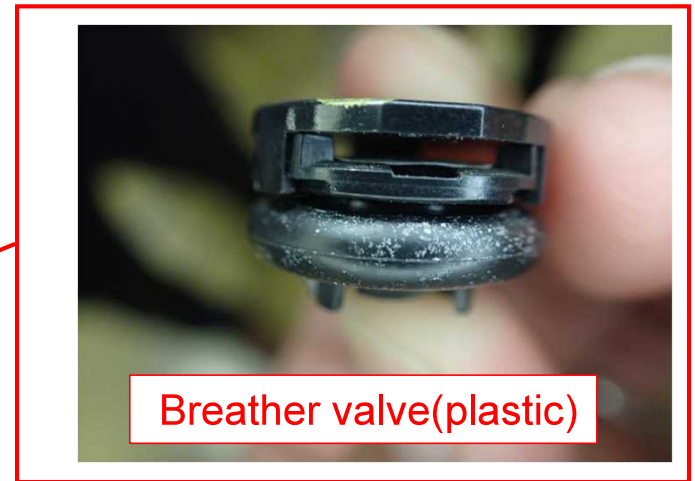
| Item | Specifications |
|---------------------|---|
| Test vehicle | Type: ZAA-AZE0 (model year: 2011-2014) with fully charged battery (10 out of 12 on the effective capacity scale) |
| Test cell | Floor diameter: ϕ 18 m, height: 16 m, volume: 4069 m ³ , structure: concrete and iron plates, ventilation rate: 750 m ³ /min |
| Compartment | Dimensions: 3.8 m (W) x 5.6 m (D) x 2.6 m (H), floor area: 21.3 m ² , volume: 55.3 m ³ , walls: wire gauzes, ceiling: open |
| Foam generator | Discharge rate: 21 m ³ /min, expansion ratio: 900 times, foam solution (98% of sea water and 2% of foam concentrate) supply rate: 23.3 L/min |
| Sea water | Simulated sea water (according to Circ.670/3.6.3) |
| F o a m concentrate | Synthetic surfactant foam concentrate (SV/HT) |



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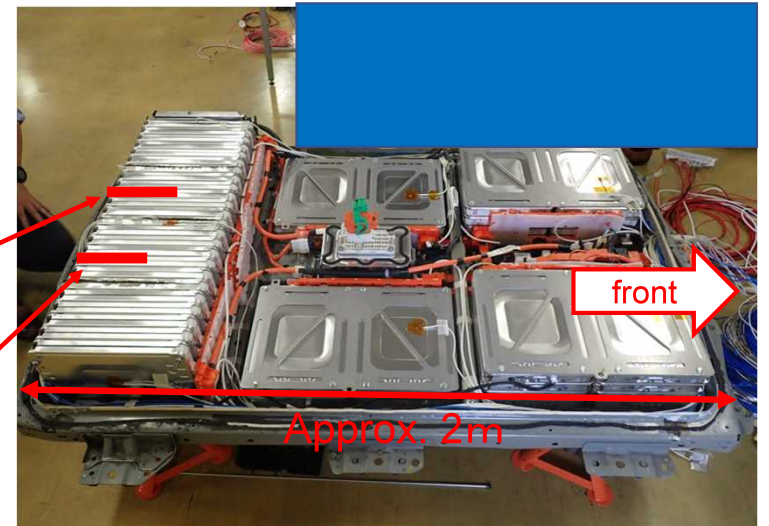


LIB pack top cover



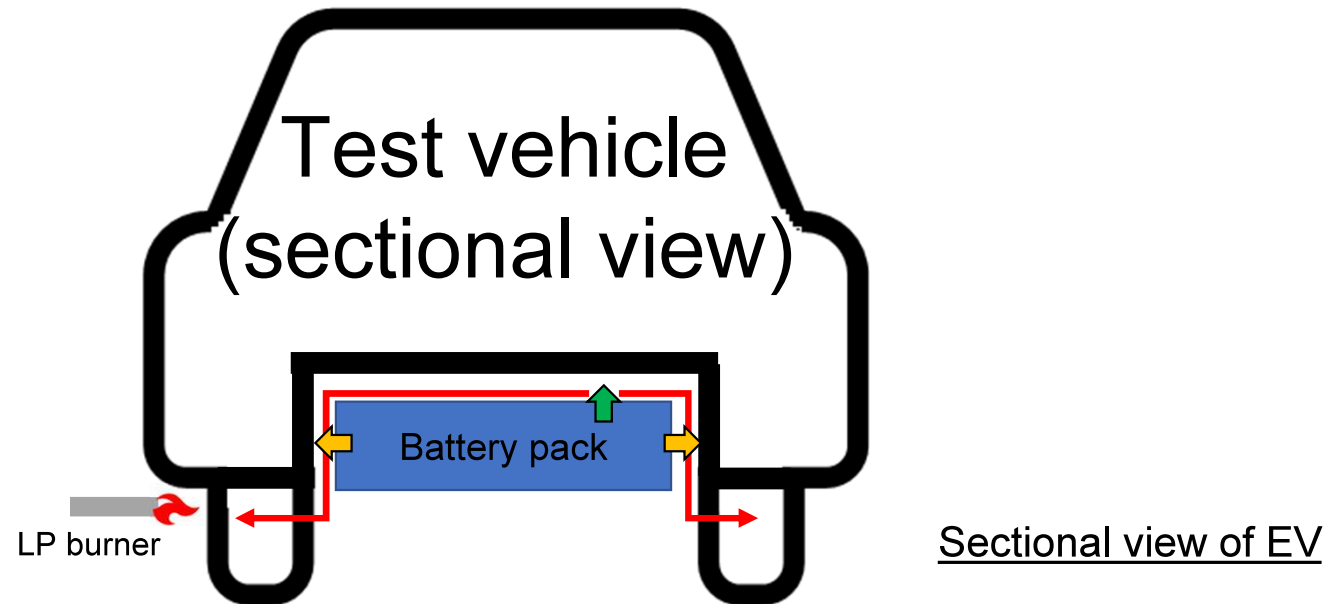
Breather valve(plastic)

* removed due to uncertain operating conditions.



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Flow of Vaporized Electrolyte



↑ : Leaking from the hole for the removed breather valve

→ : Flow of vaporized electrolyte

↑ : Leaking from the joints of the battery pack covers

— 🔥 : LP burner

Flash, Boiling, and Ignition Points of Major Organic Solvent Electrolytes Used in LIBs

| | Flash point | Boiling point | Ignition point |
|---------------------|-------------|---------------|----------------|
| Diethyl carbonate | 25°C | 146°C | 445°C |
| Dimethyl carbonate | 14°C | 90°C | 458°C |
| Propylene carbonate | 130°C | 242°C | 435°C |

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5. Test Results



| No. | Time elapsed | Operation |
|-----|--------------|---------------------------------|
| 1 | 0:00 | Heater #1 turned on |
| 2 | 1:33 | Heater #1 turned off |
| 3 | 22:00 | Heater #2 turned on |
| 4 | 23:09 | Heater #2 turned off |
| 5 | 24:00 | Burner #1 turned on |
| 6 | 27:00 | Burner #1 turned off |
| 7 | 40:00 | Fire-fighting system turned on |
| 8 | 49:00 | Fire-fighting system turned off |

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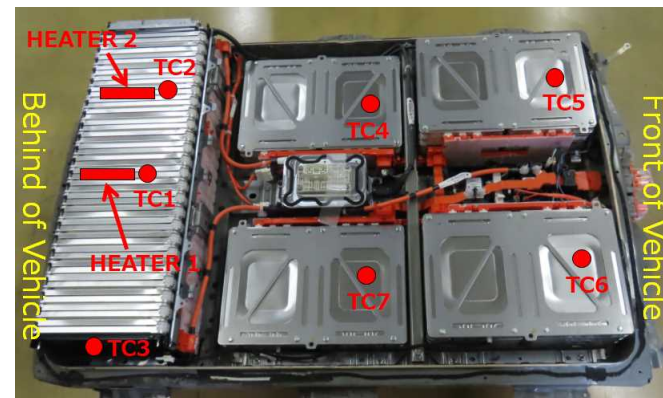
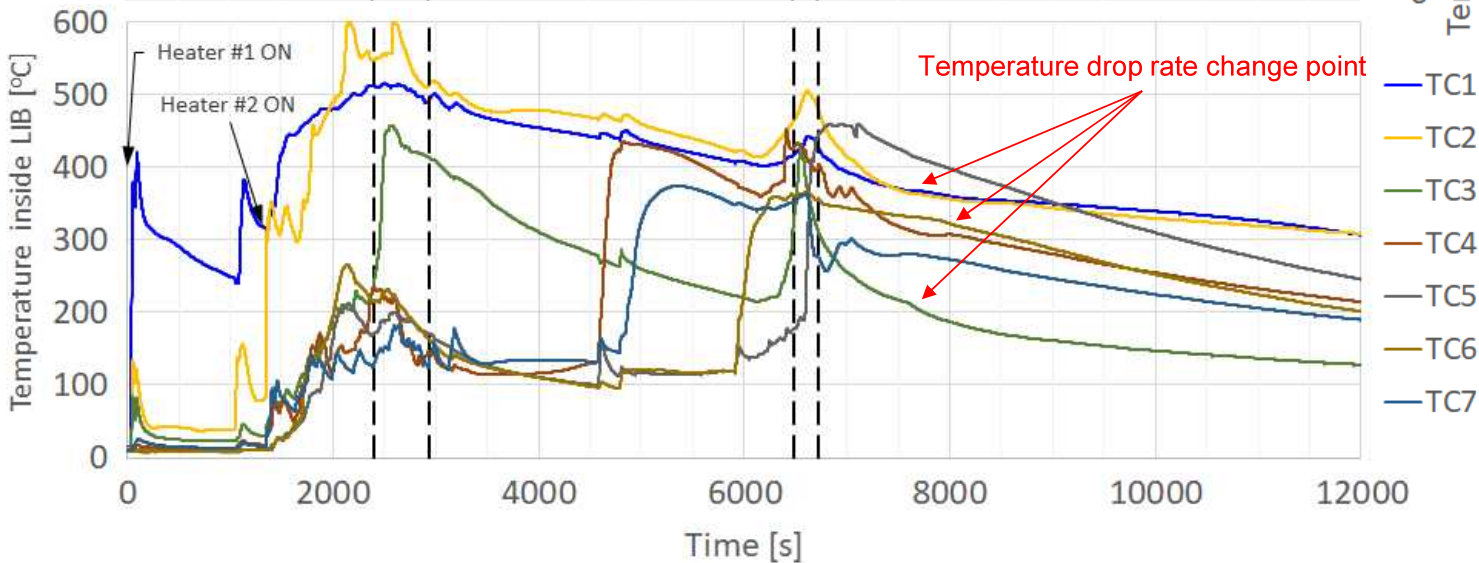
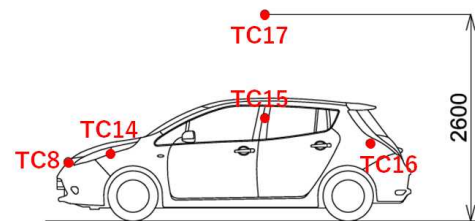
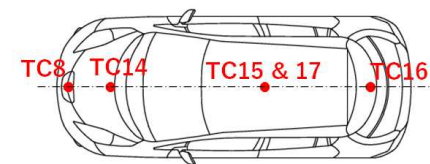
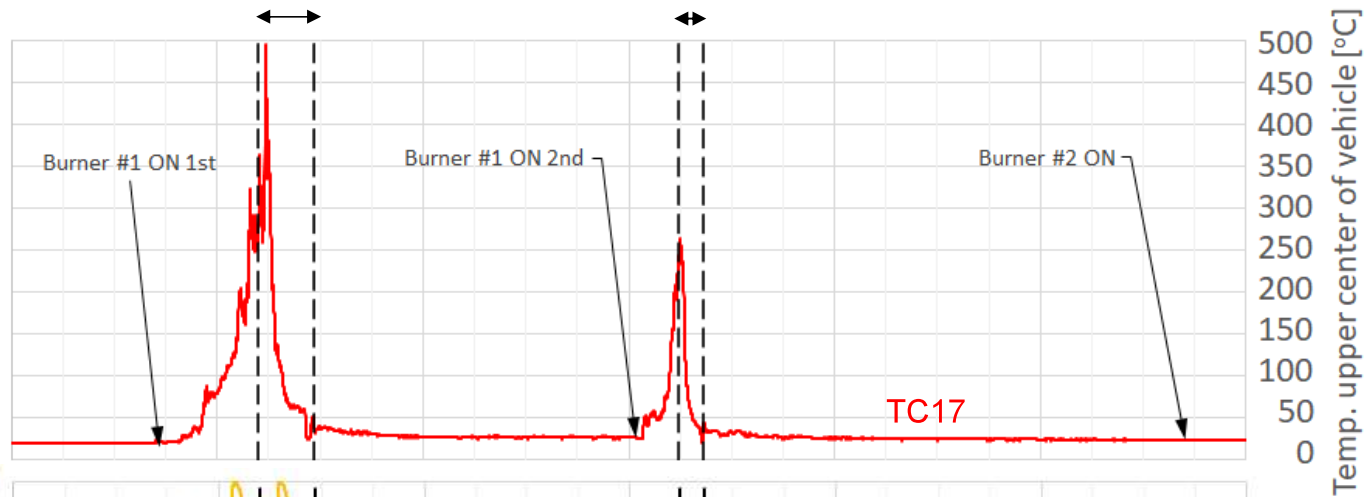
5. Test Results



| No. | Time elapsed | Operation |
|-----|--------------|---------------------------------|
| 9 | 1:41:00 | Burner #2 turned on |
| 10 | 1:43:00 | Burner #2 turned off |
| 11 | 1:48:00 | Fire-fighting system turned on |
| 12 | 1:52:00 | Fire-fighting system turned off |
| 13 | 3:10:00 | Burner #2 turned on |
| 14 | 3:15:00 | Burner #2 turned off |

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First foam discharge Second foam discharge



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Test Vehicle and LIB Pack After the Test



The battery pack was removed from the vehicle and disassembled after the test. The inside was completely burned and nothing flammable remained.

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6. Conclusion

- Although the high-expansion foam fire-extinguishing system was not able to stop thermal runaway of the battery, it successfully hindered the ignition of flammable gas including gaseous electrolyte from the battery
- The system was effective to prevent heat transmission from a vehicle on fire as long as the vehicle was submerged in the foam.
- Therefore, as the conclusion, it was confirmed that the fire could be suppressed by using high-expansion foam fire-extinguishing system.

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