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Flammability Assessment of Bulk-Packed, Nonrechargeable Lithium Primary Batteries in Transport Category Aircraft

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Final Report

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16. Abstract

This report documents the findings of a series of tests conducted to determine the flammability characteristics of primary lithium batteries and the dangers associated with shipping them in bulk form on commercial transport category aircraft.

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EXECUTIVE SUMMARY

A series of test were conducted to assess the flammability characteristics of nonrechargeable lithium primary batteries, both individually and as packaged for bulk shipment onboard cargo and passenger aircraft. The tests were designed to determine the conditions necessary for battery ignition, the characteristics of the battery fire, the potential hazard to the aircraft as a result of the fire, and the effectiveness of the standard Halon 1301 fire suppression systems in extinguishing the fire.

A relatively small fire source is sufficient to start a primary lithium battery fire. The outer plastic coating easily melts and fuses adjacent batteries together and then ignites, contributing to the fire intensity. This helps raise the battery temperature to the self-ignition temperature of lithium. Once the lithium in a single battery begins to burn, it releases enough energy to ignite adjacent batteries. This propagation continues until all batteries have been consumed.

Halon 1301, the fire suppression agent installed in transport category aircraft, is ineffective in suppressing or extinguishing a primary lithium battery fire. Halon 1301 appears to chemically interact with the burning lithium and electrolyte, causing a color change in the molten lithium sparks, turning them a deep red instead of the normal white. This chemical interaction has no effect on battery fire duration or intensity.

The air temperature in a cargo compartment that has had a fire suppressed by Halon 1301 can still be above the autoignition temperature of lithium. Because of this, batteries that were not involved in the initial fire can still ignite and propagate.

The ignition of a primary lithium battery releases burning electrolyte and a molten lithium spray. The cargo liner material may be vulnerable to perforation by molten lithium, depending on its thickness. This can allow the Halon 1301 fire suppressant agent to leak out of the compartment, reducing the concentration within the cargo compartment and the effectiveness of the agent. Holes in the cargo liner may also allow flames to spread outside the compartment.

The ignition of primary lithium batteries releases a pressure pulse that can raise the air pressure within the cargo compartment. The ignition of only a few batteries was sufficient to increase the air pressure by more than 1 psi in an airtight 10-meter-cubed pressure vessel. Cargo compartments are only designed to withstand approximately a 1-psi pressure differential. The ignition of a bulk-packed lithium battery shipment may compromise the integrity of the compartment by activating the pressure relief panels. This has the same effect as perforations in the cargo liner, allowing the Halon 1301 fire suppressant to leak out, reducing its effectiveness.

1. INTRODUCTION.

Primary lithium batteries are a popular power source for many small electronic appliances. Most of the batteries used in the United States are manufactured in Japan. The batteries are packed in bulk corrugated cardboard containers and stacked on pallets and shipped in the cargo holds of passenger and cargo aircraft. There has never been a known in-flight fire associated with shipping the batteries in this manner; however, a ramp incident involving palletized batteries has drawn attention to the flammability hazard of primary lithium batteries.

The ramp incident occurred at Los Angeles International Airport in April 1999. A pallet of batteries caught fire while being handled between flights. There was no known external ignition source. The nature of lithium fires makes them very difficult to extinguish, with all common extinguishing agents ineffective in controlling the fire.

The tests described in this report are an effort to assess the flammability characteristics of primary lithium batteries and the potential hazard associated with shipping them on transport aircraft.

2. TEST DESIGN.

2.1 SCOPE.

These tests were designed to determine the flammability characteristics of primary lithium batteries and any associated hazard to transport aircraft when shipped in bulk pallets in cargo compartments. Primary lithium batteries are defined as nonrechargeable batteries. The flammability parameters investigated included ignition source intensity, effect of battery quantity, fire propagation between batteries, effect of packing materials, temperature rise in the test chamber, pressure rise in the test chamber, effect of Halon 1301 fire suppression systems, and effect on cargo liner integrity.

Two common types of primary lithium batteries were used in this investigation: CR2 and PL123A, as shown in figure 1. These are small batteries often used in cameras and other small electronic appliances.

FIGURE 1. CR2 AND PL123A PRIMARY LITHIUM BATTERIES

2.2 TEST FACILITY.

A test chamber was constructed to measure the flammability of the subject batteries. The chamber was constructed of 1/8″ uninsulated steel sheeting and measured 4′ by 4′ by 4′, producing a 64-cubic-foot test facility. The entire front side opens for access and is fitted with a Plexiglas windowpane to allow videotaping of the fire test. The chamber was equipped with variable 1″ vent holes located on the centerline of the sidewalls, 2″ from the floor. Aluminum foil blowout panels were installed in the sidewalls near the ceiling. The facility was fitted with a Halon 1301 fire-extinguishing system designed to provide a 5 percent concentration of Halon 1301. This concentration is equal to that provided in a standard aircraft cargo compartment for initial fire knockdown. A basket was constructed from a 0.5″ square wire mesh and an aluminum angle framework to suspend the test batteries over the fire pan. Figure 2 shows a diagram of the test chamber.

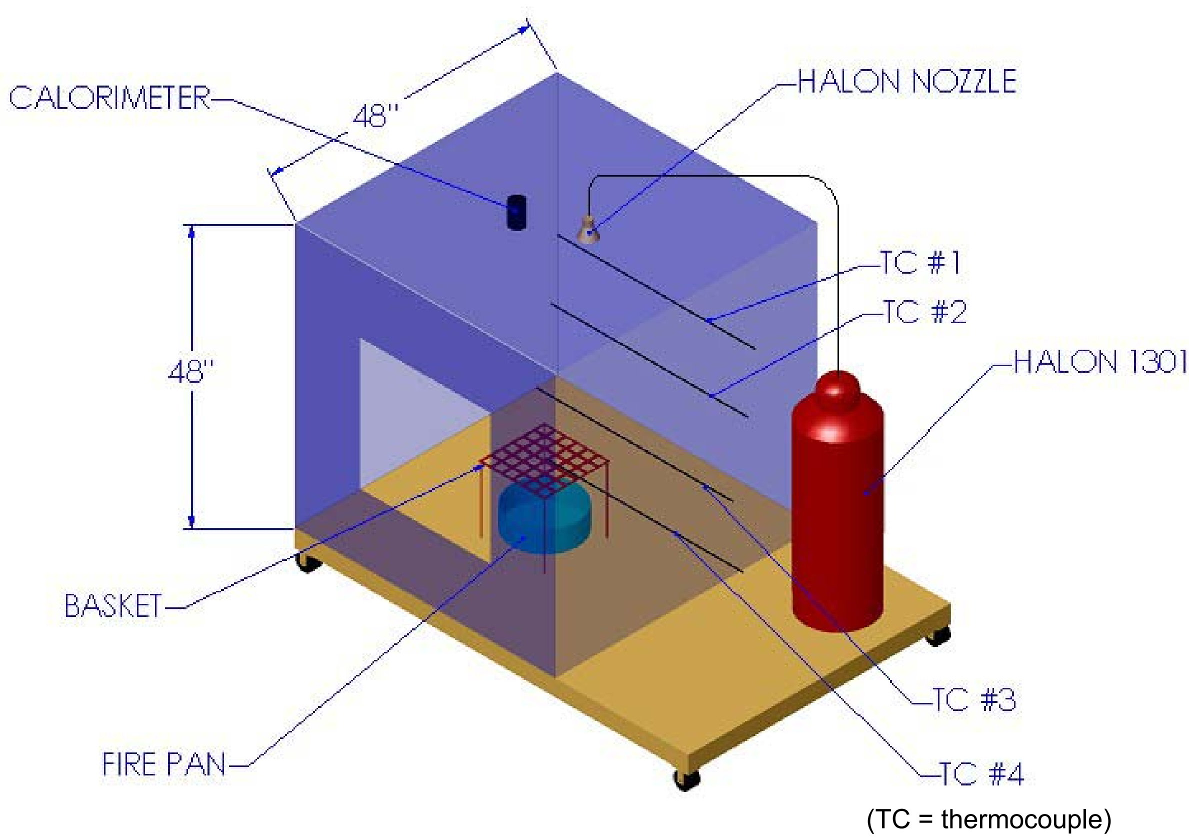

FIGURE 2. THE 64-CUBIC-FOOT TEST CHAMBER

2.2.1 Instrumentation.

The 64-cubic-foot test facility was fitted with four type C thermocouples located in the center of the chamber and spaced 12″, 24″, 36″, and 48″ from the floor. The thermocouples are numbered from the top, with the 48″ height assigned number 1 and the 12″ height assigned number 4.

These thermocouples measure the temperature rise in the chamber. In addition, two calorimeters were installed. One was centered in the ceiling of the chamber, assigned channel 5, and one in the right sidewall 12″ from the floor, assigned channel 6. The calorimeters were used to measure the heat flux produced by the ignition source fires and the battery fires.

A video camera was positioned outside the chamber and recorded the fire event through the Plexiglas door.

2.2.2 Ignition Fire Source.

The chamber was fitted with two different size fire pans to allow for different intensity ignition fires. The pans were circular with a 1″ depth. The low-intensity fire pan was 5.25″ in diameter with a surface area of 20.6 square inches, and the high-intensity fire pan was 10.75″ in diameter with a surface area of 90.7 square inches. The fire pans were centered on the chamber floor.

3. BASELINE TESTS.

The test facility was designed to simulate temperature conditions that are typical of a cargo compartment fire that has been suppressed with Halon 1301. Under these conditions, deep-seated fires can continue to smolder, producing isolated pockets of temperatures in the 1000° to 1200°F range. The air temperatures in a suppressed cargo compartment measured at the ceiling can range from 410° to 665°F [1]. The 10.75″ fire pan was designed to produce this temperature range, while the 5.25″ fire pan represents a less severe condition.

The facility was calibrated with a series of baseline tests. Fire intensity data were collected for the two fire pan sizes. 1-propanol (C3H7OH) was used as the fuel throughout these tests. The area of the fire pan determines the intensity; the volume of 1-propanol determines the duration of the fire. The amount of 1-propanol was adjusted to ensure a 3-minute ignition fire. The 5.25″ fire pan required 50 ml of 1-propanol, and the 10.75″ fire pan required 220 ml of 1-propanol.

3.1 THE 5.25″ FIRE PAN CALIBRATION.

The 5.25″ fire pan reached a peak temperature of approximately 725°F, measured 12″ above the fire pan. The temperature at the ceiling of the chamber only rose to 225°F. The heat flux measured at the top of the chamber peaked at 0.18 Btu/ft^2-sec. (figure 3). These numbers define a low-intensity fire.

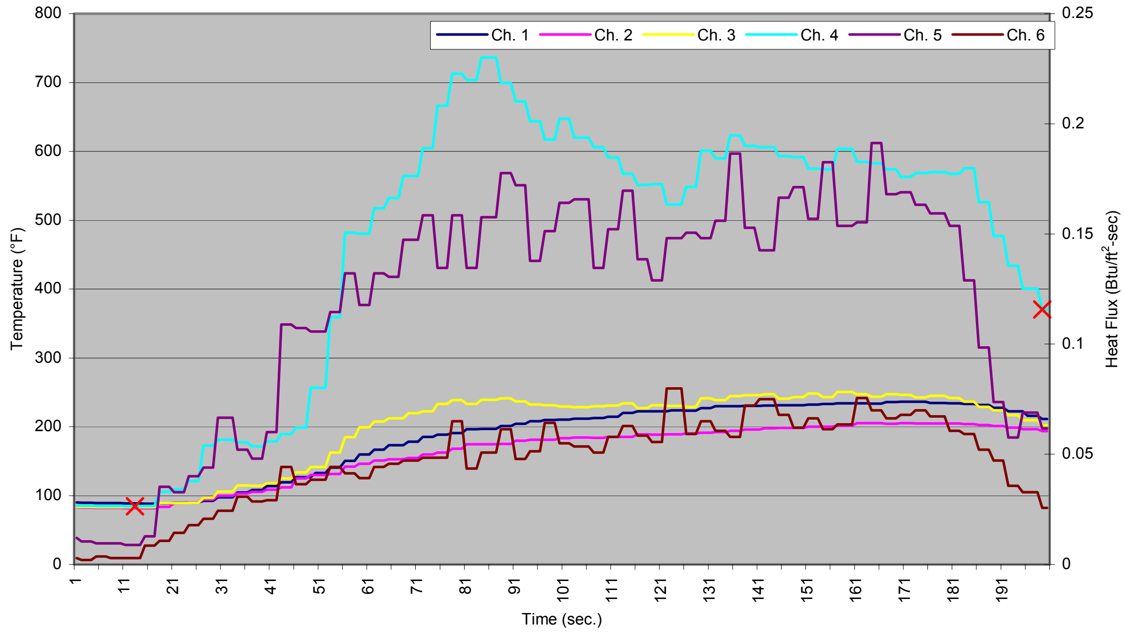

FIGURE 3. THE 5.25″ FIRE PAN CALIBRATION

3.2 THE 10.75″ FIRE PAN CALIBRATION.

The 10.75″ fire pan reached a peak temperature of 1150°F, measured 12″ above the floor of the chamber. The ceiling temperature peaked at 500°F. The peak heat flux measured at the ceiling was 0.8 Btu/ft^2-sec. This is a considerably more intense fire than the 5.25″ fire pan, more closely representing conditions found in a fully suppressed cargo fire (figure 4).

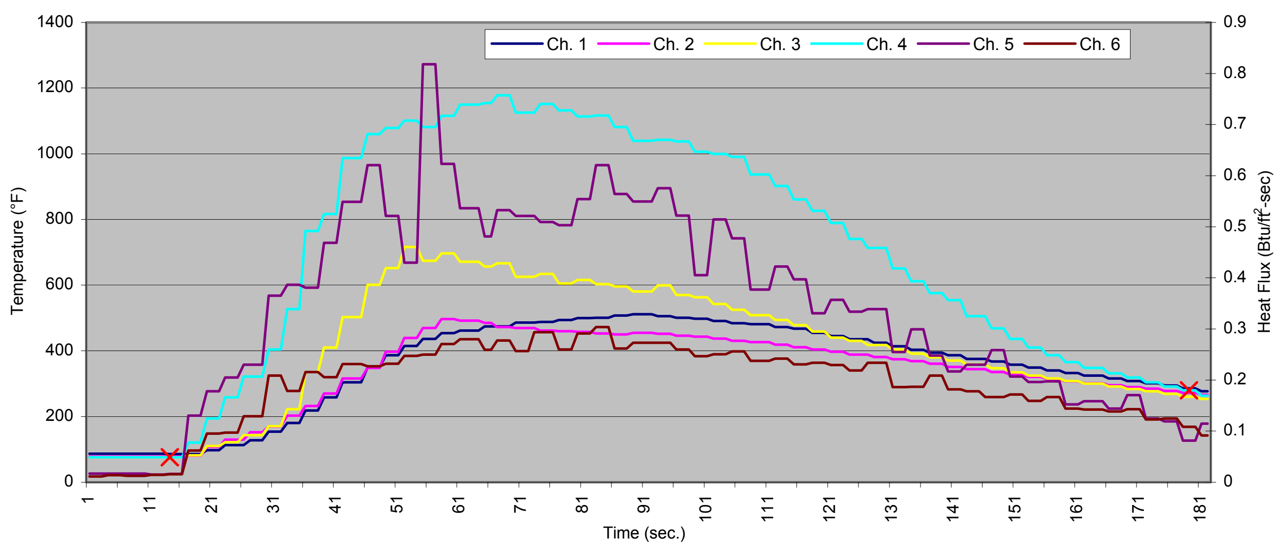

FIGURE 4. THE 10.75″ FIRE PAN CALIBRATION

4. SANYO CR2 BATTERY TESTS.

4.1 SANYO CR2 SINGLE-BATTERY FAILURE MODE.

A series of tests were conducted with the 5.25″ fire pan and a single Sanyo CR2 battery to determine the flammability behavior. The battery was suspended in a wire basket 4″ above the fire pan. The pan was filled with 50 ml of 1-propanol and ignited with a propane torch.

The battery initially vented electrolyte gas, usually at the positive electrode, when exposed to an 1-propanol fire. The electrolyte gas torched with a red flame and with some propulsive force accompanied by a small but noticeable pressure pulse, causing the Plexiglas viewing window to bulge. After the electrolyte burned off, the molten lithium burned explosively, spraying white-hot lithium through the vent holes. Unrestrained, the battery can bounce around in the test fixture.

Typically, battery failure followed the same pattern (all times are nominal), as shown below.

Time (min)	Event
0:00	1-propanol fire ignited
0:30	Plastic coating on exterior of battery bubbles and burns
1:00	Electrolyte vents and burns, producing a torch
1:30	Molten lithium fire
1:50	Battery expended

The batteries gave off a good deal of heat, raising the temperature 650°F above that produced by the low-intensity 1-propanol fire and, more significantly, sprayed white-hot molten lithium for a radius of several feet.

4.2 SANYO CR2 MULTIPLE-BATTERY FIRE TESTS.

A series of tests were conducted to determine the flammability characteristics of multiple Sanyo CR2 batteries. The tests were conducted using the 5.25″ fire pan with 50 ml of 1-propanol and a wire basket suspending the batteries 3″ above the fire pan. The number of batteries was varied from 1 to 16, doubling the number of batteries for each successive test. Each test resulted in a similar peak temperature, measured 12″ above the fire pan, of approximately 1375°F. The duration of the peak temperature increased with additional batteries, but the actual peak did not significantly vary. This is an increase of 650°F above the 1-propanol fire temperature of 725°F. The heat flux measured at the ceiling peaked at 0.55 Btu/ft^2-sec, which is about three times higher than the fire pan calibration. Figure 5 shows the temperature and heat flux profile generated by 16 CR2 batteries.

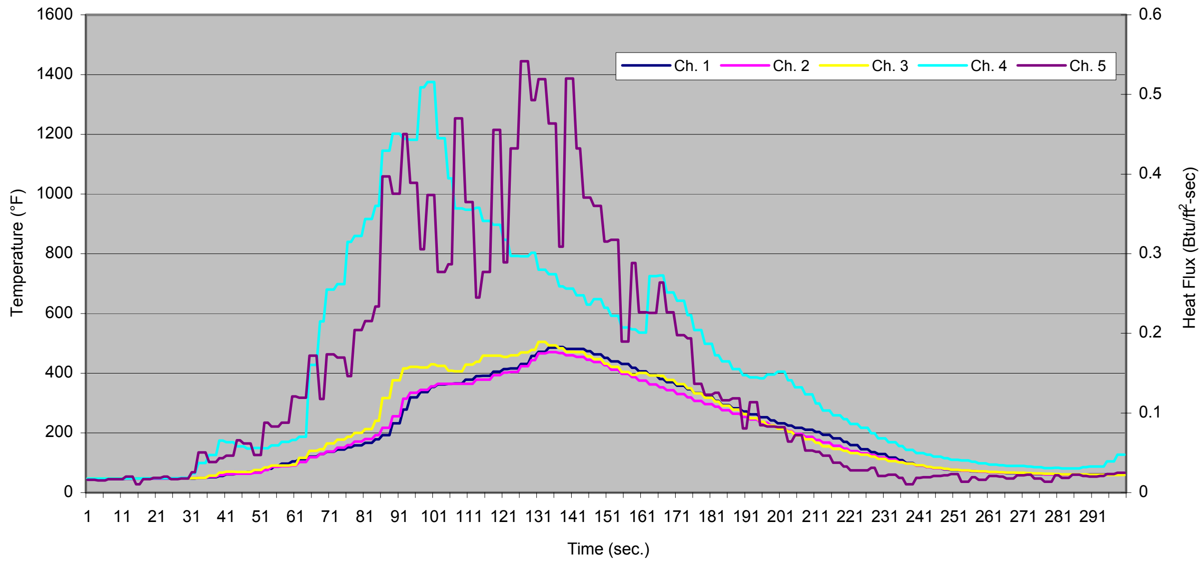

FIGURE 5. SANYO CR2 16-BATTERY TEST

It was noted during these tests that the ignition of a single CR2 battery generated sufficient heat to ignite adjacent batteries. The 1-propanol fire initially fused the batteries together by melting the plastic coating. This facilitated the chain reaction of adjacent battery ignition. Once a single battery was ignited, the heat generated would ignite an adjacent battery and the process continued until all the batteries were consumed. This process continued even after the 1-propanol fire went out.

4.3 SANYO CR2 PACKAGING MATERIAL TESTS.

A series of tests were conducted to determine the effect of the packaging materials on the ignition and propagation of CR2 batteries when exposed to a 1-propanol fire. The tests used corrugated cardboard cases, smooth cardboard separators, and polyurethane foam cushions from actual CR2 shipping boxes, as shown in figure 6. The batteries and shipping materials were suspended 3″ above the fire pan. Tests were conducted using 32, 64, and 128 CR2 batteries. The tests using 32 and 64 batteries used the 5.25″ fire pan and 50 ml of 1-propanol. The test using 128 batteries used the 10.75″ fire pan and 220 ml of 1-propanol. The 10.75″ fire pan allowed for better flame exposure to the test carton.

FIGURE 6. SANYO CR2 BATTERIES PACKED IN A STANDARD BULK SHIPPING CONTAINER

The packing material had several noticeable effects on the battery flammability compared to the multiple-battery tests conducted without packing material. The packing material is quite flammable, igniting easily when exposed to the 1-propanol fire. The packing material fire was sufficiently intense to ignite the CR2 batteries. It does, however, delay the ignition of the batteries by 30 to 60 seconds. In addition, the packing material kept the batteries in close proximity to one another, allowing the heat of the fire to fuse them together. This fusing facilitated the fire propagation between batteries once a single battery was ignited.

The peak temperatures generated by the 32-, 64-, and 128-battery tests were similar, but the duration of the peak temperature was greater with the higher number of batteries. The initial temperature peak is caused by the packing material burning and the second peak by the lithium batteries burning. Figure 7 shows the temperature profile generated by the 128-battery test.

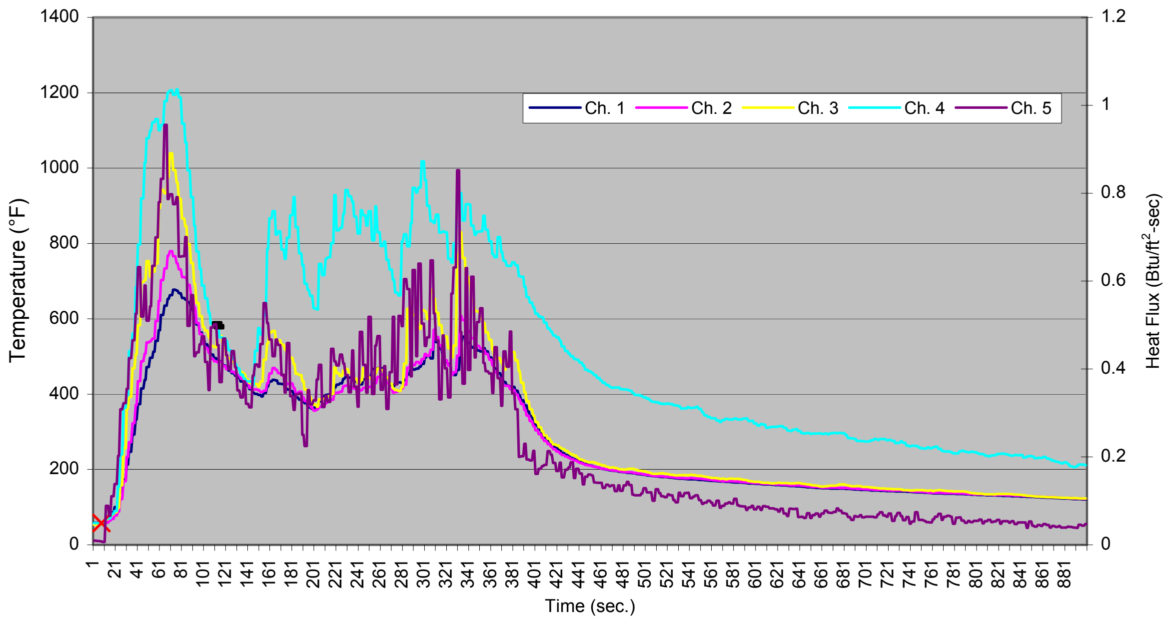

FIGURE 7. PACKING MATERIAL TEST, 128 SANYO CR2 BATTERIES

4.4 CARGO LINER INTEGRITY TESTS.

A series of tests were conducted to determine the effect of molten lithium on standard cargo liner material. The tests were conducted in the 64-cubic-foot chamber using the 5.25″ fire pan and 50 ml of 1-propanol. The tests were designed to maximize the exposure of the cargo liner to both the torching electrolyte and the spraying molten lithium.

The tests were configured by standing a 24″ high by 24″ wide piece of cargo liner vertically in a semicircle around the fire pan. Three groups of four batteries were wired to the support basket suspended over the fire pan. The batteries were arranged so that the positive ends were pointed at the cargo liner with about 3″ separating the batteries and the liner.

Tests were conducted using both a thin- and thick-wall fiberglass-based liner. The thick-wall liner consisted of two layers of fiberglass cloth, while the thin wall had only a single layer of fiberglass cloth.

In each test, the battery fire ignited the resin, causing a secondary fire fueled by the cargo liner. The molten lithium penetrated the thin-wall liner, burning small holes in the liner that ranged from pinpricks up to 0.5″ in diameter. The thick-wall liner was better able to contain the molten lithium, sustaining damage to the inner layer of fiberglass cloth but not penetrating the liner. Figure 8 shows the typical damage sustained by a thin-wall liner as a result of these tests.

FIGURE 8. THIN-WALL CARGO LINER PENETRATION

4.5 HALON SUPPRESSION TESTS.

A series of tests were conducted to evaluate the effectiveness of the standard cargo compartment fire suppression system in controlling a fire that is fueled by primary lithium CR2 batteries. The 64-cubic-foot test chamber was fitted with a Halon 1301 fire suppression system designed to flood the chamber and achieve a 5 percent concentration of Halon 1301. Cargo compartment fire suppression systems are designed to initially flood the compartment to a minimum of 5 percent Halon 1301 to knockdown the fire and then maintain 3 percent to keep the fire suppressed.

A charge of 1.3 pounds of Halon 1301 was required to achieve a nominal 5.5% concentration in the 64-cubic-foot test chamber. This was verified and monitored using an infrared gas analyzer.

Tests were conducted using 4, 8, 16, and 32 CR2 batteries, the 10.75″ fire pan, and 220 ml of 1-propanol. In each case, the results were identical. Discharging the halon prior to battery ignition resulted in the extinguishment of the 1-propanol fire and no battery involvement. However, discharging the halon after only one battery was ignited had no effect on stopping the propagation of the battery fire to adjacent batteries. The halon extinguished the 1-propanol fire immediately but had no effect on the lithium fire with the exception of turning the normally white sparks bright red.

The color change of the lithium sparks indicated that a reaction was occurring between the lithium and the Halon 1301. This reaction had no effect on the fire progression, neither hindering nor promoting the spread of the battery fire. The vented electrolyte fires, normally pale red in color, turned bright red when exposed to Halon 1301.

The battery fire continued to propagate until all batteries were consumed, continuing long after the 1-propanol fire was extinguished. The halon also had no effect on the peak temperatures in the test chamber, peaking at about 1400°F. This is similar to the peak temperatures exhibited in previous unsuppressed fires. However, the overall temperature profiles were lower, due to the extinguishment of the 1-propanol and battery plastic coating fires. Figure 9 shows the temperature profiles generated during the 32-battery test.

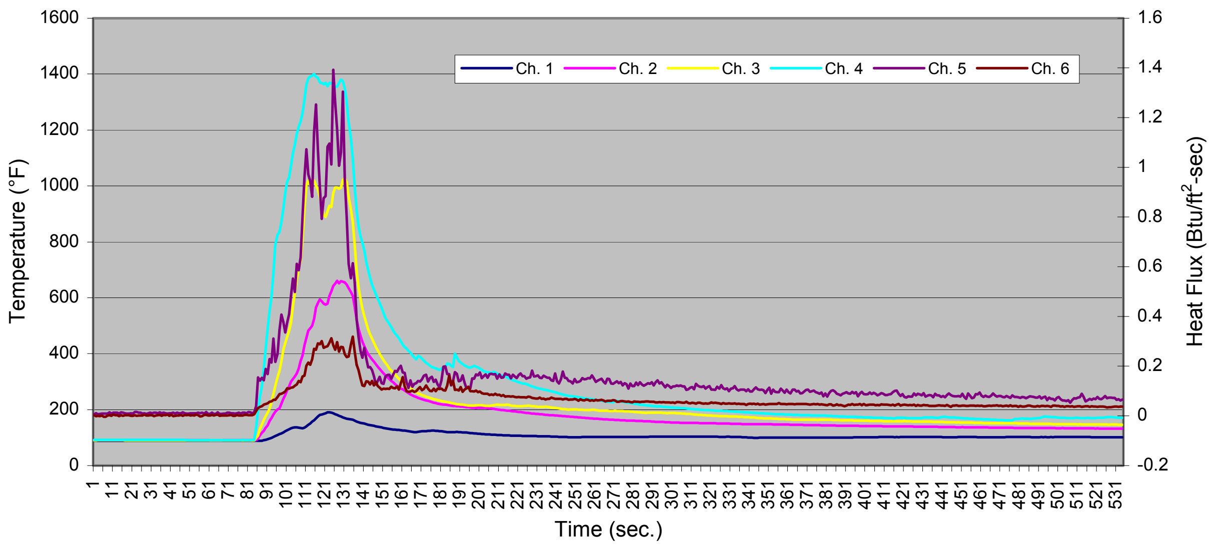

FIGURE 9. HALON 1301 SUPPRESSION TEST WITH 32 CR2 BATTERIES

5. DURACELL PL123A BATTERIES.

5.1 DURACELL PL123A SINGLE-BATTERY FAILURE MODE.

When exposed to a 1-propanol fire, the failure mode of the Duracell PL123A battery is very similar to the previously tested Sanyo CR2 battery. The battery initially vents electrolyte gas, usually at the positive electrode. The electrolyte gas torches with a red flame and generates some propulsive force along with a more pronounced pressure pulse. After the electrolyte burned off, the molten lithium burned explosively, spraying white-hot lithium through the vent holes.

5.2 DURACELL PL123A MULTIPLE-BATTERY TESTS.

A series of tests were conducted with 4, 8, and 16 Duracell PL123A batteries. The results were similar to the Sanyo CR2 tests. The ignition of a single battery provided sufficient energy to ignite adjacent batteries, propagating through the remaining batteries until all were consumed. A strong pressure pulse was noted at each electrolyte ignition, causing the Plexiglas viewing window to bulge. Peak temperatures were also similar to those noted in the Sanyo CR2 tests, approximately 1375°F, measured 12″ above the 1-propanol fire. Figure 10 shows the temperature profile generated by the 16-battery test.

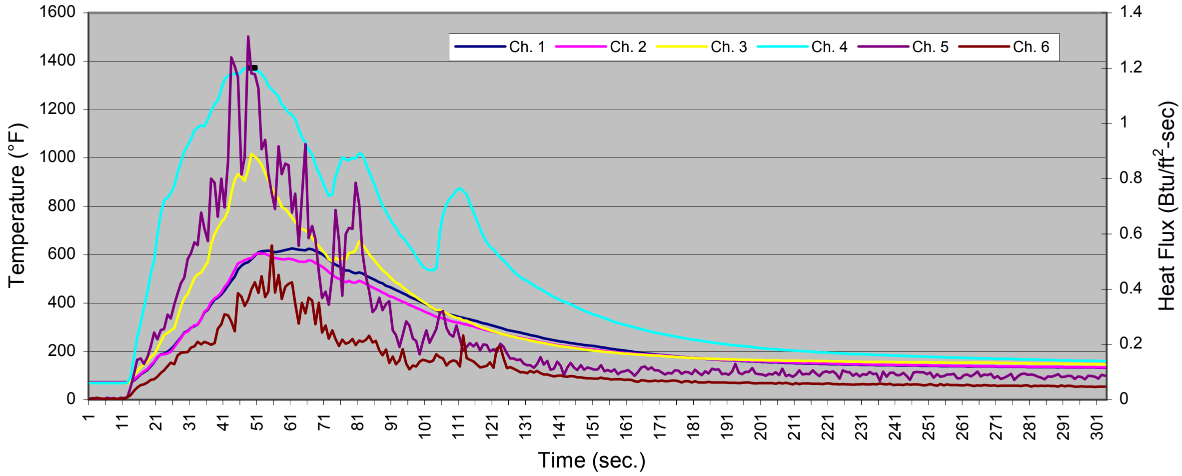

FIGURE 10. DURACELL PL123A 16-BATTERY TEST

5.3 DURACELL PL123A HALON SUPPRESSION TESTS.

Two tests were conducted in the 64-cubic-foot test chamber using the 10.75″ fire pan and 220 ml of 1-propanol. Each test was run using 16 Duracell PL123A batteries and 1.8 pounds of Halon 1301, which was discharged after the first battery was ignited. The results in each test were similar to those found in the halon suppression tests with Sanyo CR2 batteries. The halon immediately extinguished the 1-propanol fire and reduced the overall temperature profile in the chamber but did nothing to impede the progress of the battery fire once a single battery had ignited. The normally white molten lithium sparks turned bright red. The battery fire propagated until all batteries were consumed. Figure 11 shows the temperature profile generated by the 16-battery test suppressed with Halon 1301.

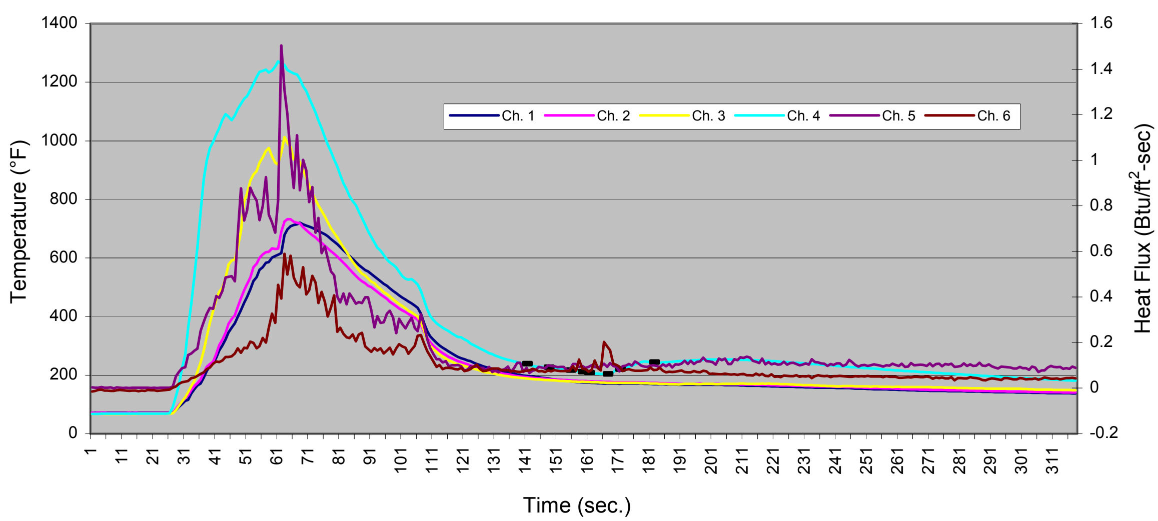

FIGURE 11. DURACELL PL123A 16-BATTERY HALON 1301
SUPPRESSION TEST

6. PANASONIC PL123A MULTIPLE-BATTERY TESTS.

A series of tests were conducted using 4, 8, 12, and 16 Panasonic PL123A batteries. The tests were conducted using the 10.75″ fire pan and 220 ml of 1-propanol in the 64-cubic-foot test chamber. These batteries proved much more explosive than the Duracell or Sanyo battery tests. The ignition mode and propagation were similar to the other batteries, but the pressure pulse exhibited appeared to be several times stronger. The tests were terminated at 16 batteries due to the explosive nature of these batteries; the pulse was strong enough to blow the clamps off the chamber door. Peak temperatures during these tests were somewhat lower than previous tests, possibly due to oxygen starvation. Peak temperatures were approximately 1175°F. No halon suppression tests were conducted with these batteries. Figure 12 shows the temperature profile generated by the 16-battery test.

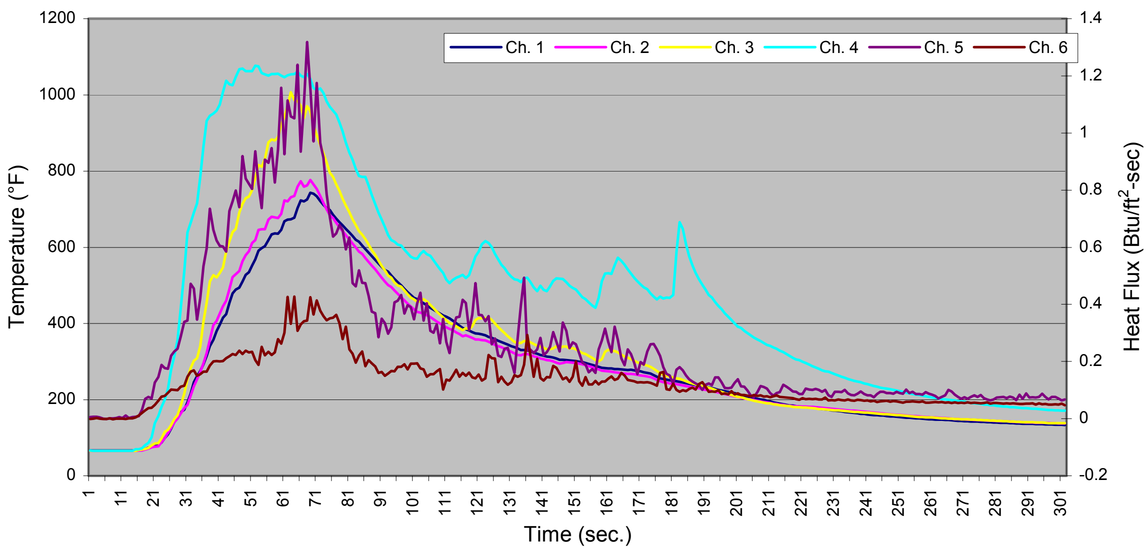

FIGURE 12. SIXTEEN PANASONIC PL123A BATTERIES, 10.75″ FIRE PAN, 220-ml 1-PROPANOL

7. EXPLOSION TESTS.

A series of tests were conducted to measure the explosive effects of three types of burning primary lithium batteries: Sanyo CR2, Duracell PL123A, and Panasonic PL123A. The tests were conducted in the Federal Aviation Administration Pressure Modeling Facility. This facility consists of a 10-cubic-meter airtight chamber that is fitted with pressure- and temperature-monitoring instrumentation. The pressure transducer sensor port and the thermocouples were located near the center of the chamber. The fire pan and the batteries were located near the end of the chamber.

7.1 SANYO CR2 BATTERIES.

Three tests were conducted with the Sanyo CR2 batteries, one test each of 4, 8, and 16 batteries. The ignition source for these tests was the 5.25″ fire pan and 50 ml of 1-propanol. Due to the airtight nature of the test chamber, each battery ignition raised the pressure in the vessel in an additive fashion: the pressure from each battery added to the total vessel pressure with no loss due to leakage. The four-battery test raised the pressure by approximately 1.1 psi (see figure 13). The eight-battery test raised the pressure in the vessel by 1.8 psi (see figure 14). The 16-battery test raised the pressure by 2.6 psi (see figure 15). In each test, the temperature in the vessel only increased a few degrees Fahrenheit, contributing little to the overall pressure rise.

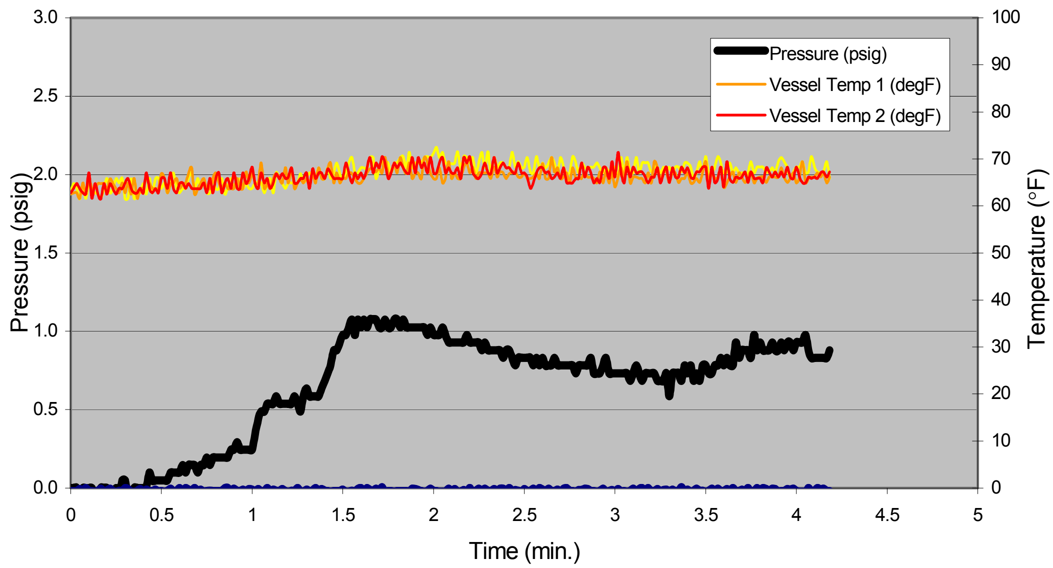

FIGURE 13. SANYO CR2 FOUR-BATTERY EXPLOSION TEST

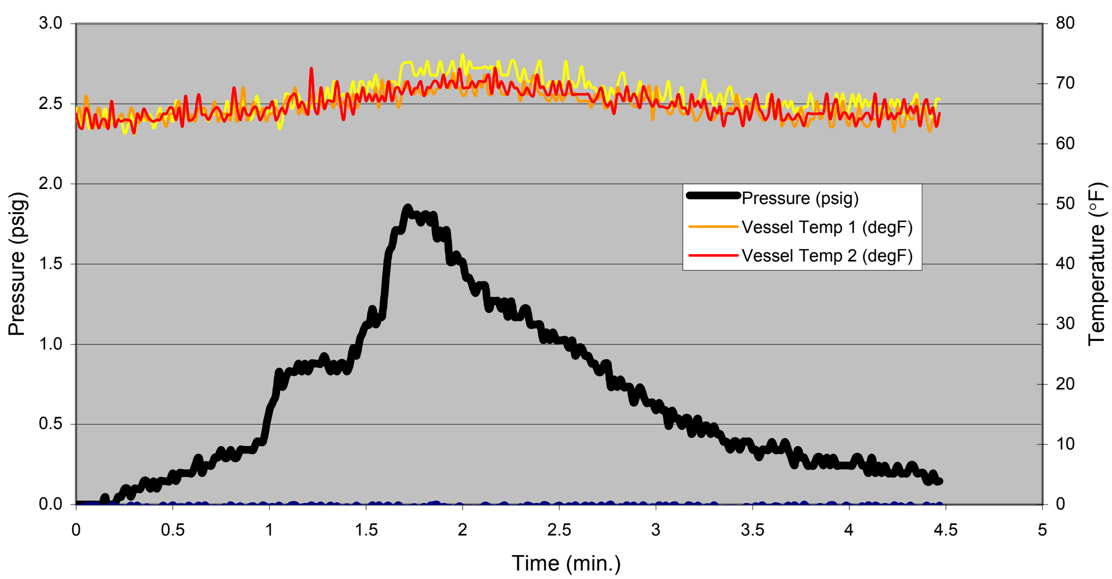

FIGURE 14. SANYO CR2 EIGHT-BATTERY EXPLOSION TEST

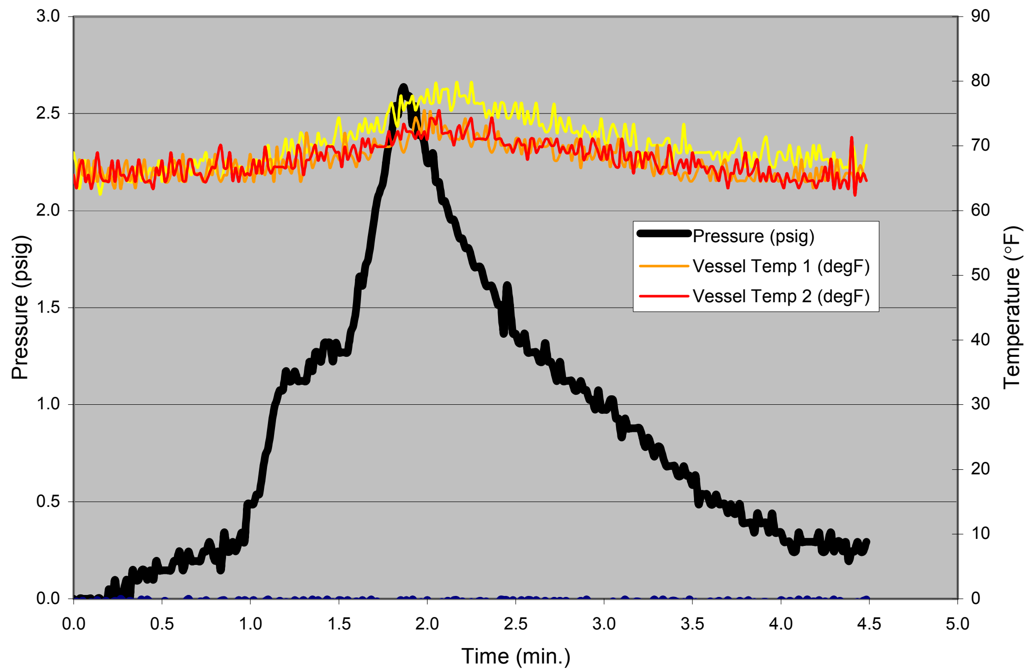

FIGURE 15. SANYO CR2 16-BATTERY EXPLOSION TEST

7.2 DURACELL PL123A BATTERIES.

One test was conducted with four Duracell PL123A batteries. The conditions were the same as the Sanyo CR2 battery test. The pressure rise in the chamber was approximately 1.2 psi (see figure 16).

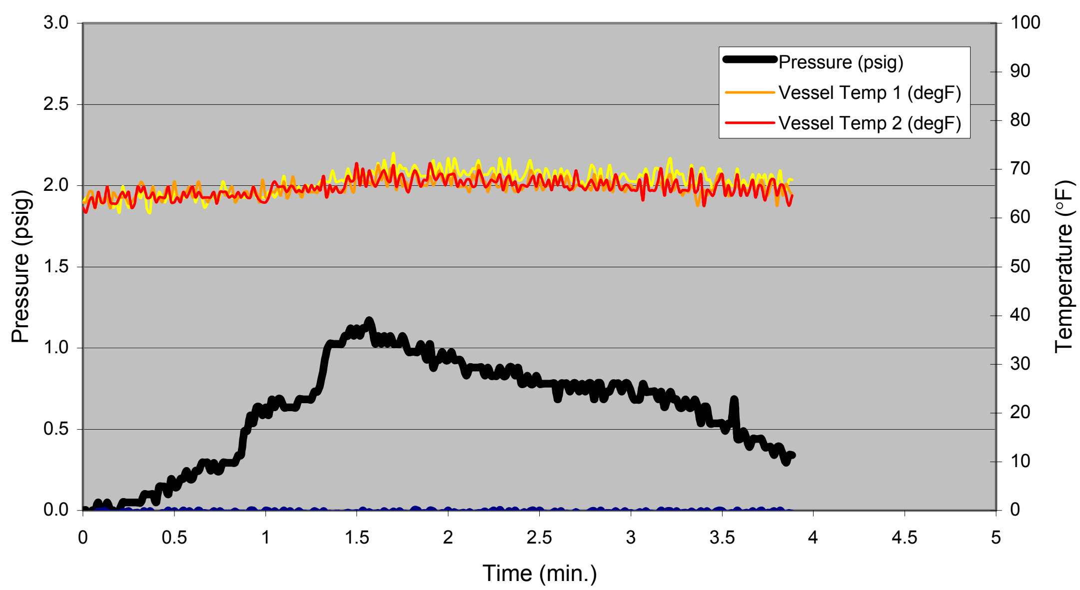

FIGURE 16. DURACELL PL123A FOUR-BATTERY EXPLOSION TEST

7.3 PANASONIC PL123A BATTERIES.

One test was conducted with three Panasonic PL123A batteries. The conditions were similar to the Sanyo CR2 and Duracell PL123A battery tests. The pressure rise in the vessel was 1.2 psi (see figure 17).

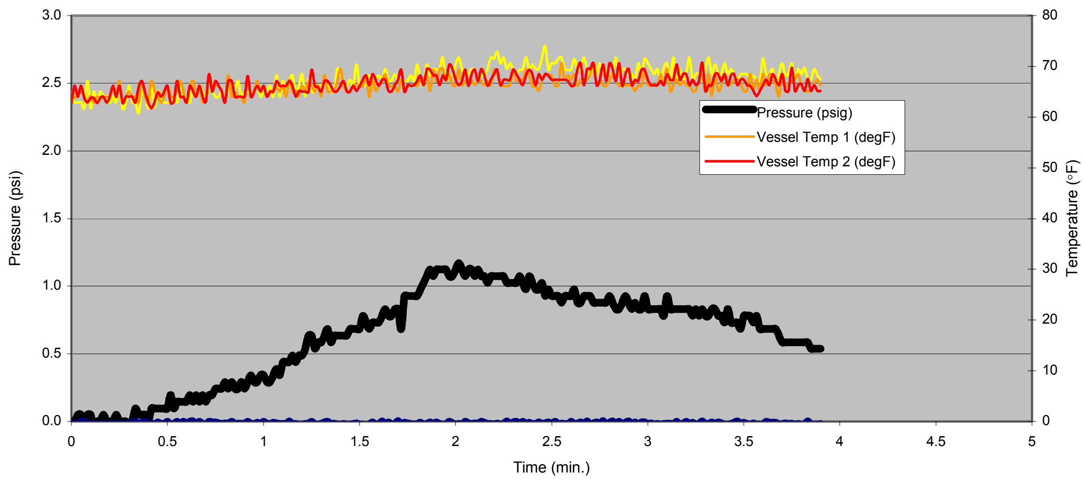

FIGURE 17. PANASONIC PL123A THREE-BATTERY EXPLOSION TEST

These results are significant. The cargo compartment is only constructed to withstand a 1-psi pressure differential in order to rapidly equalize pressure in the event of a depressurization. Anything over 1 psi would activate the blowout panels, compromising the cargo compartment's integrity. This would also allow the halon suppression gas to escape, reducing the suppression concentration and allowing the cargo fire to flare-up. Real cargo compartments differ from the test chamber in two significant ways—the volume is much larger and the compartments are not as airtight—which would tend to increase the number of batteries needed to raise the pressure above 1 psi in a cargo compartment fire. However, it appears that the cargo compartment could overpressurize due to a fire involving bulk-packed lithium batteries.

8. AUTOIGNITION TESTS.

The purpose of these tests was to determine the risk of battery ignition due to a smoldering suppressed fire in a cargo compartment. The temperature in a fully suppressed cargo compartment fire can locally exceed 1000°F in a smoldering fire, and the air temperature at the ceiling can range from 410° to 665°F [1]. The autoignition temperature of pure lithium is 355°F.

A 1-cubic-foot steel test chamber was constructed. The chamber was insulated and provided with an external propane heat source. The batteries were suspended in the center of the chamber. A thermocouple was installed near the battery to measure the chamber interior temperature.

Autoignition tests were conducted on two types of batteries, the Sanyo CR2 and the Panasonic PL123A. The battery was installed in the test chamber, and the propane burner was turned on. The temperature in the chamber was monitored, with the sudden rise in temperature signaling the ignition of the battery.

8.1 SANYO CR2.

Five tests were conducted with this battery. The average temperature when ignition occurred was 487°F. This resulted in an average temperature rise in the chamber of 524°F.

8.2 PANASONIC PL123A.

Five tests were conducted with this battery. The average temperature when ignition occurred was 524°F. This resulted in an average temperature rise in the chamber of 514°F.

These temperatures are within the range found in a suppressed cargo compartment.

9. RECHARGEABLE LAPTOP BATTERY TESTS.

Two fire pan tests were conducted with rechargeable laptop computer batteries in the 64-cubic-foot test chamber. Though outside the scope of this project, the limited results are interesting. The battery used for the test was a Compaq Presario Li-ion P/N 141161-B21, Hi Cap LiIon 14.4 V 3.2 Ahr, series CM2031. The state of charge was unknown at the time of the tests and, therefore, no conclusion can be drawn as to its importance.

The batteries were subjected to the 10.75″ fire pan with 220 and 300 ml of 1-propanol and tested in the 64-cubic-foot test chamber. The amount of 1-propanol was increased in the second test to provide an increased fire duration. In each case, the results were the same. The batteries did not burn with an open flame. The plastic case deformed and melted and eventually charred. There were some small amounts of venting and tiny sparks of lithium. The case did not self-sustain any fire once the 1-propanol was consumed. Peak temperatures, measured 12″ above the fire pan, were not significantly greater than those measured in a 1-propanol fire without batteries, peaking at about 1000°F. The shape of the temperature curve indicates that there was some heat release due to the charring of the battery case (see figure 18).

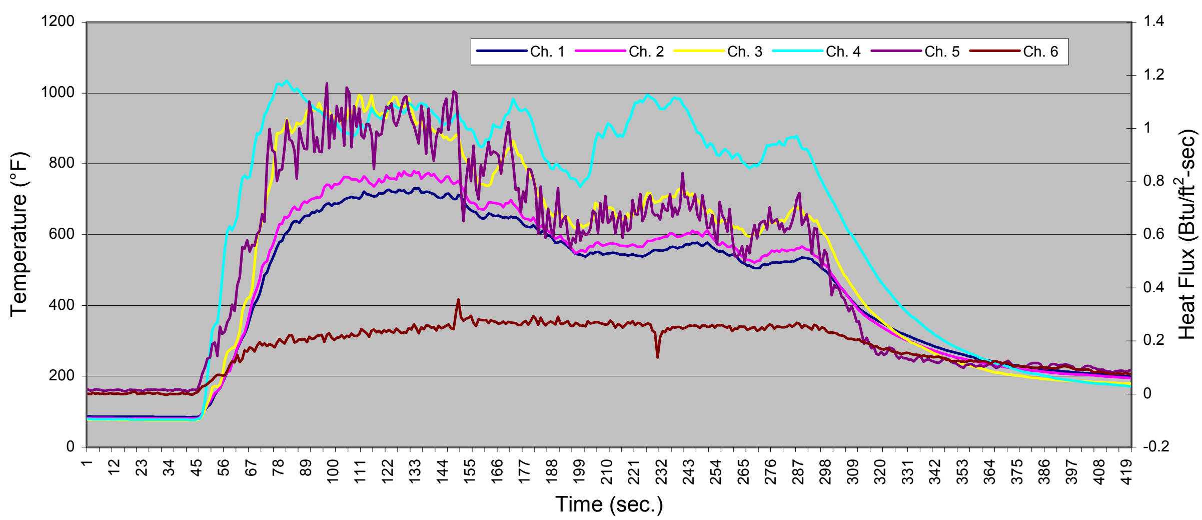

FIGURE 18. RECHARGEABLE COMPUTER LAPTOP BATTERY TEST

10. CONCLUSIONS.

A relatively small fire source was sufficient to start a primary lithium battery fire. The outer plastic coating easily melted and fused adjacent batteries together and then ignites, contributing to the fire intensity. This helped to raise the battery temperature to the self-ignition temperature of lithium. Once the lithium in a single battery began to burn, it released enough energy to ignite adjacent batteries. This propagation continued until all batteries were consumed.

Halon 1301, the fire suppression agent installed in transport category aircraft, was ineffective in suppressing or extinguishing a primary lithium battery fire. Halon 1301 appeared to chemically interact with the burning lithium and electrolyte, causing a color change in the molten lithium sparks, turning them a deep red instead of the normal white. This chemical interaction had no effect on battery fire duration or intensity.

The air temperature in a cargo compartment that had a fire suppressed by Halon 1301 can still be above the autoignition temperature of lithium. Because of this, batteries that were not involved in the initial fire can still ignite and propagate.

The ignition of a primary lithium battery released burning electrolyte and a molten lithium spray. The cargo liner material may be vulnerable to perforation by molten lithium, depending on its thickness. This can allow the Halon 1301 fire suppressant agent to leak out of the compartment, reducing the concentration within the cargo compartment and the effectiveness of the agent. Holes in the cargo liner may also allow flames to spread outside the compartment.

The ignition of primary lithium batteries released a pressure pulse that raised the air pressure within the cargo compartment. The ignition of only a few batteries was sufficient to increase the air pressure by more than 1 psi in an airtight 10-meter-cubed pressure vessel. Cargo compartments are only designed to withstand approximately a 1-psi pressure differential. The ignition of a bulk-packed lithium battery shipment may compromise the integrity of the compartment by activating the pressure relief panels. This has the same effect as perforations in the cargo liner, allowing the Halon 1301 fire suppressant to leak out, reducing its effectiveness.

11. REFERENCES.

1. Reinhardt, J. W., Blake D., and Marker, T., "Development of a Minimum Performance Standard for Aircraft Cargo Compartment Gaseous Fire Suppression Systems," FAA report DOT/FAA/AR-00/28, September 2000.