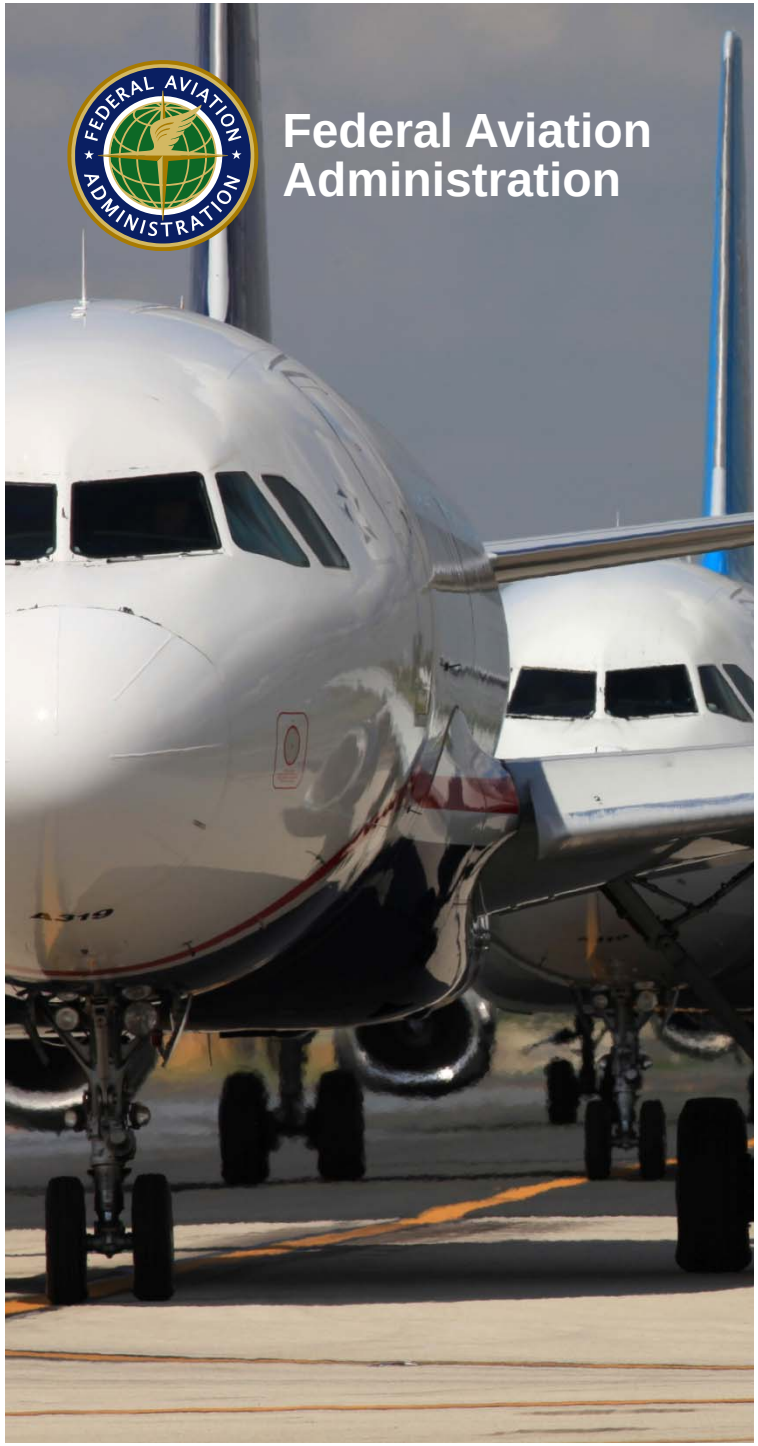
Safe Transport of PEDs in Transport Passenger Aircraft



Presented to: ICAO DGP

By: Fire Safety Branch
Federal Aviation Administration

Date: 10/20/2017

First and Foremost: Fire Prevention!

Aircraft are Designed, Certified, and Operated with the Philosophy of Preventing Accidents, which includes Preventing Any and All Fires from Occurring.

Cargo Fire Incidents (2002-2012)

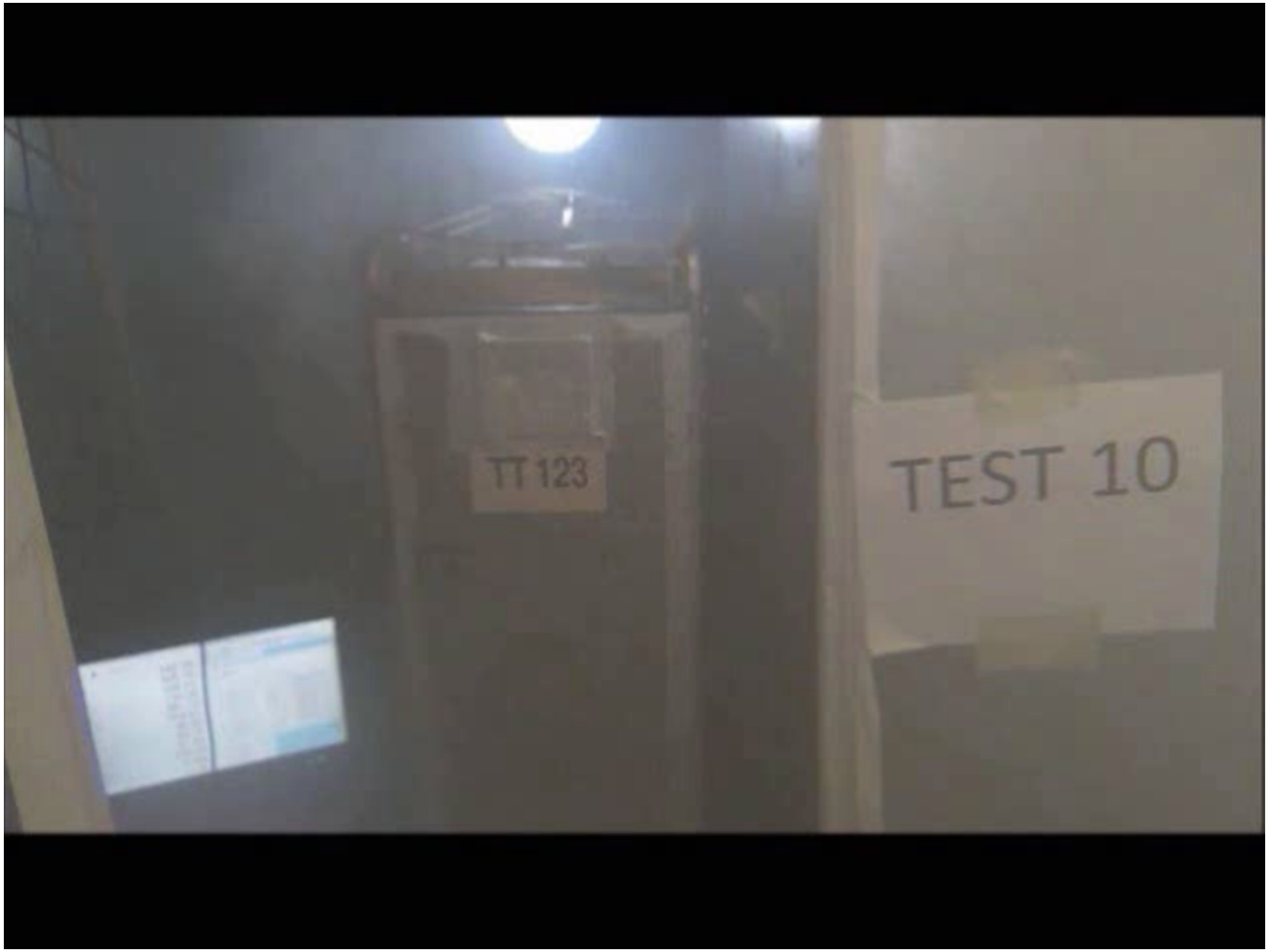
Passenger Aircraft – Class "C" Compartments

- **N Registered Aircraft**
- **3 Incidents (2 Fires)**
  - Hair spray released in compartment
  - Overheating electronic unit that was on.
  - Flashlight that was on and overheated

Why are PEDs with Lithium Batteries an Added Risk?

- **Lithium batteries are both an ignition source and a fuel.**
- **Lithium batteries have been a fire source in the cabin.**
- **Lithium battery fires may reduce the effectiveness of the fire suppression system.**
  - They produce hydrogen gas when in thermal runaway.
  - Thermal runaway can propagate from cell to cell unless cooled.

Tablets in a Galley Cart



Lithium Ion Batteries in a Cargo Container

Why do cells go into thermal runaway and start fires?

- **Over charged**
- **Discharge too fast**
- **Overheating**
- **Internal short (defective cell)**
- **Damage (punctured, dropped, etc.)**

Fire Suppression System

- **Halon system is the second line of defense.**
  - Designed for fires likely to occur
- **Lithium batteries were not considered in design of system.**
- **Halon system may or may not be effective in controlling PED fires, i.e., the reliability of the system is negatively influenced by PED fires.**

Why Might Halon Not be Effective?

- **Thermal runaway can propagate from cell to cell, and Halon is not a good cooling agent.**

- **Cells in thermal runaway produce hydrogen, and the design concentrations of halon will not provide protection from a hydrogen explosion.**

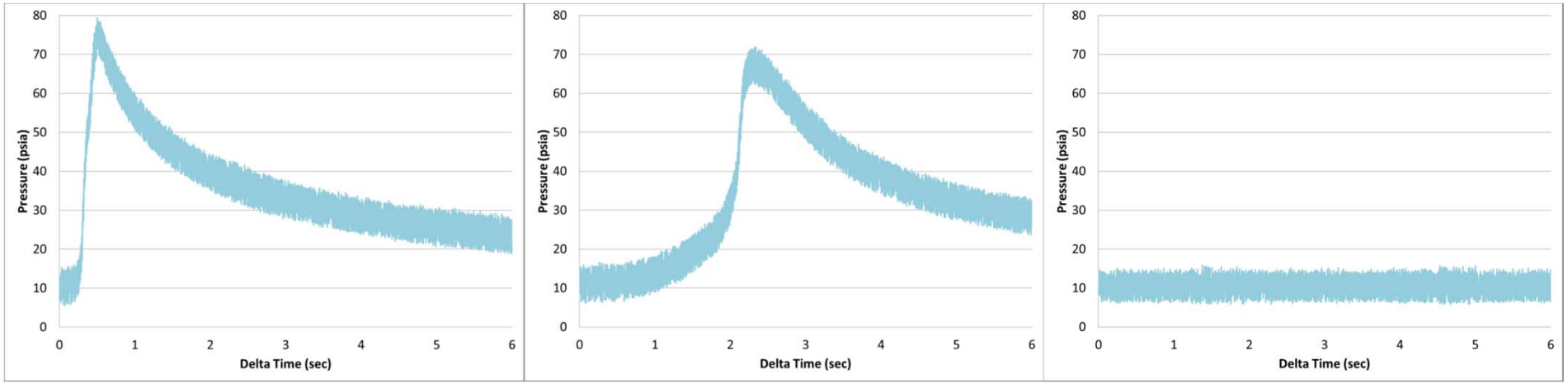
Lithium Ion Battery Vent Gas Mixture

- **Lithium batteries in thermal runaway produce flammable gasses and create significant hazards for aircraft.**
- **The three most prevalent gases are carbon dioxide (30.1 %), hydrogen (27.6 %), and carbon monoxide (22.9 %).**
- **Lithium ion battery vent gas mixture by percent concentration:**

30.10% CO_2	2.21% C_2H_4
27.60% H_2	1.57% C_4H_{10}
22.90% CO	1.17% C_2H_6
6.37% CH_4	0.56% C_4H_8
4.48% C_3H_6	0.27% C_3H_8

Results (Large Scale Tests)

6 second time window



Test without suppression

Test with 5.28% Halon

Test with 10.43% Halon

Effectiveness May Be Scenario Dependent

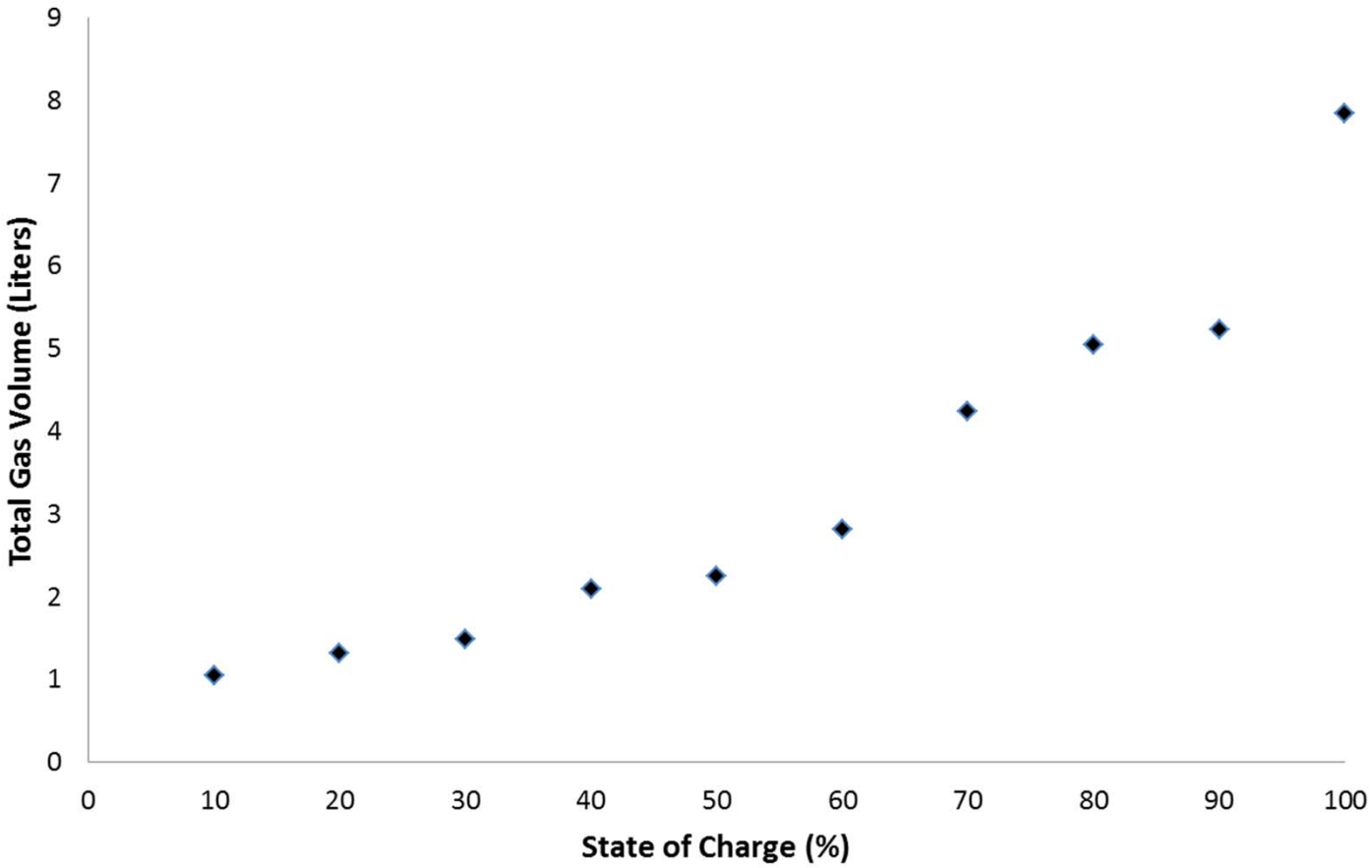
- **Fire buildup before detection**
- **Fire buildup before design concentration of agent penetrates container**
- **Fire involves other cargo**

Aerosol Can Explosion in a Class D Cargo Compartment

Why are Passenger PEDs a Greater Risk Than When Shipped by The Manufacturer?

- **From Manufacturer:**
  - Batteries not installed (unit always off).
  - Batteries at reduced state of charge (most at 30%).
  - Items are Marked and protected from damage.
- **From Passenger:**
  - Batteries installed (unit might be in sleep mode).
  - In most cases batteries are highly charged.
  - Minimal protection from damage.
  - Used (and potentially abused).

Gas Volume vs State of Charge



How to Mitigate or Reduce the Risk?

- **Prevention**
  - Contain the event within one laptop package
- **Control**
  - Control a PED fire such that the halon system can effectively suppress and contain the fire within the compartment.

Prevention

- **Operational Procedures:**
  - Laptops must be off. Much greater risk if on or in standby/sleep mode (can overheat the battery).
  - Packaged to prevent damage. (Any damage increases the risk of a fire).
  - Others as determined under **Control**.

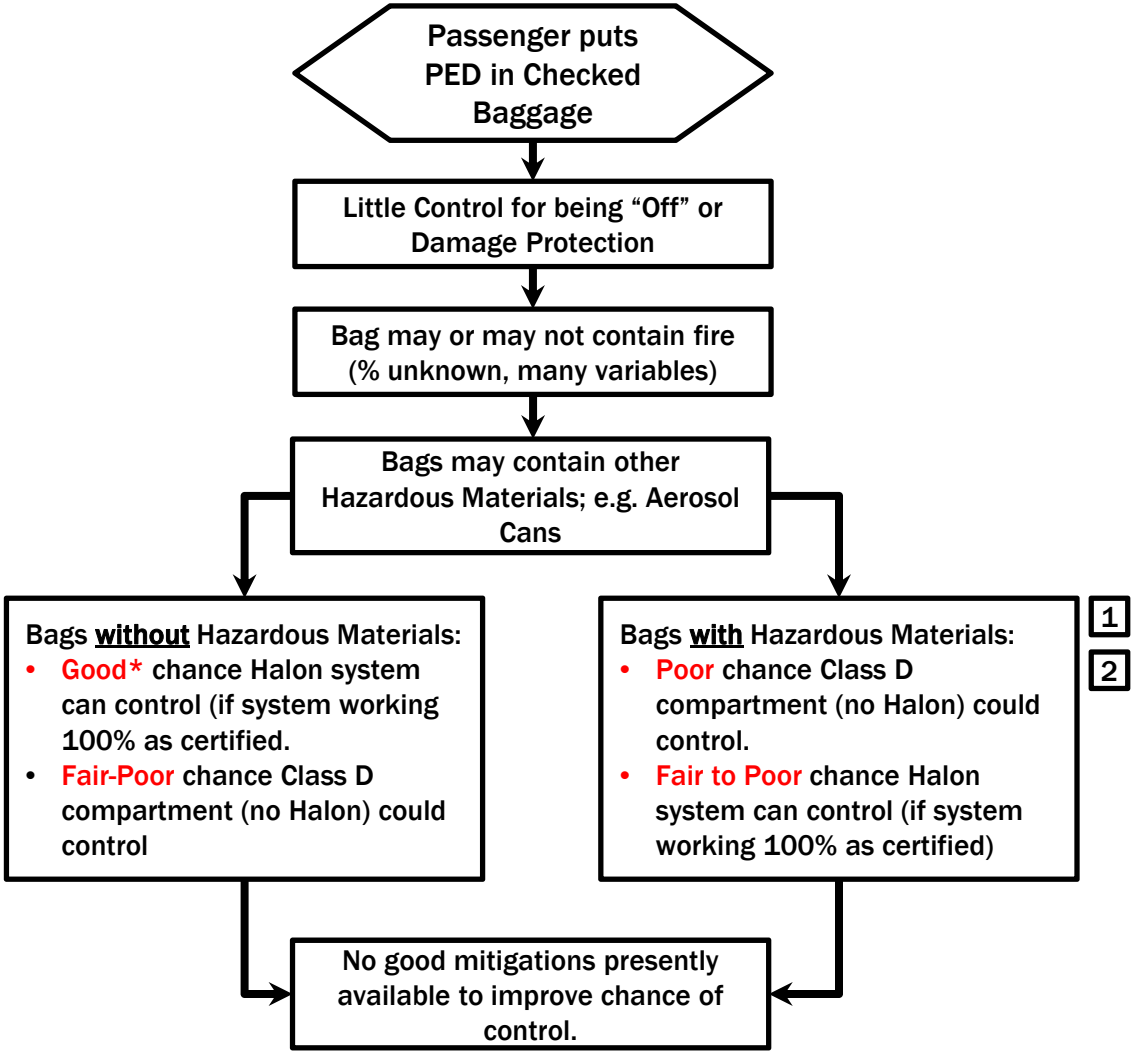
Control:

- **Improve effectiveness of Halon system**
  - Optimal Placement of Laptops?
  - Best way to maximize halon at the laptop fire?
  - Quickest way to detect fire in container?

Summary:

- **Understand Risks**
- **Minimize Risks**
- **Determine if Minimized Risks are Acceptable**

PED's in Checked Bag



Federal Aviation Administration

What Has Been Learned from Testing

Based on Laptops Powered by 18650 Cylindrical Cells

- **When packed in passenger bags:**
  - If a cell goes into thermal runaway the fire may penetrate the bag.
    - Depends on many factors, including, packing density, materials in bag, type of bag and available air in bag.
  - If other Haz. Mat.(such as aerosol cans) is in the bag an explosion can occur, not related to the gases from the battery.
    - An explosion can occur before Halon, in a Class C compartment, would be discharged and reach a 3% suppression concentration in a ULD.
    - A Class D compartment would provide no protection from an explosion

What Has Been Learned from Testing

Based on Laptops Powered by 18650 Cylindrical Cells

- **Large scale test demonstrated:**
  - About 2 minutes from agent discharge until 3% suppression concentration was reached within a ULD.
    - That time will depend on many factors, including agent discharge time, load factor of the compartment, leakage rate of the compartment and tightness of the ULD.
  - A Halon system in a class c compartment, if working as certified, can control the fire of boxes packed in a ULD.
  - A Halon system in a class c compartment, if working as certified, might not provide enough agent inside a ULD in time to suppress an explosion of an aerosol can caused by a laptop battery fire.

Pouch Cells Pose Same Risk

Laptop Luggage Test Overview

- **Luggage provided by TSL, fully loaded with various items of clothing, shoes, books and other personal items.**
- **Laptop fitted with heater and thermocouple to initiate thermal runaway.**
- **Laptop placed in bag with clothing items above and below the laptop.**
- **Thermal runaway is initiated and the bag monitored for smoke, open flames, and temperature.**

Test 1: Soft Sided Luggage

- **Luggage was opened, some contents removed and the laptop was placed inside.**
- **The remaining contents were replaced on top of the laptop.**

Test 1 Results

- **The laptop was put into thermal runaway.**
- **Smoke was observed escaping the bag**
- **No open flames were observed.**
- **Some charring of bag contents was found post test.**

Test 2: Hard Sided Luggage

- **Luggage prepared in same manner as test 1.**
- **Large amounts of smoke were observed.**
- **No open flames were observed**

Test 2: Results

- **Considerable charring of contents.**
- **Some damage to inside of bag .**
- **Small penetration on the underside of the bag**

Test 3: Soft Sided Bag

- **Smoke observed.**
- **No open flames were observed.**
- **Charring of contents**
- **Damage to inner liner**

Test 4: Soft Sided Luggage Results

- **Smoke observed at thermal runaway.**
- **Bag was breached and open flames were observed.**
- **Hot vigorous fire developed.**
- **Bag completely destroyed.**

Test 4: Soft Sided Luggage Results

Test 5: Small Duffel Bag Results

- **Smoke observed.**
- **No open flames were observed.**
- **Charring of contents**
- **Some slight burning/charring through to exterior of bag**

Observations

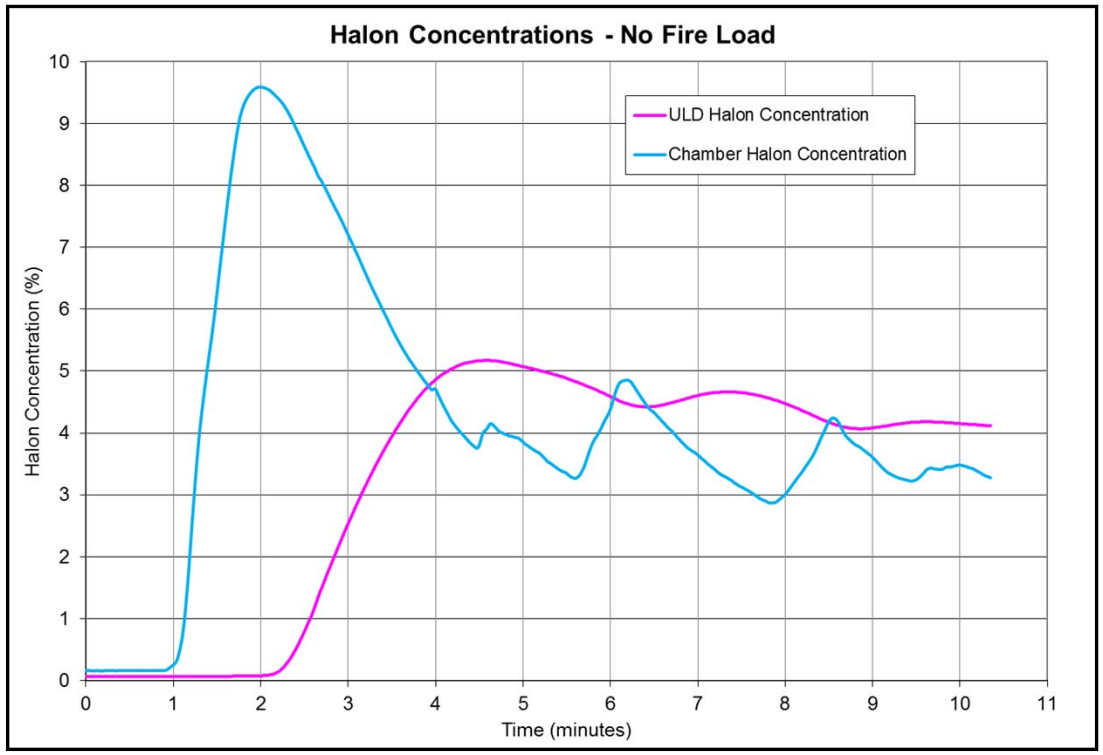
- **Tightly packed suitcases seem to contain the laptop fire better than loosely packed suitcases**
- **Laptop fire will spread to the suitcase contents if there is a sufficient air source, such as a hole in the bag.**
- **The type of bag contents has an effect on flammability.**
- **There does not appear to be a difference between soft sided and plastic hard sided bags in terms of containing a laptop fire.**
- **Metal sided suitcases were not available for testing.**

Test Setup: Simulate Class C Cargo Compartment

- **381 cubic foot test chamber.**
- **32 cubic foot ULD**
- **Halon system installed with 5% initial concentration and 3% maintained concentration**
- **Forced leakage rate 10 cubic feet/minute**
- **60-70 % cargo loading by volume**

Halon Concentration Test

- **Halon was measured in two locations:**
  - Outside the ULD near mid chamber height
  - Inside the ULD near mid chamber height
- **7.5 lb Halon discharge yields 5% in the chamber when empty**
- **Peak concentration is higher due to chamber loading.**
- **Additional Halon added as concentration depleted to maintain 3-4%**

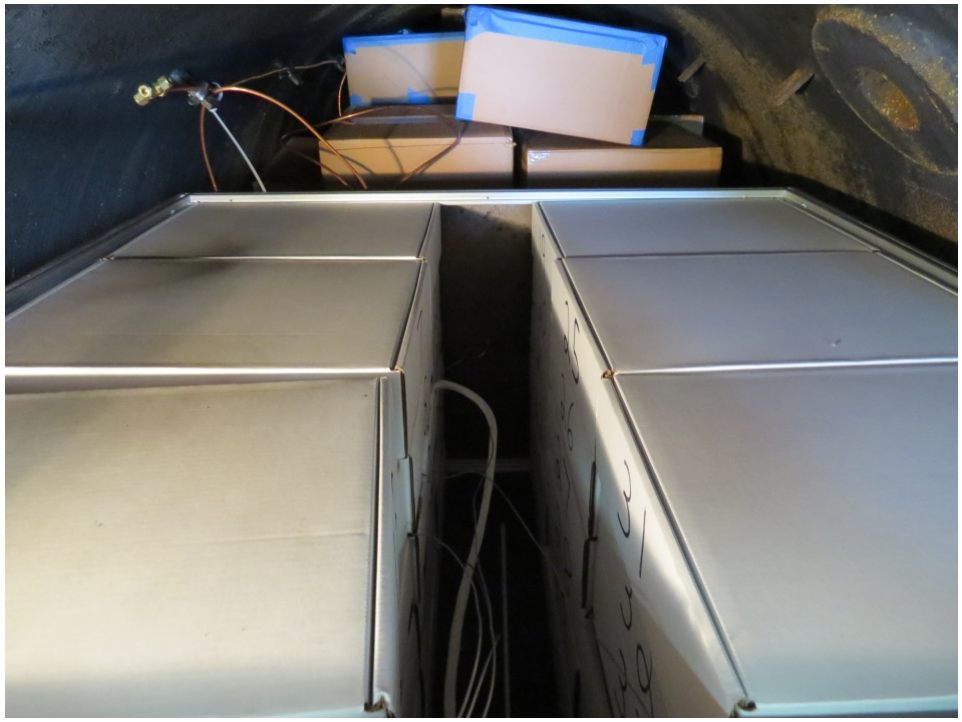


Laptop Fire Test with Halon

- **36 laptops, Emirates style packaging**
  - Charged to 100%
  - Packed in bubble wrap inside Emirates style box
- **Laptop in position 9 fitted with a heater to induce thermal runaway**
- **Halon discharged when visible smoke is observed**
- **3% Halon concentration maintained for duration of test.**

Results: Laptop Fire with Halon

- Heater was energized at time 0.
- Thermal runaway was detected at 8:21
- Smoke was observed at 8:21
- Halon was discharged at 9:50
- Halon maintenance began at 15:30
- Peak Halon concentration in the chamber was 9.25%
- Peak Halon concentration in the ULD was 7.65%
- Test terminated after 60 minutes



Results: Laptop Fire with Halon

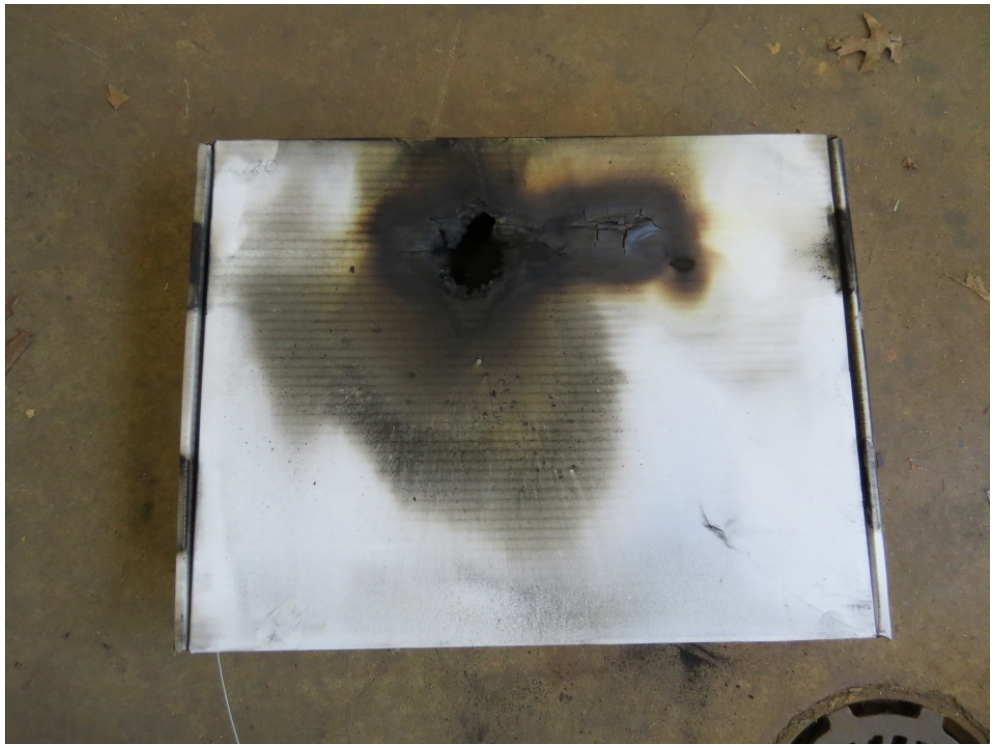
- **Soot visible on the boxes above the laptop in thermal runaway in box 9.**
- **Bottom of box 9 burned through**

Results: Laptop Fire with Halon

- **Laptop in thermal runaway**
  - Bubble wrap on top charred
  - Bubble wrap on bottom consumed
  - All cells in battery pack went into thermal runaway

Results: Laptop fire with Halon

- **Lid of box 10, located directly below box 9, was penetrated.**



Results: Laptop Fire with Halon

- **Laptop in box 10**
  - Bubble wrap melted.
  - Laptop was charred.
  - Temperature data for this laptop indicated the interior of the laptop never exceeded 100°F.

Observations: Laptop Test

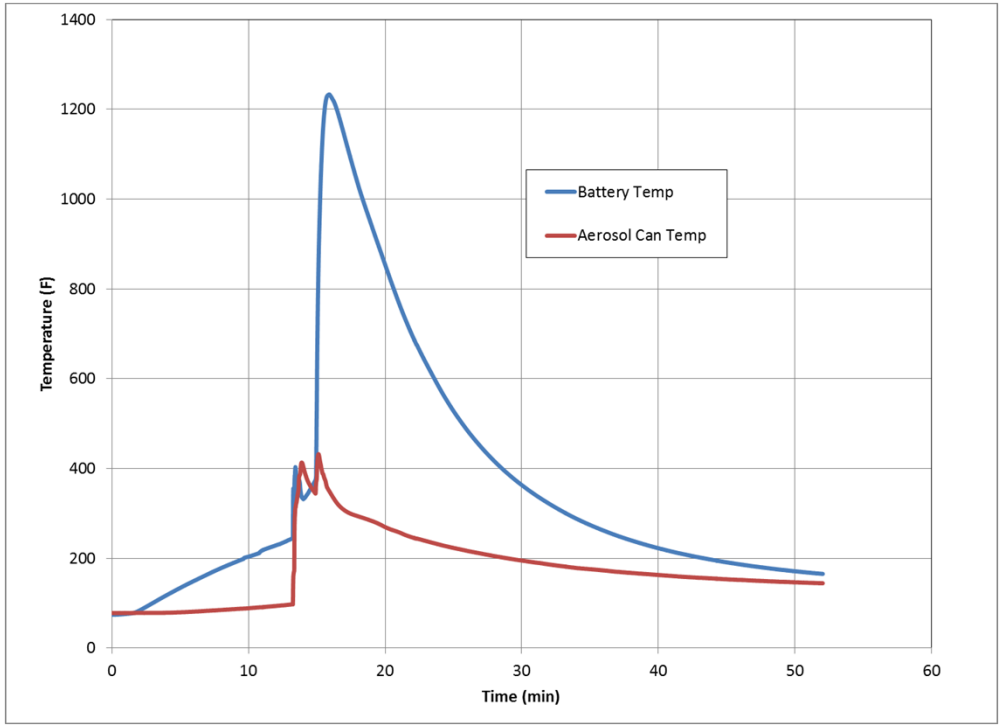
- **Halon was able to penetrate the simulated ULD and achieved a sufficient concentration to suppress the fire.**
- **The laptop in thermal runaway generated enough heat to both char and penetrate the bottom of the box and the top of the box below it.**
- **There was no propagation of thermal runaway to adjacent laptops**

Laptop/Aerosol Can Test 1

- **Laptop prepared as before.**
- **12 ounce aerosol can of hairspray strapped to laptop battery to ensure it stays in close proximity**
- **Laptop/can placed in hard sided suitcase**

Laptop/Aerosol Can Test 1 Results

- **Thermal runaway of battery resulted in some smoking.**
- **Temp reading of aerosol can appears to have been affected by the TR event.**
- **This temperature remained well above 200F for ~15 minutes**
- **No resulting explosion of can**



Laptop/Aerosol Can Test 2

- **Laptop prepared as before.**
- **8 ounce aerosol can of dry shampoo strapped to laptop battery to ensure it stays in close proximity**
- **Laptop/can placed in soft sided suitcase**

Laptop/Aerosol Can Test 2 Results

- **Fire observed almost immediately after first thermal runaway event.**
- **Fire rapidly grew and within 40 second can exploded**
- **Fire continued to rapidly consume bag/contents**

Laptop/Aerosol Can Test

Observations

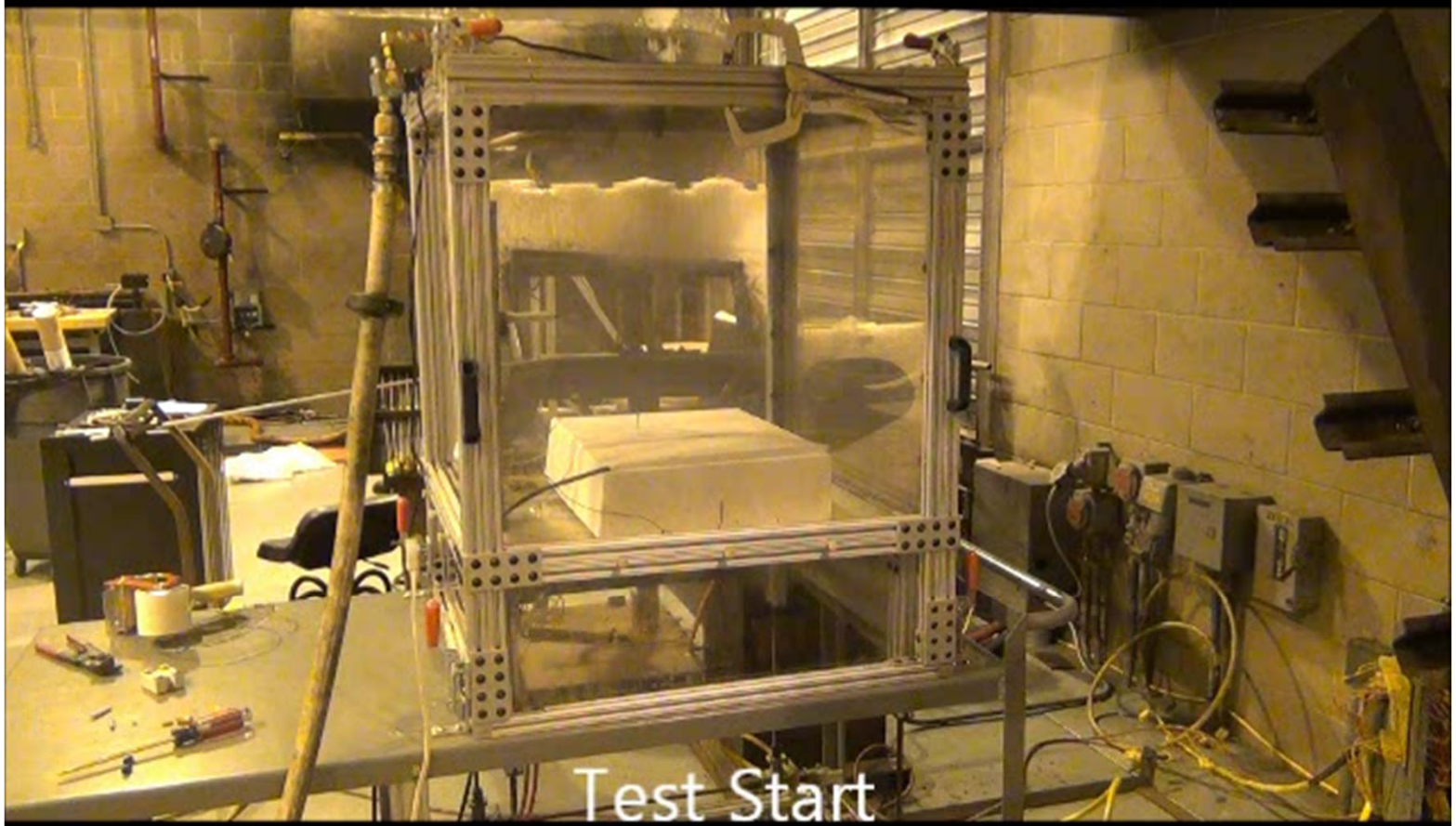
- **If an aerosol can is packed in a suitcase and a thermal runaway event occurs, there is the potential for an aerosol can explosion.**

Effectiveness May Be Scenario Dependent

- **Fire buildup before detection**
- **Fire buildup before design concentration of agent penetrates container**
- **Fire involves other cargo**

Aerosol Can in Class D Compartment

Laptop in Box Lined With Fire Barrier Tested to G27 Proposed Standard



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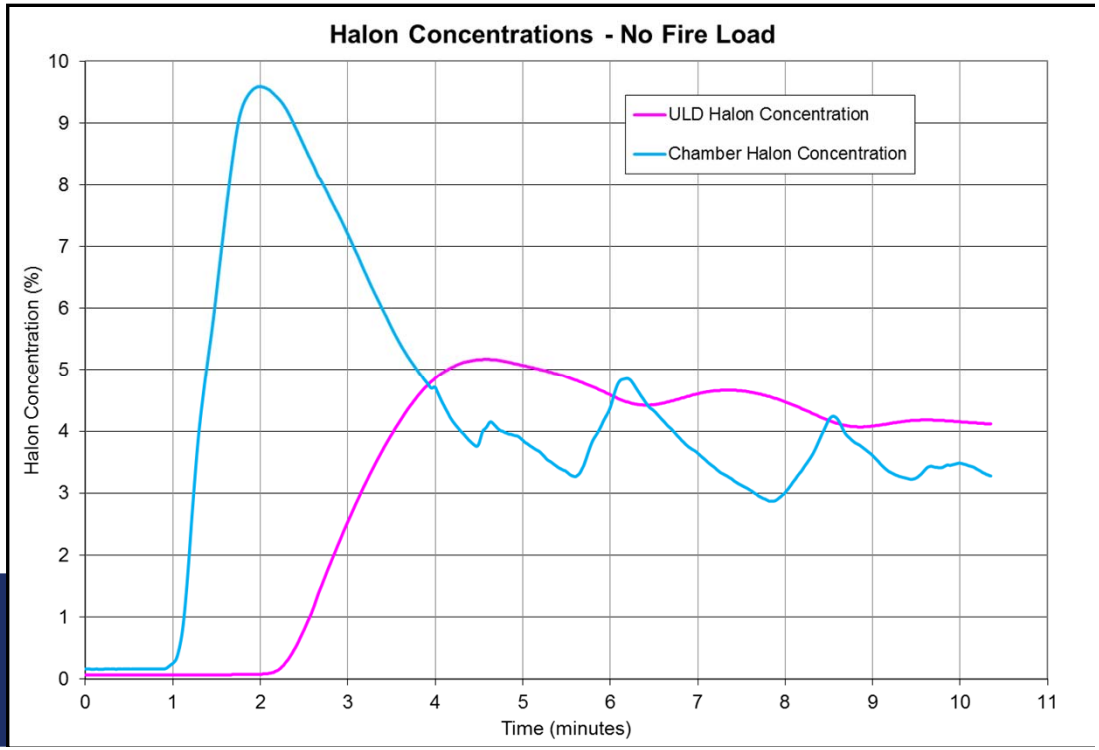


Luggage fire test with Halon

- **5 bags of luggage, filled with misc. clothing and personal effects.**
- **Ignition source in cardboard box filled with shredded paper placed in center position**
- **Halon discharged when visible smoke is observed**
- **3% Halon concentration maintained for duration of test.**

Results: Luggage fire test with Halon

- **Heavy smoke observed shortly after halon discharged – did not clear until after ~1 hour**
- **Cardboard box not fully consumed**
- **Soot/smoke particles observable throughout pressure vessel post-test**

Results: Luggage fire test with Halon

- **Peak temperatures inside the 5 pieces of luggage ranged from 120 - 150°F**
- **2 of the 5 bags had minor charring.**

Observations- Luggage test

- **Halon was able to penetrate the simulated ULD and achieve a sufficient concentration to suppress the fire.**
- **Fire did not propagate from cardboard box to the pieces of luggage, however some charring did occur.**
- **Heavy smoke throughout pressure vessel for the full hour duration of test due to likely smoldering fire within cardboard box.**
- **Halon performed as expected**

6-22-17 Luggage Test #1 - Results

- **Fire visible approximately 20 s after initial TR event**
- **Approximately 8.5 minutes after fire initiated, aerosol can exploded.**

6-22-17 Luggage Test #1 - Results

6-22-17 Luggage Test #2 - Results

- **1st evidence of TR observed ~18.5 mins after heater activation.**
- **Heavy smoke coming from bag following TR.**
- **No evidence of flames.**
- **No involvement of aerosol can.**
- **Burning/charring of contents evidenced post-test.**

6-22-17 Luggage Test #2 - Results

6-22-17 Luggage Test #3 - Results

- **Initial TR event occurs with release of smoke/flame**
- **Fire progresses and within 10 seconds, aerosol can explodes.**

6-22-17 Luggage Test #3 - Results

6-22-17 Luggage Test #4 - Results

- **~10 mins after start of test, first TR event occurs**
- **Fire immediately visible**
- **Burning continues for 5-6 minutes followed by violent aerosol can explosion**

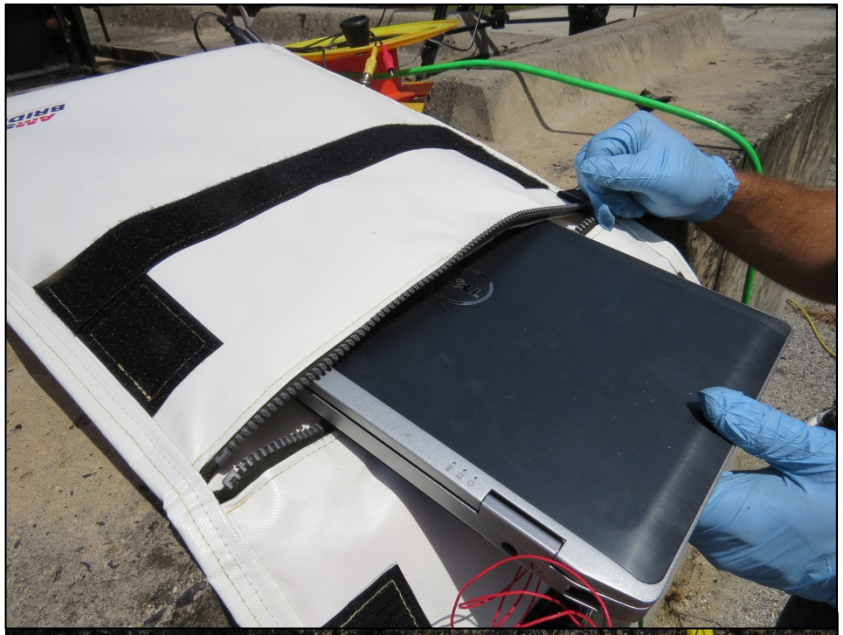
6-22-17 Luggage Test #4 - Results

Luggage Test Observations

- **Tightly packed suitcases seem to contain the laptop fire better than loosely packed suitcases**
- **Laptop fire will spread to the suitcase contents if there is a sufficient air source, such as a hole in the bag.**
- **The type of bag contents has an effect on flammability.**
- **The presence of flammable toiletries increases the potential for fire.**
- **There does not appear to be a difference between soft sided and plastic hard sided bags in terms of containing a laptop fire.**
- **Metal sided suitcases were not available for testing.**
- **If an aerosol can is packed in suitcase and a thermal runaway event occurs, there is the potential for an aerosol can explosion.**

6-22-17 AMSafe Pouch Test

- **Laptop instrumented as previous tests**
- **Placed in pouch**
- **Pouch zippered and sealed.**
- **Additional T/C positioned inside flap of the pouch**



6-22-17 AMSafe Pouch Test - Results

- Significant smoke seen emanating from pouch as TR events occurred
- Pouch expanded during TR events due to pressure build up
- Flames escaped from pouch ~30 sec after initial TR event
- Post-test evaluation showed a rupture had occurred in back surface of bag.

6-22-17 AMSafe Pouch Test - Results