The Deputy Secretary of Transportation
WASHINGTON, D.C. 20590

October 16, 2009

The Honorable Deborah A.P. Hersman
Chairman
National Transportation Safety Board
490 L'Enfant Plaza, SW
Washington, DC 20594

Dear Madam Chairman:

Thank you for your letter summarizing the recommendations the National Transportation Safety Board has issued to the Pipeline and Hazardous Materials Safety Administration (PHMSA) and other modal administrations. Enclosed is a status report on actions we are taking to address the safety issues you have identified.

One item of particular note is the progress we have made on a rule for the loading and unloading of bulk hazardous materials. I have directed PHMSA immediately to begin drafting a notice of proposed rulemaking that addresses the Department's jurisdictional issues with respect to the loading and unloading of hazardous materials when transporting them by cargo tank and rail tank car.

Thank you for providing me with the opportunity to discuss these critical issues with you and your staff. The Secretary and I are committed to working with PHMSA and the modal administrations to address the safety of the transport of hazardous materials.

Sincerely yours,

John D. Porcari

Enclosure

Pipeline and Hazardous Materials Safety Administration Actions to Address Outstanding NTSB Recommendations

Safe Transportation of Lithium Batteries on Aircraft

NTSB Recommendations

A-07-104

Require aircraft operators to implement measures to reduce the risk of primary lithium batteries becoming involved in fires on cargo-only aircraft, such as transporting batteries in fire resistant containers and/or/ in restricted quantities in any single location on the aircraft.

A-07-105

Until fire suppression systems are required on cargo-only aircraft, as asked for in Safety Recommendation A-07-99, require that cargo shipments of secondary lithium batteries, including those contained in or packed with equipment, be transported in crew-accessible locations where portable fire suppression systems can be used.

A-07-107

Require commercial cargo and passenger operators to report all incidents involving primary and secondary lithium batteries, including those contained in or packed with equipment, that occur either on board or during loading or unloading operations and retain the failed items for evaluation purposes.

A-07-108

Analyze the causes of all thermal failures and fires involving secondary and primary lithium batteries and, based on this analysis, take appropriate action to mitigate any risks determined to be posed by secondary and primary lithium batteries, including those contained in or packed with equipment, on board cargo and passenger aircraft as cargo; checked baggage; or carry-on items.

A-08-001

In collaboration with air carriers, manufacturers of lithium batteries and electronic devices, air travel associations, and other appropriate government and private organizations, establish a process to ensure wider, highly visible, and continuous dissemination of guidance and information to the air-traveling public, including flight crews, about the safe carriage of secondary (rechargeable) lithium batteries or electronic devices containing these batteries on board passenger aircraft.

A-08-002

In collaboration with air carriers, manufacturers of lithium batteries and electronic devices, air travel associations, and other appropriate government and private organizations, establish a process to periodically measure the effectiveness of your efforts to educate the air-traveling public, including flight crews, about the safe carriage of secondary (rechargeable) lithium batteries or electronic devices containing these batteries on board passenger aircraft.

We agree with NTSB that air carriers should be required to report all incidents involving lithium batteries, consistent with Safety Recommendation A-07-107. To this end, on January 14, PHMSA published a final rule under Docket No. HM-215J/HM-224D entitled "Hazardous Materials: Revision to Requirements for the Transportation of Batteries and Battery-Powered Devices; and Harmonization With the United Nations Recommendations, International Maritime Dangerous Goods Code, and International Civil Aviation Organization's Technical Instructions" (74 FR 2200; copy enclosed). In this final rule, we amended the Hazardous Materials Regulations (HMR) to include a comprehensive incident reporting requirement for batteries and battery-powered devices. As specified in the final rule, incidents involving batteries and battery powered devices that result in a fire, violent rupture, explosion, or dangerous evolution of heat must be reported. In addition to the written incident report, the final rule requires immediate telephonic reporting of incidents involving batteries and battery-powered devices in air transportation.

We agree that an examination of failed batteries and associated electronic devices and equipment will provide valuable data and information as we continue to assess the transportation risks associated with these items. To that end, we are working with FAA and airlines to establish a cooperative program for effectively securing and preserving evidence and passenger information when incidents occur. We developed a standard protocol to be used by aircraft operators in the event of an incident. This protocol includes procedures for: (1) immediate reporting of the incident to DOT; (2) preservation of the batteries and/or electronic equipment that failed and transfer to appropriate authorities for analysis and evaluation; and (3) obtaining relevant information from passengers and crewmembers, including contact information for follow-up interviews as necessary. In addition, we are proposing a regulatory change to require a shipper, carrier, package owner or person reporting an incident to provide upon request by an authorized government representative reasonable assistance in investigating the damaged package or article.

Consistent with Safety Recommendation A-07-108, PHMSA has completed an analysis of the causes of lithium battery incidents (copy enclosed). The data suggest that the most likely causes of lithium battery incidents are:

1. External short circuiting — occurs when an exposed battery terminal contacts a metal object. When this happens, the battery can heat up and may cause ignition of the battery and/or the surrounding combustible materials.

2. In-use situation — generally relating to improper "charging" and/or "discharging" conditions associated with the use of equipment (e.g., computer or cell phone). This also includes inadvertent activation and subsequent overheating (such was the case when a power drill activated and burned in a passenger's checked baggage).

3. Non-compliance — includes faulty design of the battery (cells or battery packs), false certification of compliance with regulatory testing/classification requirements, and improper packing and handling including some counterfeit batteries.

4. Internal short circuit — can be caused by foreign matter introduced into a cell or battery during the manufacturing process. An internal short circuit can also occur when a battery is physically damaged (e.g. dropped or punctured).

PHMSA has initiated a rulemaking project to propose enhanced regulatory requirements to mitigate the risks identified in the incident analysis. The rulemaking is intended to strengthen the current regulatory framework by imposing more effective safeguards, including design testing, packaging, and hazard communication measures for various types and sizes of lithium batteries in specific transportation contexts. PHMSA plans to publish an NPRM this fall. The rulemaking will address the following issues:

- <u>Elimination of current exceptions for small lithium batteries.</u> Currently, shipments of small lithium batteries are excepted from certain packaging and hazard communication requirements. Instead, packages must conform to minimum packaging requirements and must be identified as containing lithium batteries for which special procedures should be followed in the event the package is damaged. We are considering eliminating the exceptions for small lithium batteries and imposing more stringent packaging and hazard communication requirements, including shipping papers, package marks and labels, and emergency response information. Elimination of the current exceptions would enhance safety by ensuring that all lithium batteries would be packaged to reduce the possibility of damage to the batteries that could lead to an incident and accompanied by hazard information that would ensure appropriate and careful handling by air carrier personnel and inform transport workers and emergency response personnel of actions to be taken in the event of an emergency.

- <u>UN design type test results.</u> Currently, all lithium battery and cell types must be subjected to a series of tests as specified in the UN Manual of Tests and Criteria. The tests are intended to ensure that lithium batteries and cells will withstand conditions encountered during transportation. We are considering adopting a requirement for manufacturers to provide evidence of satisfactory completion of the UN design type tests for each lithium battery and cell that is offered for transportation in commerce. The intended effect would be to enhance compliance with the test requirements.

- <u>Lithium battery shipping descriptions.</u> Currently, all types of lithium batteries are transported using the same UN identification number. However, differences in chemistry, functionality and behavior when exposed to a fire are well documented for different types of batteries. The fact that all types of lithium batteries share the same UN number has the potential to cause significant problems in acceptance procedures for carriers and may unnecessarily hinder or delay the transportation of these products. Thus, we are considering revising the current shipping descriptions to account for different battery types and chemistries and for consistency with shipping descriptions in international transport standards and regulations.

- Stowage in crew accessible locations. We are proposing restricting stowage of lithium batteries on an aircraft to crew accessible locations to permit immediate investigation and response to smoke or fire.

- Recalled batteries. We are considering the development of appropriate safety measures for the air transport of lithium cells or batteries identified by the manufacturer, the Consumer Product Safety Commission, or the Department of Transportation as being defective for safety reasons, or those that have been damaged or are otherwise being returned to the manufacturer.

PHMSA and FAA also plan to continue to evaluate the risks posed by all types and sizes of lithium batteries with a view towards further risk reduction. Depending on the availability of resources, we plan to address the following areas:

- Fire behavior. Test fire behavior of lithium batteries of various sizes and packaging configurations to better understand the transportation risks posed by these batteries and to develop more effective requirements to prevent fires and overheating.

- Fire resistant containers. Develop performance standards for fire resistant containers, including fireproof overpacks and ULDs, which can be used for the transportation of lithium cells and batteries of all types on board aircraft.

- Cargo compartments. Analyze aircraft cargo compartment configurations and how both current and performance based container designs and their locations may decrease potential risks of fire.

- Fire detection and suppression. Analyze possible container internal detection and suppression methods and their effectiveness on the control or containment of lithium battery fires.

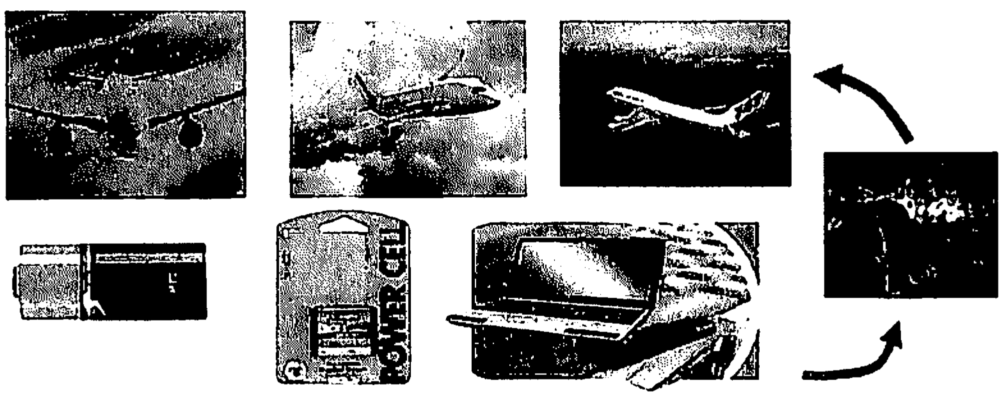
We are continuing our efforts to heighten public awareness related to the hazards associated with the air transportation of lithium batteries, including batteries contained in electronic devices. This is a key component of our comprehensive strategy to enhance safety and reduce incidents. Since 2007, PHMSA has been working with air carriers, battery manufacturers, air travel associations, airline pilot and flight crew associations and other government agencies, including the Transportation Security Administration, to educate the public about potential safety problems and measures that will reduce or eliminate those problems. PHMSA agrees that these efforts must be highly visible and continuous to be effective.

One of our most visible programs to promote battery safety is the SafeTravel Web site, which includes guidance and information on how to travel safely with batteries and battery-powered devices. We have also been working with the major airlines, travel and battery industries to provide SafeTravel information for ticketed passengers and frequent flyers, and place printed battery safety materials in seat pockets on passenger planes. We have recorded several million hits on our SafeTravel Web site. PHMSA continues to maintain and update the SafeTravel website as new information becomes available and is currently in the process of a major revision to the site. TSA includes SafeTravel information and links on its popular public website and FAA has issued Travel Tips and FAQs on Batteries Carried by Airline Passengers with a link to the SafeTravel website.

We are mindful that NTSB stressed actions to promote lithium battery safety awareness among flight crew specifically, and that Recommendation A-08-002 focuses on more robust assessment of passenger and flight crew awareness and behavior. We are working with FAA, ATA, its member airlines, the Airline Pilots Association, and the Association of Flight Attendants (AFA) to raise flight crew awareness of measures they can take to avoid incidents as well as how to respond effectively should an incident occur in the cabin. Thousands of pilots and flight attendant personnel have been trained in how to appropriately respond to and mitigate a fire involving lithium batteries in a passenger aircraft cabin. Additionally, the ICAO Dangerous Goods Panel added the appropriate procedures to the ICAO Emergency Response Guidance for Aircraft Incidents Involving Dangerous Goods (Red Book).

We have requested available metrics for partner actions, and are coordinating with FAA to continually assess incident data focusing on root causes, in order to gauge any changes in passenger behavior. In the coming year, we will work to capture information about passenger behaviors independent of incidents, and work with FAA and with partners representing airline flight crews to ensure that battery safety and response information is made available. We also will develop a method for evaluating the effectiveness of our efforts to educate the public and flight crews.

Risk Assessment for Aircraft Transportation of Lithium Batteries



September 15, 2009

Abstract

The Pipeline and Hazardous Materials Safety Administration (PHMSA) completed this analysis in response to recommendations from the National Transportation Safety Board (NTSB) to analyze the causes of thermal failures and fires involving secondary and primary lithium batteries. Data used in this analysis was collected from the Hazardous Materials Information System and the Federal Aviation Administration. The incident data suggests four likely causes of incidents: (1) External short circuiting; (2) Charging/discharging during use; (3) Non-compliance; and (4) Internal short circuiting.

Executive Summary

Lithium batteries fall into one of two basic categories, lithium metal including lithium alloy (aka primary lithium batteries), and lithium ion, including lithium ion polymer (aka secondary lithium batteries). In general, the risks posed by lithium batteries depend on battery size (the amount of lithium content and corresponding energy density) and the likelihood of short circuiting or rupture. The major hazards posed by lithium batteries are (1) electrical, caused by short circuits (both external and internal), and (2) thermal, attributed to the relative instability of the material contained in lithium batteries leading to overheating or fire. Based on an analysis of known incidents and other information we concluded that lithium battery incidents in transportation are likely caused by: (1) External short circuiting, (2) Internal short circuiting (3) Charging/discharging during use, and (4) Non-compliance with applicable regulations. This same incident analysis and other supporting data suggest that lithium battery incidents in normal transportation are a low probability occurrence, but the results of an incident could have significant consequences, particularly in air mode.

The goal of this analysis was to analyze publicly available data to determine the main drivers of transportation risks and provide a practical approach to managing this risk. The analysis also uses non-lithium battery incident information to draw comparisons and show incident trends. We developed several recommendations for managing risk arising from the different categories of incidents. The recommendations focus on:

- Continuing outreach efforts to educate and provide guidance to the air traveling public, including flight crews, about how to safely carry authorized lithium cells or batteries or electronic devices containing such cells or batteries on board aircraft;

- Revising the Hazardous Materials Regulations to require enhanced packaging and hazard communication for the transport of lithium cells, batteries and electronic devices containing lithium cells and batteries;

- Developing improved smoke/fire detection and suppression methods for lithium cells, batteries and electronic devices containing lithium cells and batteries;

- Working with cell, battery and device manufacturers to incorporate robust safety systems that account for consumer use and abuse.

TABLE OF CONTENTS

Introduction

Batteries are woven into the fabric of modern American life. They power portable computers, phones, and audio devices. They make possible motorized wheelchairs and cordless power tools. We as a population have come to depend on batteries to support an increasingly mobile lifestyle. Today's batteries contain more power than ever, making possible a steadily growing number of higher-powered devices on the market. But with that increased power there is greater risk and the need to manage the risk. The Pipeline and Hazardous Materials Safety Administration (PHMSA) working closely with the Federal Aviation Administration (FAA) is addressing the risks posed by lithium batteries in transportation including the incidents that have occurred and the consequences of those incidents. This study focuses on the risk posed by lithium batteries and battery powered devices when transported aboard aircraft as cargo and by passengers and crew members.

In general, the risks posed by lithium batteries are a function of battery size, chemistry and how they are prepared for transport (e.g. properly packaged and protected from short circuit, shock and vibration that may lead to damage that can result in overheating and fire). Lithium batteries present a risk compared to other types of batteries because unlike standard alkaline batteries, most lithium batteries manufactured today contain a flammable electrolyte and have a higher energy density. Lithium batteries can overheat and ignite under certain conditions and, once ignited, can be difficult to extinguish. We have seen lithium battery incidents begin as smoldering fires and propagate unnoticed. This fire behavior and the various packaging and shipping configurations pose significant challenges to managing transportation risks. In addition, although an infrequent event, a lithium battery is susceptible to thermal runaway, a chain reaction leading to a violent release of its stored energy.

An estimated 3.3 billion lithium cells and batteries were transported worldwide in 2008 by all modes of transportation, including passenger and cargo aircraft. This represents an increase of 18 % in volume over 2007. Rechargeable lithium ion batteries comprised nearly 80% of the total lithium battery market. The majority of the lithium ion batteries found their application in cellular phones followed by notebook personal computers (about 75 % of total market for portable lithium ion batteries). As the consumer demand for lithium batteries increases, so does the risk that batteries pose in transportation.

Despite current restrictions and testing requirements applicable to the transport of lithium batteries, and the heightened attention and resources focused on improving safety by regulators and the industry battery incidents continue to occur. Particularly troubling is the fact that these incidents have occurred aboard passenger and cargo aircraft and have involved fire and overheating. Safety advocates including the National Transportation Safety Board (NTSB) and the public are demanding that government agencies more effectively address the risks and reexamine their efforts at risk reduction including evaluation of the current rules concerning lithium batteries. The assessment of the incidents involving the transportation of lithium batteries addressed in this report was based on an analysis of historical air incident data on lithium batteries compiled by the Department of Transportation (DOT).

1.1 Incidents involving lithium batteries

Incidents involving overheating and fires aboard aircraft are a serious concern that must be addressed through effective preventative measures. However, before effective preventative measures can be implemented, it is necessary to understand the root causes of the incidents that have occurred, the potential for incidents in the future and the consequences of such incidents. Sections 1.2 and 1.3 briefly describe the two main sources of incident data available to PHMSA, the HMIS and the FAA data. Incidents meeting the criteria of §§ 171.15 and 171.16 must be reported to PHMSA. PHMSA compiles and stores this incident report information in the Hazardous Materials Information System (HMIS). Information stored in the HMIS includes all modes of transport including air. The FAA compiles incident report data from media sources, reports provided by individual airlines and other sources.

This study examined incident data from 1991 to the present. During that time period we documented 40 lithium battery incidents in the aviation mode worldwide. This amounted to about 2 incidents per year. However, during the period from 1999 to the present we documented approximately 38 incidents resulting in an average of nearly 4 incidents per year. Many factors can explain this increase in incident reports including an increase in the overall volume of shipments, exponential growth of the consumer lithium battery market and the heightened awareness of concerns related to lithium battery incidents. PHMSA actions including public meetings, safety advisories and extensive outreach may have positively impacted the voluntary reporting of incidents particularly in air transport. Recently PHMSA amended the incident reporting requirements to specifically require the reporting of incidents that result in a fire, violent rupture, explosion or dangerous evolution of heat as a direct result of a battery or battery-powered device. Prior to this revision, most incidents involving lithium batteries were excepted from reporting requirements. Since compliance with this revision is not required until January 1, 2010 the full effects of the enhanced reporting requirements may not be fully realized until that date and those required to report have been appropriately educated. These factors suggest that the current trend of increased reporting of lithium battery incidents will continue into the foreseeable future.

1.2 FAA Data

The Federal Aviation Administration (FAA) maintains incident data related to the transportation of batteries by aircraft and published the findings on a publically accessible web page. The FAA data include a date and source of information, the type of battery involved, the device involved if applicable, whether the incident involved a passenger or a cargo aircraft and a brief narrative summary of the incident. Information contained in the narrative reports typically included the type of battery and devices involved, how the incident was discovered, response actions and the apparent cause of the incident.

As of September 10, 2009 107 air incidents involving batteries had been recorded since March 20, 1991. The incidents included those associated with batteries of all types and batteries contained in or packed with devices. Incidents occurred during different transportation phases - while the aircraft was in flight or on the ground, and while a truck was en route from and to an aircraft. The 107 incidents consisted of 40 incidents involving lithium batteries, 59 incidents involving non-lithium batteries and 8 incidents involving batteries of unknown types. The chart below shows a break down of incidents by battery and aircraft type.

	Passenger Aircraft		Cargo on Passenger Aircraft	Cargo Aircraft	Unknown Aircraft	Grand Total
	Carry-on	Checked Baggage				
Lithium Batteries	14	3	2	21	0	40
Non-Lithium Batteries	1	15	4	37	2	59
Unknown Battery Type	4	1	0	3	0	8
Total	19	19	6	61	2	107

1.3 HMIS data

In accordance with 49 CFR §§ 171.15 and 171.16, incidents involving unintentional releases of hazardous materials during transportation are required to be reported to the DOT. The HMIS maintains this data for lithium batteries under the UN identification numbers UN3090 and UN3091.

Prior to the year 2004, incidents involving "Battery" and "Consumer commodity" were excepted from this reporting requirement. As indicated previously, lithium-ion batteries where not commonly transported prior to 1991. During the period of years 1995 through 2007, the HMIS data recorded 14 incidents involving lithium batteries and 211 incidents involving non-lithium batteries in the air mode as it related to the transportation phases of in-transit, loading, unloading, and in-transit storage. It is not clear why the HMIS had more incidents of non-lithium batteries than the FAA data despite the exceptions provided in the DOT regulation. Nevertheless, it is not appropriate to compare the number of lithium battery incidents between the FAA data and the HMIS because of the different reporting systems.

1.4 Purpose of this analysis

This report, prepared in partnership with relevant program offices in PHMSA and FAA is intended to better understand the nature of the incidents that have occurred with the ultimate objective of gaining a better understanding of the risks factors and measures that can be taken to reduce risk. This report is intended to:

- Analyze publically available data of incidents that occurred during transportation of batteries by air;

- Create a path forward for developing informed courses of action for reducing risk and validating the best allocation of resources to achieve these objectives; and

- Identify means of reducing risks posed by the air transportation of batteries.

The HMIS data was not used in the detailed analyses because of the exceptions provided for incidents involving batteries. The FAA incident data was used to assess, to the extent possible, the degree of hazards and consequences as well as some risk measures relevant to air transport of lithium batteries and devices containing lithium batteries. Although the data involving lithium batteries was the primary focus of the analysis, the analysis of the data for non-lithium batteries was also considered primarily because lithium and non-lithium batteries were included in the same dataset and because a substantial portion of the battery incidents occurred during the air transportation of non-lithium batteries.

1.5 Limitation of FAA/HMIS Data

The FAA data was based on information collected from FAA staff reports that in many instances did not involve a formal root cause investigation or was limited due to the absence of evidence, while the HMIS data was based on DOT form F 5800.1 submitted by the carrier who transported the batteries. This data set is limited in its use for the purposes of risk analysis since the data was not originally collected for risk assessment purposes. We acknowledge the difficulties in analyzing empirical incident data due to incomplete and differing reporting requirements and an evolving recognition of the importance of a complete narrative of events. Despite these limitations, various broad conclusions may be drawn from the limited data available. A brief synopsis of the incident data and how the information was used are presented below.

The FAA data provided specific information on the type of battery, devices containing batteries, and aircraft type involved (i.e. cargo or passenger aircraft). However, the narrative portions were not consistent in terminology or of the types of information provided so we were limited in our ability to conduct a thorough analysis aimed at identifying the root causes. For example, a probable cause of the incident was provided in some instances while no causes were indicated in others. Also in a number of reports, the information provided was insufficient to draw specific conclusions. For example, in a number of instances it was not apparent whether the lithium battery(ies) were a non-rechargeable (metal or primary type) or a rechargeable (lithium-ion or secondary type). In other cases, the data provided no clear distinction between lithium and non-lithium batteries. For these reasons, some of the information was deduced from information provided in the narrative portions of the reports. Assumptions were made relative to the probable causes, potential consequences, mitigation actions, condition of the batteries, sizes of the batteries, compliance levels, phases of transportation, exposure and abuse conditions and failure modes.

Nevertheless, the FAA data contained the most inclusive data covering the years 1991 though 2008 for lithium battery incidents that occurred in air transportation relative to other publically available data. Even though incidents in air transportation are more likely to be reported, it is not clear whether the reports are inclusive of all the battery incidents that occurred in air transportation or in related phases during these time periods. Many of the incident reports were derived from information voluntarily provided by airline operators or industry representatives, media reports and information provided by other government agencies. Information was not as readily available relative to incidents that occurred on non-US carriers or in countries operating outside of the United States. PHMSA and FAA are working through the International Civil Aviation Organization to raise the awareness of the importance or reporting incidents, collecting evidence and conducting follow up investigations and root cause analyses. Incidents occurring outside the U.S. are not usually reported but we remain hopeful that recent changes to the International Civil Aviation Organization Technical Instructions on the Safe Transport of Dangerous Goods by Air requiring battery incident reports will enhance the available data for addressing risk reduction.

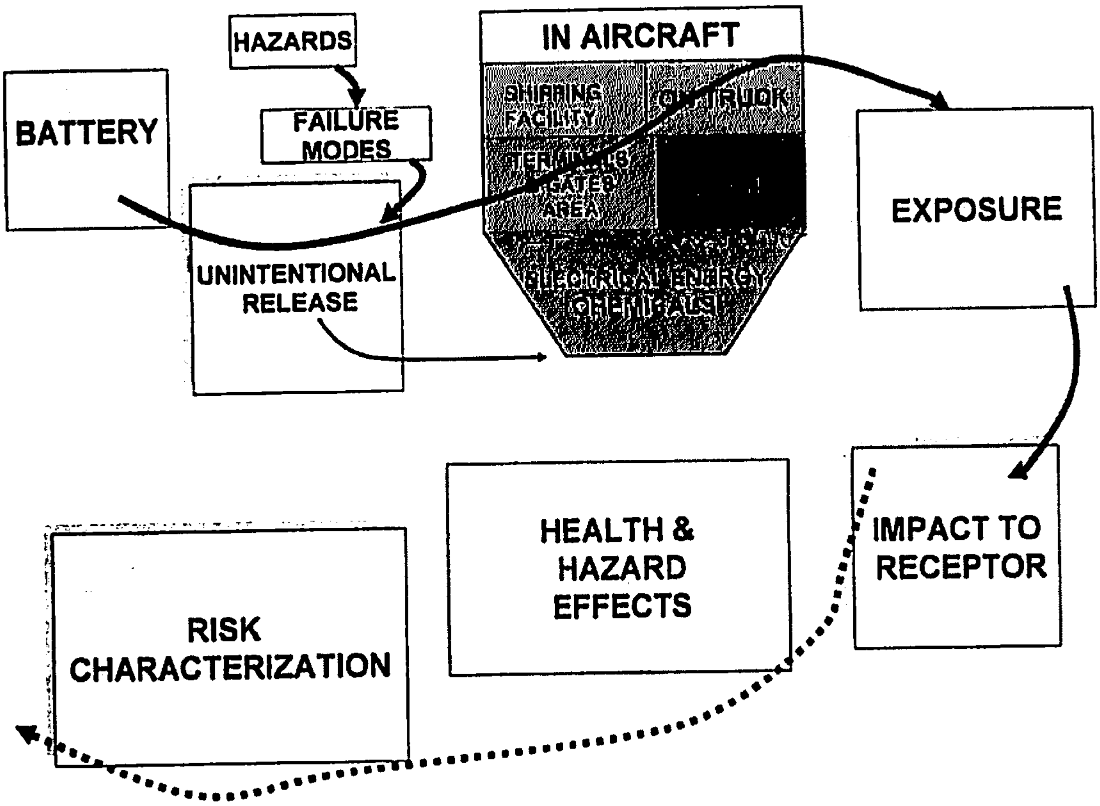
The HMIS data is a compilation of the DOT forms completed by the carrier or person in physical possession of the hazardous material at the time of the incident. The HMIS did not include incident information involving lithium batteries carried by passengers or crewmembers. This might be one of the reasons why the number of the lithium battery incidents reported in the HMIS data was considerably smaller than the number reported in the FAA data.

The HMIS data form was designed to cover the incidents resulting from the universe of all hazardous materials in all transportation modes and was not specifically intended to address the battery incidents on aircraft. This form had an entry for lithium battery (UN3090); lithium batteries, contained in equipment (UN3091); and lithium batteries packed with equipment (UN3091), and hence did not identify whether the battery was a lithium ion or metal type.

The HMIS data listed standard entries for "What Failed," "How it Failed," and "Failure Cause." These standard entries were given as part of guidance for completing the form. These entries were not designed for lithium batteries and hence the information relative to battery incidents was not as comprehensive as was desired. For example, the most frequent failure cause for lithium batteries for the period from 1990 through 2007 was "Blank (9 occurrences);" meaning the cause was not identified, followed by Improper Preparation for Transportation/Fire (2 occurrences); Temperature or Heat (2 occurrences); and Loose Closure, Component, or Device (1 occurrence). No information was provided on the type of batteries, energy levels, consequences, etc. let alone information on passenger-carried batteries or devices. The HMIS data in its present form does not provide adequate information for sufficient risk analysis for lithium battery incidents that occur on aircraft.

2. <u>Risk assessment using FAA data</u>

Traditionally, risk assessment involves the process of Hazard Identification, Exposure Assessment, Health Effects Assessment, and Consequence analyses as part of the overall risk characterization. Risk Management is a process that makes use of risk assessment results in decision making. The illustration provided below was intended to provide a perspective of the flow of analytical components, and some of the risk assessment processes and factors involved. Batteries contain hazardous materials in the form of chemicals and electrical energy. These hazards triggered by failure modes could result in unintentional releases of the chemicals and electrical energy to impact receptors through exposure pathways resulting in negative consequences. Receptors could be battery manufacturers, shippers, carriers, passengers, crew members, cargo handlers, the aircraft or others. There were no reported fatalities associated with direct chemical exposure or reactions from battery incidents based on the available data.



The risk analyses were grouped in three broad categories of components- Hazards Identification, Exposure Assessment, and Consequences (Impacts and Effects). The risk management issues were separately addressed.

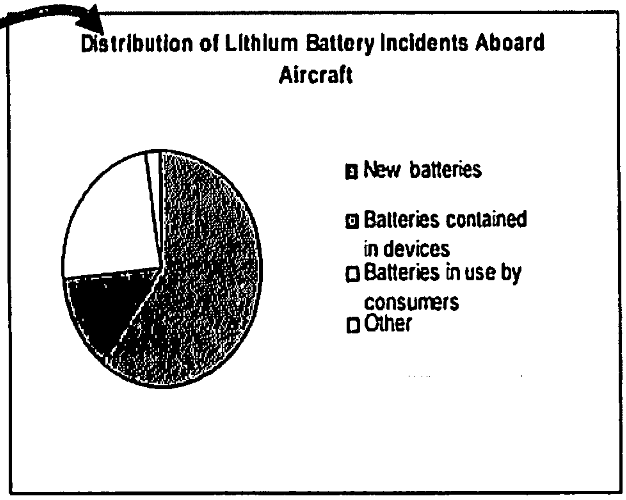
2.1 What can be done with the FAA DATA?

Despite its limitations, the FAA data was most comprehensive data publicly available to carry out data-driven risk assessment for lithium batteries transported aboard passenger and cargo aircraft. The FAA data was used to identify hazards associated with stored electrical energy and release of chemicals contained in batteries, exposure pathways, and consequences. Variables identified in the course of this assessment included lithium battery type, battery age, types of devices containing batteries, battery energy levels, interventions applied at the time of incidents, information on offerors, shipment type (consumer or in commerce), and compliance with regulatory standards.

2.2 Risk characterization

The FAA data showed that lithium batteries involved in incidents comprised about 54 % new batteries, 23 % contained in devices and the remaining 23 % in use by consumers in the course of transportation or incidental to transportation. A graphical representation of these groups is shown below.

Distribution of battery grouping (source: FAA 1991-2009 data)	
Battery grouping	Number
New batteries	23
Batteries contained in devices	5
Batteries in use by consumers	9
Other	1
Total	38



The category "New batteries" included batteries shipped from the manufacturer, packages of batteries shipped by consumers via common carriers, and unused or spare batteries carried by consumers in baggage. The category "Batteries contained in devices" included batteries contained in consumer devices carried in cargo compartments or passenger cabins. The category "Batteries in use by consumers" referred to those batteries involved in incidents while consumers were using them in flight or at the airport prior to boarding the aircraft. The category "Other" referred to an incident in which several thousand used batteries were shipped loose in a package.

Industry experts project the market for lithium cells and batteries will continue to grow into the future. Market growth information provided a baseline for assessing risk exposure (i.e. as production grows, so does the amount of batteries in the transportation system.)

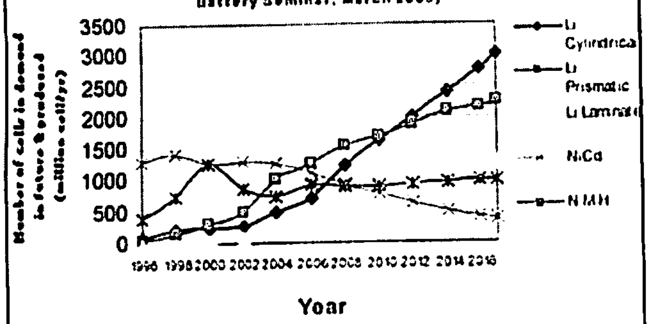


Figure 1. Market demand for lithium & some nonlithium batteries (source: 25th International Battery Seminar, March 2008)

Production data for lithium and non-lithium batteries. The market for non-lithium batteries was projected to flatten or decline as the growth in lithium battery market replaces the non-lithium market. The demand data might be useful in evaluating risk for new battery shipments.

2.2.1 Hazard identification

2.2.1.1 Failure modes

Failure mode is a structured method of assessing the real cause of the incidents which lead to unintentional release of battery hazards causing exposure to the receptors, and their effect on safety.

The failure modes for lithium battery incidents were grouped in 8 broad categories based on the types of the causes indicated in the FAA data. These were in the order of frequency of occurrences:

1. External-short
2. External or internal short
3. In-use situation
4. Unintentional activation
5. Discharging (not in use, not turned off)
6. Improper handling
7. Malfunctioned
8. Unknown.

When it was not clear as to whether the short-circuiting was due to external or internal short-circuiting, the failure mode was assigned "external or internal short-circuiting."

2.2.1.2 Lithium Battery Type

Lithium batteries are manufactured in a number of different shapes, sizes and utilize various chemistries. Current and future demand for different battery types will revolve around power and capacity demands, charge and discharge characteristics, a desire for a particular shape and portability and reliability. Below are a few of the most common battery geometries.

• Cylindrical
Cylindrical lithium batteries are made in different sizes (CRs, SRs, 18650 etc.) and have applications in audio visual equipment, communication devices such as cellular phones and personal digital assistants (PDAs),and notebook PC's. As these markets grow, the demand for this type of cells and batteries could accelerate. The 18650 lithium ion cell is currently the most prolific lithium ion cell type available.

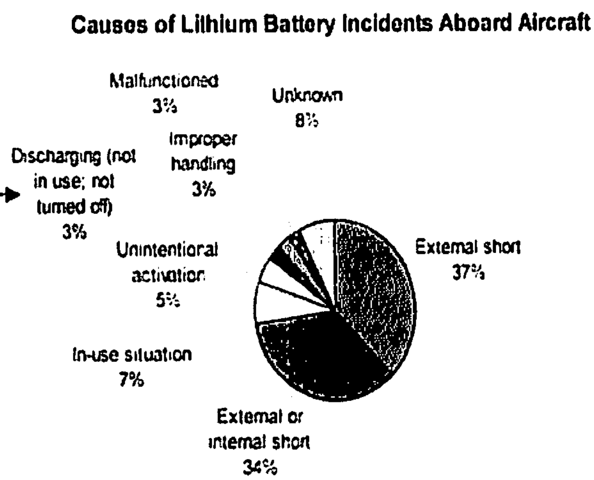
• Prismatic
Prismatic lithium batteries refer to any rectangular shaped batteries and are used in many of the same applications as the cylindrical lithium batteries including digital cameras, and other portable applications. Between 2000 and 2007, demand for prismatic lithium batteries exceeded that of any other lithium battery type.

• Laminate
Laminate type batteries allow a large number of electrode terminals to be connected in series. Laminate batteries are typically used in applications requiring a high current and high voltage. These batteries are used in power tools, electrically assisted bicycles, and in development of hybrid automobiles. No laminate type batteries were explicitly reported as having been involved in the incidents as they related to aircraft transportation so far.

2.2.1.3 Failure rates
Table 1 below shows failure rates of lithium batteries by various causes and indicates that the highest rate is attributable to short-circuiting caused by various reasons.

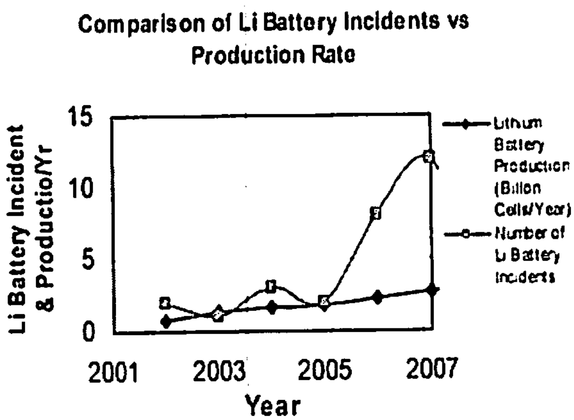
Table 1. Failure Rates of Lithium Batteries by Various Causes (Source: FAA 1991-2008)

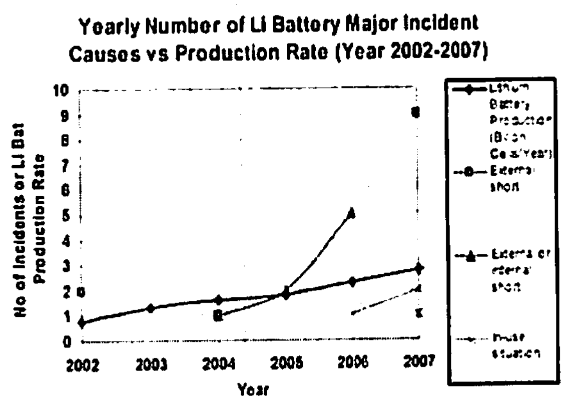
Failure Modes	Number	Frequency (%) ≈
External short	15	37
External or internal short	14	34
In-use situation	3	7
Unintentional activation	2	5
Discharging (not in use; not turned off)	1	3
Improper handling	1	3
Malfunctioned	1	3
Unknown	3	8
Grand Total	40	100



Lithium batteries have various applications including notebook personal computers, cellular phones, portable tools, digital cameras, personal digital assistants, etc. Each of the batteries used in these devices is comprised of one or more component cells. The number of cells and the configuration of cells often changes depending on the application. As we stated earlier, notebook computers and cellular phones make up the largest segment of the lithium ion battery market. On average a notebook personal computer uses between 5 and 7 cells per battery pack, while a cellular phone might use an average of about two cells per battery pack. Based on about 2.8 billion cells produced in the year 2007, it was estimated that about 1.8 billion cells were transported by air which resulted in a total of 640 million battery packs transported by air. The 12 lithium battery incidents in the year 2007 translated to roughly 2 transport incidents per 100 million cells produced.

The following charts compare the lithium battery incidents with production rate.





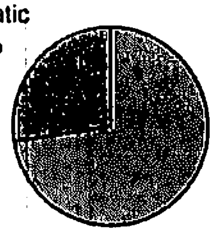
As illustrated by the graph on the left, the number of documented lithium battery incidents significantly increased in between 2005-2007. The incident rate was compared to the production rate of lithium cells during the same time period. Though the number of incidents increased faster than the production rate, the small number of incidents made it difficult to draw any conclusion about a causal relationship between production rates and incident trends.

The graph on the right displays a plot of the number of incidents associated with various general causes including: "External short," "External or internal short" and "In-use situation." The discontinuity observed in the graphical representation of incident rates is attributed to the fact that we did not observe a lithium battery incident involving that particular cause during that year. However, the data do reveal some trends. The sharp increases in the incidents between 2005 and 2007 were mainly attributed to the categories of "external short-circuiting" and "external and internal short-circuiting." Again, this observation was based on limited data comprising only the years 2002 to 2007. Nevertheless, production rate increases could not entirely explain the increased incidents.

The failure rates of lithium batteries are shown for cylindrical and prismatic types (Table 2). Short-circuiting was the predominant failure modes for both types of the battery. About 72 % of the lithium batteries observed in incidents were of the cylindrical type.

Table 2. Failure Rates according to Lithium Battery Type (source:1991-2009 FAA data)			
	Lithium Battery Type		
	Cylindrical	Prismatic	Grand Total
Failure Modes			
External short	14	1	15
External or internal short	8	3	11
In-use situation		3	3
Unknown	3	1	4
Unintentional activation	1	1	2
Discharging (not in use; not turned off)		1	1
Improper handling	2	1	3
Malfunctioned	1		1
Grand Total	29	11	40

Failure Rates by Lithium Battery Type

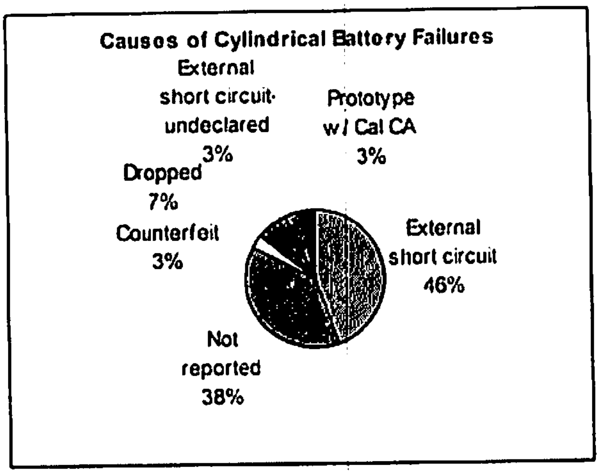


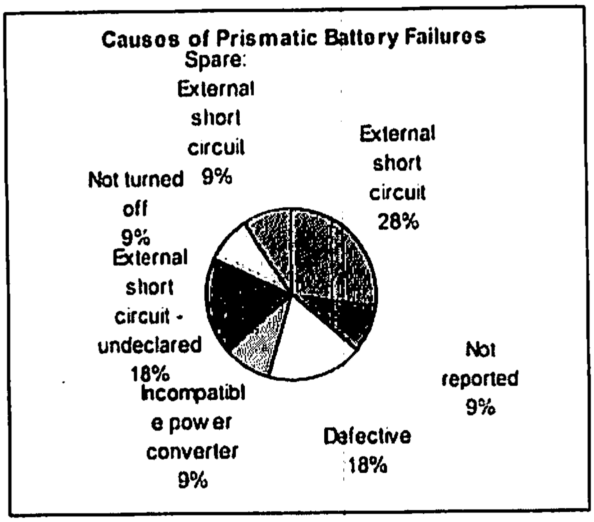
The causes of the failure modes were analyzed. These included electrolyte leakage (only happened to non-lithium batteries), inadequate short circuit protection, defective batteries, and counterfeit batteries. Many causes were not reported in the FAA data.

"Inappropriate short circuit protection included: the packages were not packed correctly; terminals that were improperly insulated or protected; terminal protection features to insulate the terminals were displaced or improperly installed or used. This grouping also included the case where metallic materials such as cables, wire, tools or other metallic objects were placed in the same package and caused short circuits and improper packaging where terminals were exposed to make them prone to short-circuiting.

One incident involved a prototype cylindrical lithium battery. This incident was noted in the table as "Prototype w/ CAA," indicating that the battery was authorized for transportation through a Competent Authority approval but did not comply with the terms of the approval. An enforcement action was taken against the shipper based on a joint PHMSA/FAA investigation.

Causes of Failure Modes according Lithium Battery Type (source:1991-2009 FAA data)			
	Lithium Battery Type		
Causes of Failure Modes	Cylindrical	Prismatic	Grand Total
External short circuit	13	3	16
Not reported	11	1	12
Defective		2	2
Counterfeit	1		1
Dropped	2		2
Incompatible power converter		1	1
External short circuit -undeclared	1	2	3
Not turned off		1	1
Prototype w/ Cal CA	1		1
Spare: External short circuit		1	1
Grand Total	29	11	40





Cylindrical batteries were involved in more incidents in these categories. It was interesting to note that Figure 1 showed that the projected demand for the cylindrical type would surpass that for the prismatic type, though the demand for prismatic type has been greater than the cylindrical type during the period that the FAA data was analyzed.

2.2.2 Exposure assessment

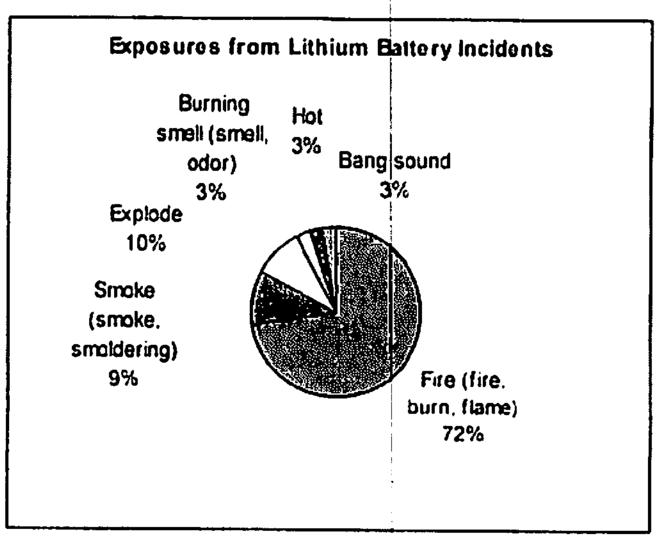
Batteries contain chemicals which are converted to electrical energy. Incidents involving the release of the contents of these batteries can result in explosions, fires, property damage, and damage to an aircraft resulting in a diversion or crash, and other consequences that can have a significant impact.

The narrative descriptions in the FAA incident data described several exposure terms in different ways for similar incidents. When an explosion was accompanied by fire, sparks, or smoke, double counting of exposure was avoided by counting explosion once without counting fire, sparks or smoke. When a fire was accompanied by smoke or odor, only fire was counted to avoid double counting of exposure. On the other hand, when smoke was indicated and fire was not noted in the incident report, only smoke was counted as exposure. The same procedure was followed for other types of exposure. The exposure considered to be more severe in its type was used in counting. "Fire," "burn" and "flame" were combined into one category and reported as "fire." Thus, the severity pecking order used in the exposure assessment was explosion, fire, smell, sparks, hot, and warm.

Fire was expressed in several terms in the data – flame, burning, blaze, ignited, or also as smoldering. Fire could accompany sparks in some cases or was initiated by sparks. However, explosion might not necessarily cause a fire. Explosion was sometimes caused by build-up of gas inside a battery and existence of an ignition source. In some cases, fire was followed by a pop sound and the box lifted-off. In other cases, sparks were noted without a fire. Firefighters included involvement of the fire department or fire fighters, and the airport fire fighters to extinguish the fire.

Table 3. Exposures from Lithium Battery Incidents

EXPOSURES	NUMBER OF TIMES APPEARED	% of Total
Fire (fire, burn, flame)	29	72.5
Smoke (smoke, smoldering)	4	10
Explode	4	10
Burning smell (smell, odor)	1	2.5
Hot	1	2.5
Bang sound	1	2.5
Total	40	100



Approximately 71% of exposures resulted from lithium battery incidents caused by fire followed by about 11 % which resulted in explosion. Smoke occurred in about 9 % of the incidents (See Table 3.).

2.2.3 Consequences – lithium and non-lithium batteries

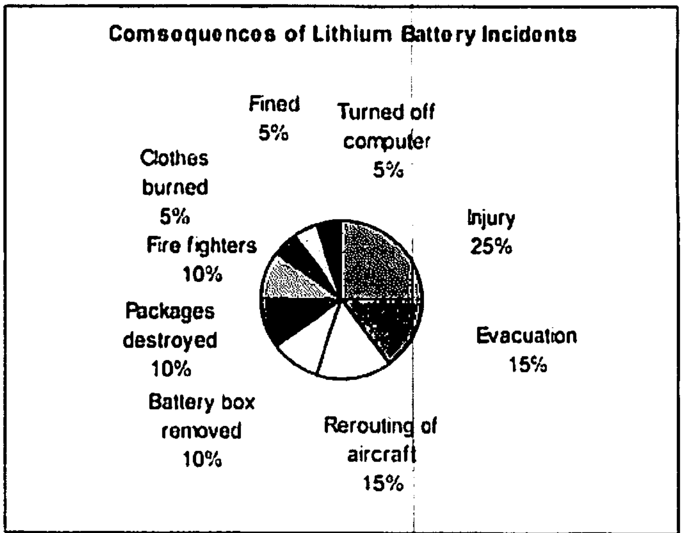
Consequence is a direct result of an incident such as fatalities, injuries, persons evacuated, property damage, closing of facilities, and interruption of the flight pattern or routing of an aircraft. Based on the types of the consequences reported in the data, 13 categories of consequences were considered for evaluation. These were injury, aircraft destroyed, packages destroyed, evacuation, bomb squad called in, fire fighters called in, rerouting of aircraft, battery box removed, clothes burned, terminals protected, fined, turned off computer, and emergency responders called in.

The consequences to the extent the data were reported in the data were accounted for and tabulated. The examination of the data showed that not all of the consequences were reported in the inspection reports. For example, the inspection report normally noted the exposure such as fires or smoke or their probable causes such as short circuits, but did not normally elaborate what happened after the incident subsided i.e. no consequences were reported in many cases. It could be that in minor incidents no serious or reportable consequences were observed. This was generally true for small incidents of fires or smoke not requiring the help of fire fighters or emergency responders.

- Lithium Batteries

Though no fatalities were reported in the FAA data as they related to battery incidents, several injuries were reported. "Evacuation" involved evacuation of passengers from the aircraft due to the battery incident. "Rerouting" included an emergency landing at another airport, returning to the original airport for emergency landing, or returning to gate. Boxes or packages containing batteries that were removed from the aircraft or the shipping facility were grouped in the "Battery box removed." "Packages destroyed" included the damaged baggage or packages in addition to packages of batteries and devices containing batteries.

Table 4. Consequences associated with Lithium Battery Incidents		
CONSEQUENCES	NUMBER OF TIMES	%
Injury	5	25
Evacuation	3	15
Rerouting of aircraft	3	15
Battery box removed	2	10
Packages destroyed	2	10
Fire fighters	2	10
Clothes burned	1	5
Fined	1	5
Turned off computer	1	5
Total	20	100



In one case, fire fighters were called in to extinguish the fire. In another case, it was reported hat a laptop computer was turned off by the security screener and no other consequences or measures were reported. In about one third of the lithium battery incidents, injury was reported. Not all of the 40 lithium battery incidents reported consequences within the categories listed above. In all, only 18 of the 35 incidents reported consequences.

- Non-lithium Batteries

Reported consequences for non-lithium battery incidents were slightly higher than for lithium battery incidents. This might be due to the higher number of incidents reported for non-lithium batteries. The packages were destroyed about 23 % of the time. About 14 % of the non-lithium battery incidents resulted in injuries of the passengers or crew members.

2.3 Risk management

Risk management is an evolutionary process that uses the results of a risk assessment to aid decision making for risk reduction and should be integrated with other management processes. Risk management involves a broad array of disciplines aimed at decision making about control. In addressing various methods available for its control, costs and benefits should be considered. A cost benefit analysis is being developed by PHMSA and FAA.

2.3.1 Controls that could be taken

Interventions afford opportunities to mitigate the adverse effects resulting from battery incidents. The most appropriate intervention depends on many factors including the type of battery and the location of the battery. Two types of interventions were considered. Specifically, direct and indirect interventions. Direct intervention involved the actions of crew members, control officers and sometimes passengers to mitigate incidents. Indirect intervention involved an evaluation of the causes of an incident to achieve an acceptable outcome in the future. Examples of such indirect interventions include enhanced packaging, package limits, enhanced short circuit protection and improved battery design.

Direct intervention typically involved actions taken after an incident has occurred while indirect interventions would prevent an incident from happening. Since the incident data only provided information about actual transportation incidents, naturally the incident data only provided information on the direct interventions used. Age and configuration of the battery did not appear to affect the type of intervention practiced.

Many of the incidents involving lithium batteries occurred on passenger aircraft in carry-on or checked baggage. These batteries were personal items and may not have been new atteries or batteries that were produced by original equipment manufacturers. Many of these batteries had exposed terminals leading to short-circuits. It was not always possible to determine all of the facts that may have contributed to the incident (e.g. were the batteries defective, abused by the consumer, counterfeit or properly handled and protected from short circuit). In contrast to lithium battery incidents, most incident involving non-spillable batteries occurred on cargo aircraft and were shipped separate from the device it was intended to power.

- Lithium Batteries

Lithium batteries were grouped in three categories - new batteries, batteries contained in devices; and batteries in use by consumers. The majority of batteries constituted the new battery type comprising about 54 % of the total. The make-up consisted of a mix of batteries shipped in commerce and those shipped as non-commerce commodities.

- New Batteries

The interventions practiced in the majority of the incidents occurred from the new battery grouping were not reported. The interventions ranged from the use of fire extinguisher to evacuating from the affected area to the removal of damaged box. The types of the new lithium batteries relevant to the interventions practiced were mostly lithium ion batteries. The use of fire extinguishers was commonly practiced to deal with fires.

- Batteries installed in devices

Batteries installed on devices were also a source of incidents during transportation. Fire extinguishers were mentioned as a fire suppression system used at the time of incidents. Any details about the types of fire extinguishers were not generally given in the inspection reports. An inadvertently turned-on laptop, though not in use, was indicated in the report and was turned off because it was "hot." Many interventions practiced for these types of battery grouping were not reported.

Many of the devices were consumer items consisting of flashlights, personal use items, and battery-driven toys.

- Non-lithium Batteries

Non-lithium batteries grouped in three categories shown had incidents consisting of about 73 % new batteries, 25 % batteries contained in devices, and 2 % batteries in use by consumers. "New batteries" mostly consisted of packaged batteries, batteries on pallets, and batteries not installed in devices or used by consumers at the time of the incidents.

Distribution of battery grouping (source: 1991-2008 FAA data)		FAA
Battery grouping	**Number**	
New batteries	43	
Batteries contained in devices	15	
Batteries in use by consumers	1	
Total	59	

Most of the incidents involving non-lithium were involved cargo shipments as compared to the shipment of lithium batteries that consisted of a mix of cargo, batteries contained in devices or in use by consumers.

Batteries of unknown types were not included in the grouping of non-lithium batteries.

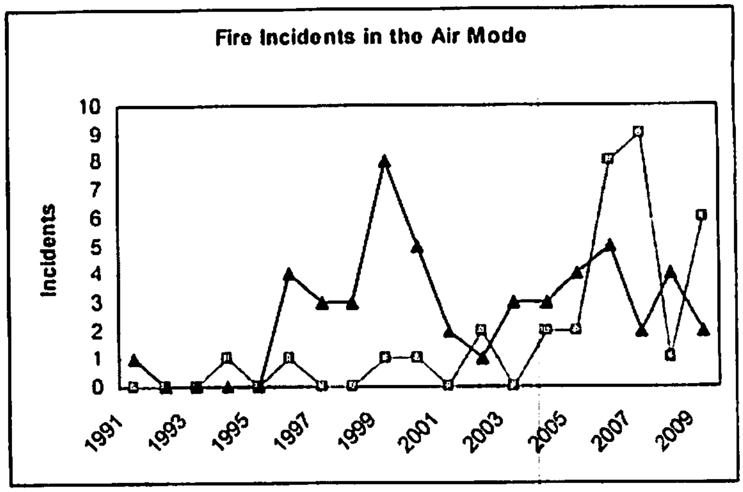
2.4 Additional information obtained from FAA data

Additional information could be derived from the FAA data. This included change of fire-causing battery incidents over time; type of devices organized based on whether or not they are new or established; percentage of failures for consumer-carried batteries and devices; failure modes for consumer-carried batteries and devices; failure modes according to energy levels for consumer-carried lithium batteries and devices; incidents based on shipment types; and quality control measures that can be used to prevent failure modes. Limitation of space did not permit presentations of all these results. As an example, the trends for fire causing incidents are presented below.

Not all of the incidents resulted in a fire. In the tabulation below, the "fire-causing incident" included fire (burn, flame) and smoke (smoldering) and is shown separately for lithium and non-lithium cells/batteries. The incidents that only led to sparks or leaking of electrolyte were not included in the "fire-causing incidents"

Overall, lithium battery incidents have increased in recent years, while incidents associated with non-lithium batteries have remained relatively constant. Since many of these incidents were caused by external short circuiting, proper insulation and protection of terminals especially for lithium batteries proper packaging could have prevented many of these incidents. Improper handling of packages containing batteries may have contributed to the observed incidents.

	Number of Fire Incidents in the Air Mode	
Year	Lithium	Non-lithium
1991	0	1
1992	0	0
1993	0	0
1994	1	0
1995	0	0
1996	1	4
1997	0	3
1998	0	3
1999	1	8
2000	1	5
2001	0	2
2002	2	1
2003	0	3
2004	2	3
2005	2	4
2006	8	5
2007	9	2
2008	1	4
2009	6	2



Lithium: ________

Non-lithium: ________

3. Summary of findings and recommended actions

- **Summary**

As of September, 2009, the results can be summarized as follows.

1. 37 % of the observed incidents involved lithium batteries; 55 % were non-lithium batteries; and 7 % unknown types.

2. Increased production could not fully explain the increase in lithium battery incidents observed during the study period.

3. For lithium batteries, the distribution of the causes of incidents was: 37% external short-circuiting; 34 % external or internal short-circuiting; 7 % in-use situation; 5 % unintentional activation; and 17 % from all other causes (discharging- not in use but not turned off, improper handling, malfunctioned, and unknown).

4. For non-lithium batteries, the distribution of the causes of incidents was: 65 % external short-circuiting; 11 % unintentional activation; 5 % external or internal short-circuiting; 4 % improper handling; and 15% others.

5. For lithium batteries and devices containing lithium batteries, consumer-carried items constituted about 43 % of the battery incidents, the remaining being the bulk shipment in commerce.

6. For non-lithium batteries and devices containing non-lithium batteries, consumer-carried items constituted about 29 % of the battery incidents, the remaining being the bulk shipment in commerce.

7. About 49 % of the lithium battery incidents were from the ion type, about 37 % from the metal type, and the remainder of an unknown type.

- **Recommendations**

DOT's "Battery Safety Action Plan" identified multi-faceted recommendations to reduce battery risks. The action plan was developed through a collaborative effort where PHMSA reached out to numerous entities (e.g. airlines, pilots, flight attendants, battery manufacturers, shippers, etc.) through a number of safety-focused forums. The recommendations provided below are a result of the analysis of the battery incident data and supplement those identified in the "Battery Safety Action Plan" with a direct focus on preventing the specific battery incidents aboard aircraft and during the routine operations based on an analysis of the incident data. Actions identified below that are not covered in the action plan will be considered for revising the action plan.

While this analysis provides a starting point the investigation is far from complete. We continue to observe lithium battery incidents in air transportation and we must collect useful data from the incident scene as soon as possible and determine the root cause of the incident. Data collection and analysis must improve in order to observe useful trends. Individuals investigating the cause of the incident must follow-up with shippers and manufacturers to determine specific causes and ensure corrective actions are taken in the future.

- **Consumer-carried batteries and devices:**

   a. Develop an advisory to educate air travelers relative to the potential for battery failures during device use and charging aboard aircraft.

   b. Develop an outreach plan to raise awareness regarding the need to ensure that battery powered devices are turned off while not in use and that simple measures are taken to prevent inadvertent activation during transport.

   c. Develop an outreach plan to raise awareness concerning the risks associated with the use of inferior or counterfeit batteries and how to identify them.

   d. Develop an outreach program to increase awareness of the hazards of using improper charging equipment.

e. Alert air travelers of the hazards associated with carrying unprotected loose batteries and the importance of securely packaging their spares.

f. Review the packaging requirement for the carriage of spare batteries and for batteries packed with or contained in equipment.

- **Cargo Shipments**

a. Review the current battery packaging requirements and consider how enhanced packaging can reduce the risk of fire and overheating and the potential consequences.

b. Review current requirements for the transport of *Bulk* Shipments of batteries and cells. Consider enhanced regulations to for bulk quantities of batteries and cells including hazard communication and hazmat employee training.

c. Require manufacturers to be able to produce proof the battery and cell design types have successfully passed the applicable UN tests.

d. Examine the benefits of requiring batteries to be stowed in crew accessible locations.

e. Test various packaging and quantity configurations of batteries to better understand the risks and to develop more effective requirements to prevent fires and overheating.

f. Develop a plan for identifying and prohibiting the transport of defective and counterfeit batteries aboard aircraft.

g. Continue to work with the international regulatory bodies to develop requirements for addressing and identifying design defects, manufacturing defects, and testing inadequacies.

h. Amend the design type tests to reduce risk and enhance safety.

i. Review current requirements for loading and handling of batteries (e.g. preventing damage that results from improper handling)

j. Examine the adequacy of on-board intervention systems including fire detection and suppression capabilities.

k. Consider the feasibility and costs of using fire proof overpacks and ULDs consistent with NTSB recommendations.