Fire Suppression Tests Using a Handheld Water Mist Extinguisher Designed for Spacecraft Applications

SUPDET 2012 – Phoenix, AZ

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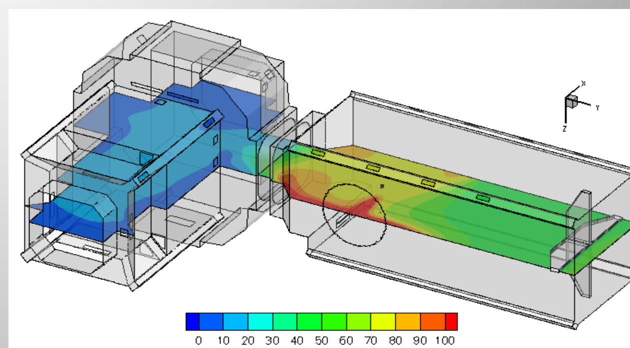
NASA Need: New ISS Handheld Extinguisher

- Current ISS CO_2 Fire Extinguisher has cryogenically formed stainless steel tank
- Volume: 881 in^3 (~3.8 gal)
- Size: 11 in diameter, 15 in tall
- Weight: 15 lbm (full), 6 lbm (CO_2 charge)
- Discharge time: 45 seconds
- Nozzles are optional
- Operation: Push pin, remove pip pin,
  aim and squeeze handle
- ISS Quantity: presently 13
- **Issue: local CO_2 levels will be well above flight rule limits if fully discharged**

ISS Locker Stowed CO2 PFE



ppCO2 gradient at midsection X, 40 sec

ADA Technologies Water Mist Extinguisher

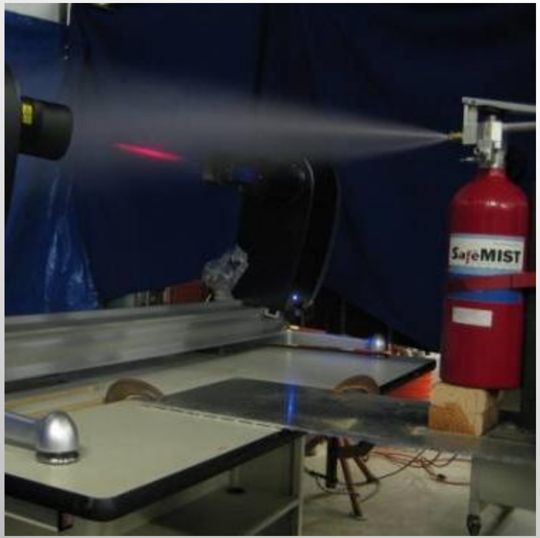
- NASA recommended the development of a non-CO_2 based PFE to reduce crew exposure to CO_2 toxicity during fire response and post-fire cleanup.

  Requirements: (1) be safe to use without PPE, (2) extinguish rack (hidden) and open cabin fires, (3) not hurt the vehicle.

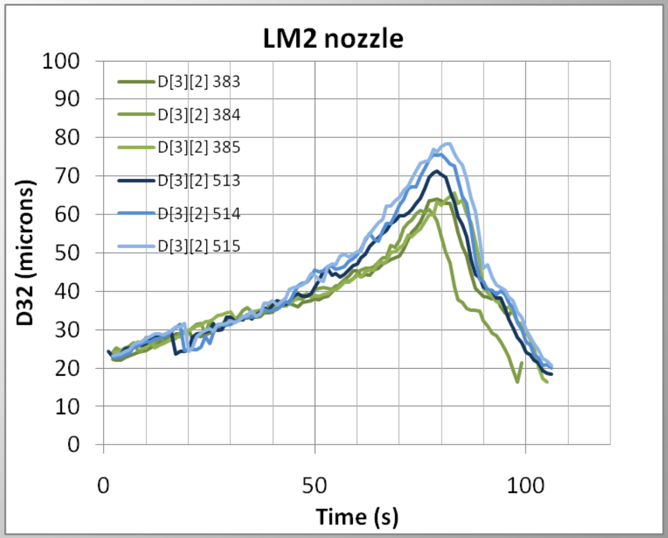
  Fine Water Mist (FWM) PFE meets these criteria.
- NASA has funded ADA to develop advanced prototypes.

"Off-the-shelf" tank prototype

Only water and nitrogen are discharged



Fine water spray fully characterized



Fine Water Mist Characteristics

Fine droplets → higher surface area for evaporation/cooling + radiation absorption and scattering

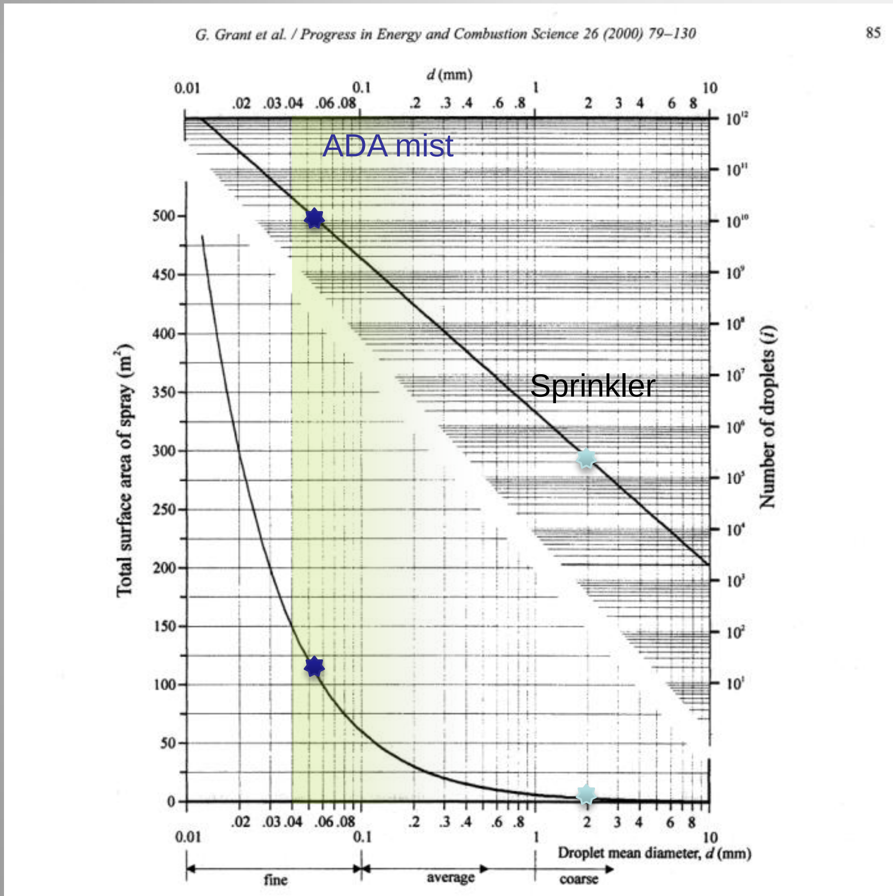


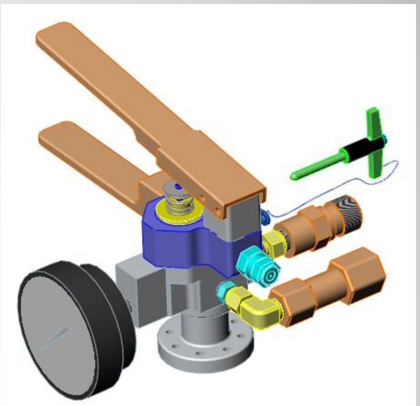
Fig. 3. Number of droplets and total surface area produced by one litre of water, as monodisperse sprays with various mean droplet diameters, d [10]. Reproduced from O. Herterich, Water as an extinguishing agent (published by Alfred Huthig Publishing Company, Heidelberg, 1960).

For each sprinkler droplet, the ADA mist has 60,000 smaller ones, offering 150x surface area

(assuming mist mean 50 μm diameter droplets)

FWM PFE Conceptual Architecture Overview

- Two primary system components: the **Tank Housing** and the **Nozzle Assembly**.
- Nozzle Assembly: controls the flow of water and expellant gas from the tank. Activated by the operator after removal of the safety pin and by manual action.
- Tank Housing: maintains the contents of the extinguisher at pressure actuation. The tank contains water and expellant gas separated by a physical barrier until mixed in the Nozzle Assembly.
- The inert gas propels the mist cloud from the extinguisher into the fire-affected zone.
- Discontinuing the manual action stops the flow of gas and water.



(Notional)

Development of Fire Test Scenarios

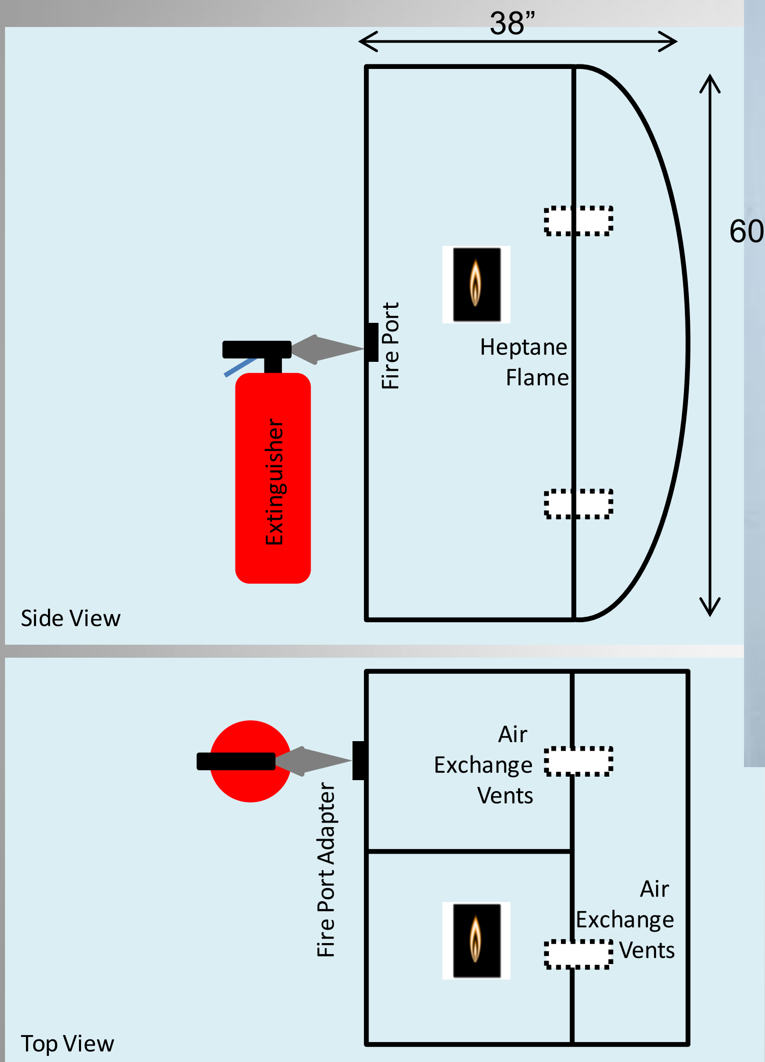
- Objective: define standard fire tests for ISS

- The scenarios (based on risk assessment for ISS):
  - **Rack Fire Test (ISS enclosed volume)**
  - Open Cabin Fire Test
  - **Stored Energy Battery Fire Test**
  - Stored Energy Oxygen Candle Fire Test
  - Elevated Oxygen Fire Test

- Design of Experiments (DOE) was employed where it aided in determining significance of variables and interactions

- For the International Space Station (ISS) application these fire test standards will become the basic performance criteria for the Fine Water Mist Portable Fire Extinguisher (FWM PFE)

Rack Fire Test Configuration



Rack Fire Test Methodology

- Test Parameters
  - Flight-like ISS rack divided into 3 volumes (2 equal volumes, left and right front boxes and a common back rack box)
    - Rack size and shape were set to flight-like structure
    - Volume size and shape were set by engineering conservatism
  - Simulate use of ISS fire port access hole. Two fire port locations were defined on left volume.
  - Fires and locations: Used 3 fires in right volume in top, middle and bottom locations
  - Fuel: Liquid heptane, burns in low oxygen environment, simple, reproducible, same as FAA standard
    - 35 mm diameter cup
    - 5 ml heptane on top of 10 ml water

Rack Fire Test Methodology (cont.)

- Test Variables
  - Agent: Watermist, Low Pressure N_2, High Pressure N_2, CO_2
  - Packing Density/Configuration:
    - Preliminary tests: empty rack, with/without obstruction
    - Packing of rack to reduce internal volume by 50% and 75% (keep “duct holes” clear of obstruction)
    - Force suppressant to travel a tortuous path (at least 6 x 90° turn)
- Test Operations
  - Ignite fuel and close rack, pre-burn 30 sec
  - Fully discharge PFE into left volume
  - Observe extinguishment of flame
  - Open rack and re-ignite flame to confirm that fuel did not run out

Rack Fire Tests Results

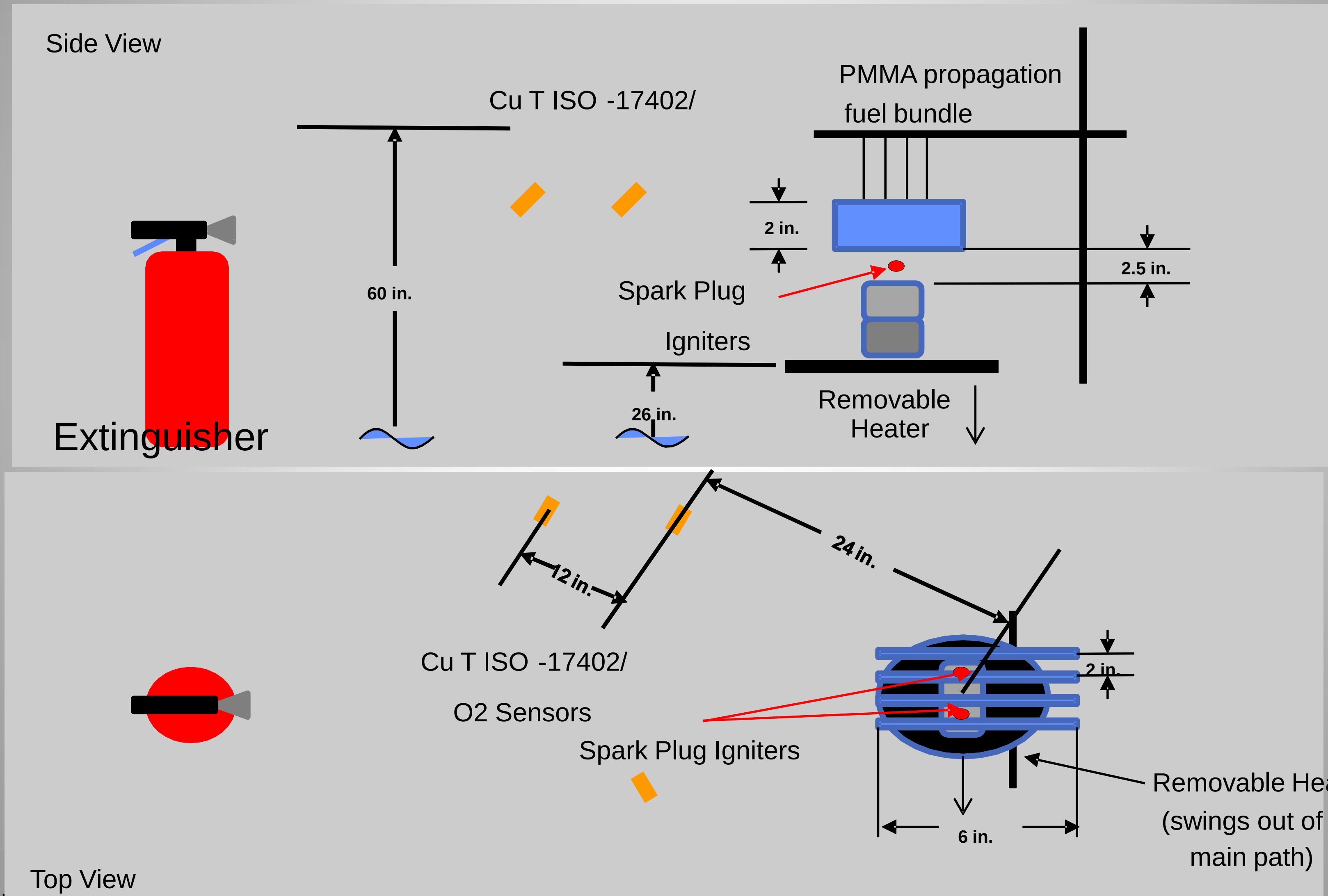
Run No.	Whole Plots	Agent	Configuration - Pack Density	Fireport	Time to Extinguish Fire 1 (BOTTOM)	Time to Extinguish Fire 2 (MIDDLE)	Time to Extinguish Fire 3 (TOP)
1	1	FWM	Simple 75%	High (3)	14	25	2
2	1	CO2	Simple 75%	High (3)	4	3	1
3	1	CO2	Simple 75%	Low (2)	5	8	13
4	1	HPN2	Simple 75%	Low (2)	5	7	8
5	2	FWM	Tortuous 75%	High (3)	28	9	3
6	2	LPN2	Tortuous 75%	High (3)	12	6	1
7	2	HPN2	Tortuous 75%	Low (2)	13	6	4
8	2	CO2	Tortuous 75%	High (3)	3.5	1	1
9	3	HPN2	Tortuous 50%	High (3)	6	12	9
10	3	FWM	Tortuous 50%	High (3)	43	52	58
11	3	LPN2	Tortuous 50%	Low (2)	NE	NE	99
12	3	CO2	Tortuous 50%	High (3)	6	14	34
13	4	LPN2	Simple 75%	High (3)	14	14	1
14	4	LPN2	Simple 75%	Low (2)	12	9	9
15	4	HPN2	Simple 75%	High (3)	2	1	1
16	4	FWM	Simple 75%	Low (2)	22	13	6
17	5	LPN2	Tortuous 75%	Low (2)	48	22	12
18	5	HPN2	Tortuous 75%	High (3)	2.5	2	1
19	5	FWM	Tortuous 75%	Low (2)	43	23	30
20	5	CO2	Tortuous 75%	Low (2)	11	9	8
21	6	CO2	Tortuous 50%	Low (2)	10	36	NE
22	6	FWM	Tortuous 50%	Low (2)	NE	100	89
23	6	LPN2	Tortuous 50%	High (3)	18	46	67
24	6	HPN2	Tortuous 50%	Low (2)	16	26	39
25	7	FWM	Simple 50%	High (3)	15	39	54
26	7	CO2	Simple 50%	Low (2)	11	23	52
27	7	CO2	Simple 50%	High (3)	12	11	14
28	7	LPN2	Simple 50%	Low (2)	73	53	75
29	8	HPN2	Simple 50%	High (3)	7	5	4
30	8	HPN2	Simple 50%	Low (2)	44	12	13
31	8	FWM	Simple 50%	Low (2)	54	NE	101
32	8	LPN2	Simple 50%	High (3)	14	28	37

NE = Not Extinguished

Rack Fire Tests Conclusions

- All agents were generally successful but experienced at least one failure to extinguish
- High momentum extinguishers (CO_2, HPN_2) extinguished flames in less time than LPN_2 and FWM. However, some flames were blown due to flow turbulence out rather than extinguished via inerting
- Finest droplets of FWM were observed to travel through tortuous path but did not seem to accelerate extinguishment (compared to N_2 only)
- Identified most challenging configuration for NASA standard test (middle fire port, middle flame, low turbulence)
- Next step: repeat tests in now standard configuration to improve statistical analysis

Battery Fire Overall Set Up - Schematic



Battery Fire Configuration / Technique

Test Parameters

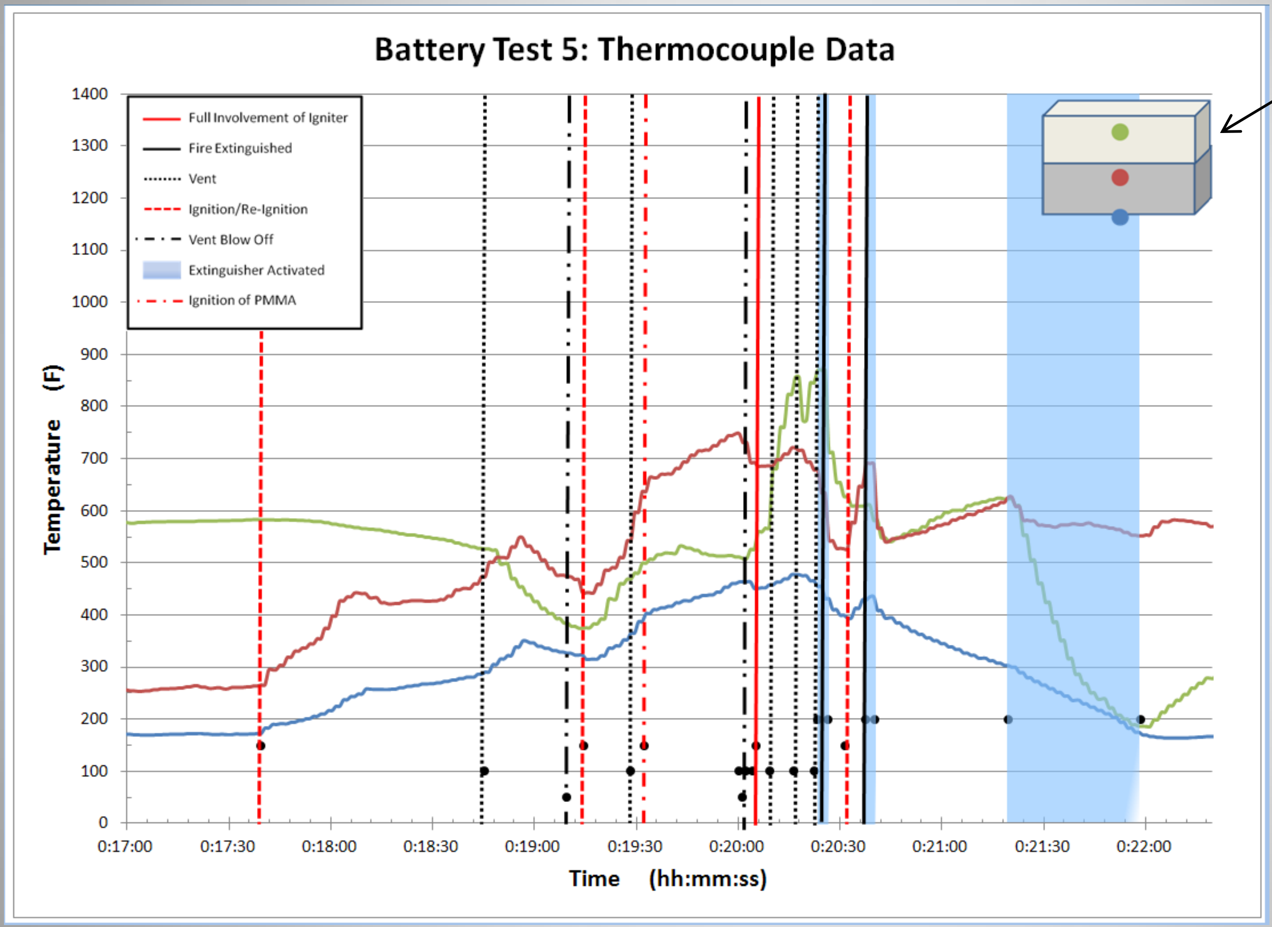
- Ignition via overheating
- 2 stacked 4 cell camcorder battery pack (1st is igniter, 2nd is propagation)
- Spark ignition source to increase ignition repeatability

Test Operations

- Full engulfment of igniter battery: 15 seconds after 4 cells of igniter battery visually vented + witness PMMA ignited
- Firefighter starts discharging extinguisher (5.5 ft away) from fixed location, pulsing as needed and cooling test articles
- Pass/ Fail: all flames fully extinguished, stop thermal runaway leading to re-ignition and propagation (batteries or materials)
- Monitor: 15 minutes post extinguishment

- Note: to be valid, test should not have cells ejected

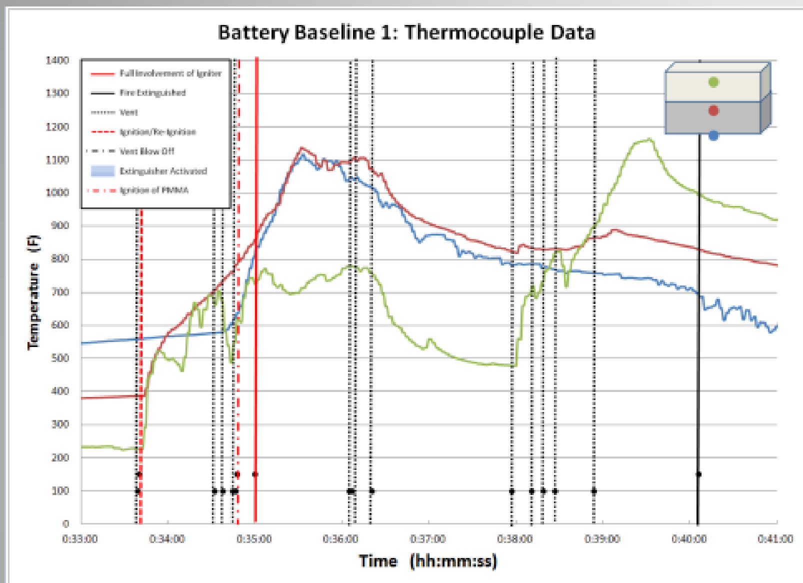
Results – Battery Fire Extinguished with FWM

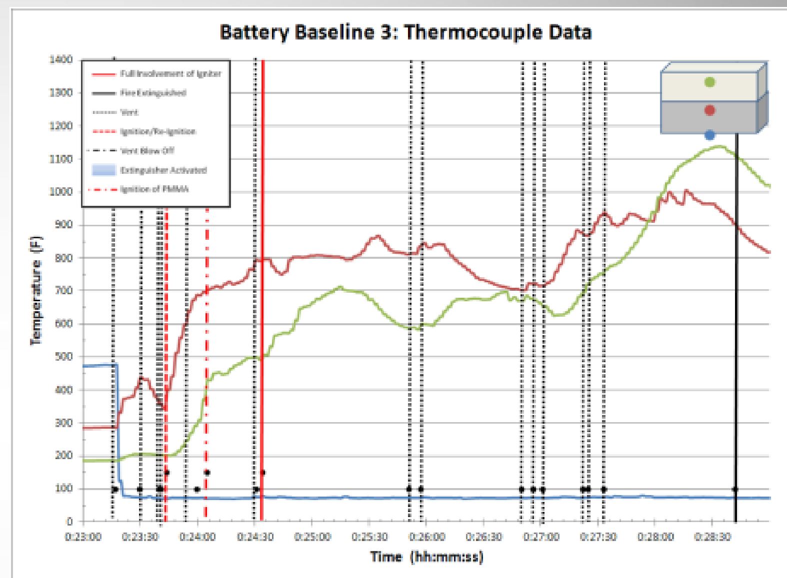


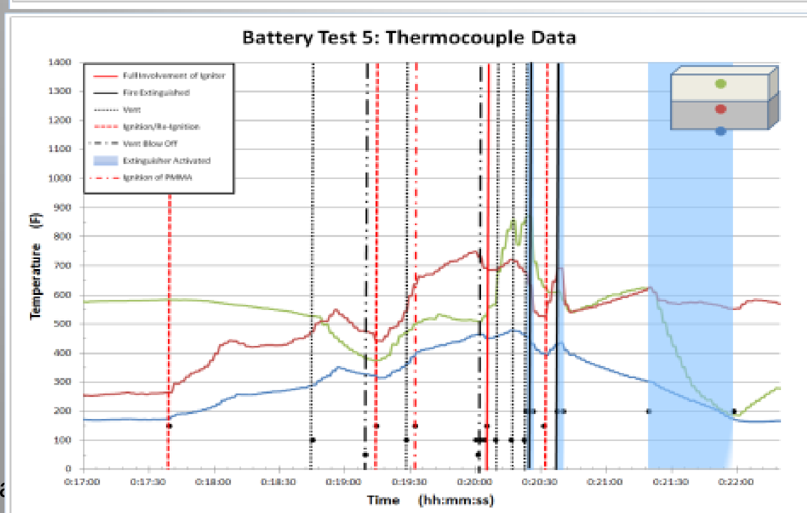
Stacked battery packs. Colored dots represent location of TC's

- Flames extinguished. Thermal runaway stopped after 1 reignition
- Temperature cooling clearly observed with FWM FTE pulses

Results – Comparison with Baseline Tests (free burn)







- FWM FE tests lowered max 1300ºF to 900ºF
- FWM FE tests lowered event duration time from max 41min to 22min

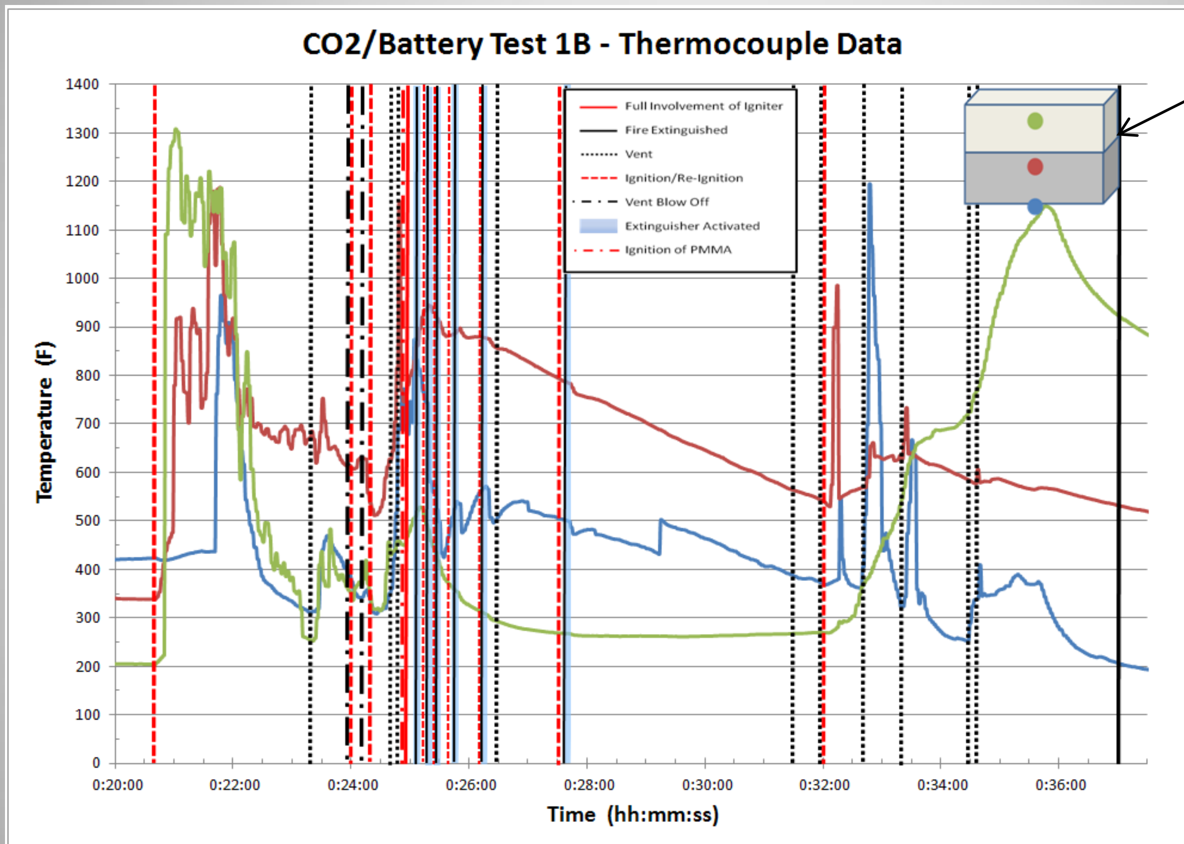
Results – Post-test Visual Inspection

Baseline

Test with Extinguisher

- Baseline fully consumed casing and vented cells
- FWM extinguisher tests stopped propagation leaving casing material and an average of 2 cells with charge >0

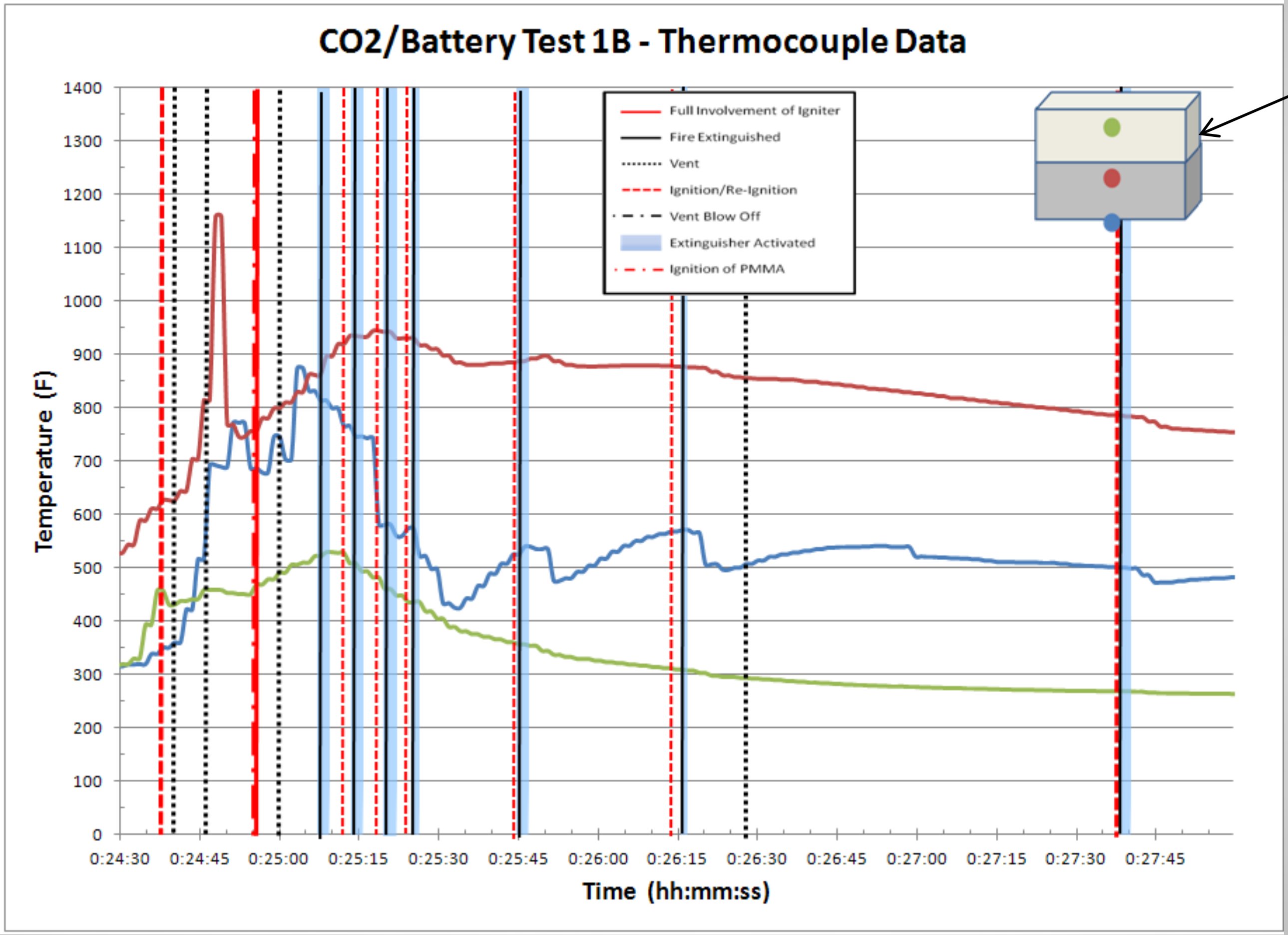
Results – Battery Fire Extinguished with CO_2



Stacked battery packs. Colored dots represent location of TC's

- 3 tests with commercial 14 lb handheld CO_2 conducted
- 2 tests required 5.9 lb and 9.1 lb to extinguish fire, with one cell lost
- Fire not extinguished with full 14 lb in third case
- For comparison, ISS uses 6.5 lb CO_2 extinguisher

Results – Battery Fire Not Extinguished with CO_2



Stacked battery packs. Colored dots represent location of TC's

- 6 reignitions occurred using 14 lbs of CO_2 extinguisher
- Max 1 reignition seen with FWM, stopping thermal runaway and propagation

Summary and Conclusions – Battery Fire Tests

- Fine Water Mist Test Conclusions:
  - In 5/5 tests, all flames were fully extinguished
  - In 5/5 tests, cooling was sufficient to prevent continuation of thermal run-away and consumption of propagation battery pack
  - FWM left casing material and an average of 2 cells with charge >0
  - Baseline tests fully consumed casing and vented all cells
  - Additional Findings
    - FWM lowered max temp from 1300ºF to 900ºF
    - FWM lowered event duration time from max 41 min to 22 min
    - ISO Environmental Calorimeters saw a worst case 5.5 F increase in environmental temperatures (No keep out zone implications)
    - No oxygen depletion was observed (No keep out zone implications)
- CO_2 Test Conclusions:
  - More difficulties extinguishing fires (2/3 tests)
  - 1/3 test not extinguished with 14 lbs when all cells present