International Civil Aviation Organization

WORKING PAPER

DANGEROUS GOODS PANEL (DGP)
WORKING GROUP MEETING (DGP-WG/15)

Montreal, 27 April to 1 May 2015

Agenda Item 5: Development of mitigating measures to address risks associated with the transport of lithium batteries including measures that address recommendations from the Second International Multidisciplinary Lithium Battery Transport Coordination Meeting
5.2: Performance-based provisions

TRANSPORT OF LITHIUM BATTERIES AS CARGO VIA AIR

(Presented by the International Coordination Council for Aerospace Industry Association (ICCAIA) and the International Federation of Airline Pilots Association (IFALPA))

SUMMARY

This working paper presents the expertise of the International Coordination Council for Aerospace Industry Association (ICCAIA) with respect to cargo compartment fire protection capability, especially related to the carriage of lithium batteries as cargo.

Action by the DGP-WG: The DGP-WG is invited to consider the ICCAIA's recommendations:

a) that appropriate packaging and shipping requirements are established to more safely ship lithium ion batteries as cargo on passenger aircraft;

b) that high density packages of lithium ion batteries and cells (UN 3480) not be transported as cargo on passenger aircraft until such time as safer methods of transport are established and followed; and

c) that appropriate packaging and shipping requirements are established to more safely ship lithium metal and lithium ion batteries as cargo on freighter aircraft.

1. INTRODUCTION

1.1 The Dangerous Goods Panel (DGP) asked the International Coordination Council for Aerospace Industry Association (ICCAIA) for their expertise with respect to cargo compartment fire protection capability, especially related to the carriage of lithium batteries as cargo. ICCAIA agreed to develop a technical related working paper that provides safety recommendations for transporting lithium batteries (both lithium ion and lithium metal batteries) as cargo on passenger and freighter aircraft.

2. CARGO COMPARTMENT FIRE PROTECTION STANDARDS

2.1 The position of ICCAIA is that the fire protection capabilities and certification of original equipment manufacturers' (OEMs) airframes and systems were developed considering the carriage of general cargo and not the unique hazards associated with the carriage of dangerous goods, including lithium batteries.

2.2 A growing body of test data (see Appendix C, Reference 1, 2, 3, 4) has identified that existing cargo compartment fire protection systems certified to EASA CS 25.857 and US CFR Part 25.857 (CS/CFR Part 25) regulations are unable to suppress or extinguish a fire involving significant quantities of lithium batteries, resulting in reduced time available for safe flight and landing of an aircraft to a diversion airport. Therefore, continuing to allow the carriage of lithium batteries within today's transport category aircraft cargo compartments is an unacceptable risk to the air transport industry. Appendix A to this working paper provides a description of aircraft cargo compartment fire protection standards and an explanation of why they are inadequate to control fires involving an unrestricted quantity of lithium batteries.

3. LITHIUM BATTERY HAZARDS

3.1 It has been demonstrated that the current regulations for the transport of lithium batteries by air provided in the Technical Instructions are not able to control or at least to contain a lithium battery fire within the required packaging. It has also been demonstrated that the current regulations do not prevent the propagation of the fire from one package of lithium batteries to another adjacent package (see Appendix C, Reference 1).

3.2 Testing conducted at the Federal Aviation Administration (FAA) Technical Center has shown the uncontrollability of lithium battery fires can ultimately negate the capability of current aircraft cargo fire suppression systems, and can lead to a catastrophic failure of the airframe (see Appendix C, References 1 and 2).

3.3 Both lithium metal and lithium ion batteries are transported by air, with lithium metal batteries now prohibited as cargo on passenger aircraft. Lithium metal battery fires have been proven to propagate at a more rapid rate than a lithium ion battery fire; however, this is balanced by the fact that the quantity of lithium ion batteries carried by air is significantly greater.

3.4 New findings, confirmed by FAA tests and expertise from industry, show that electrolyte gases exhausted during the propagation of both lithium metal and lithium ion battery thermal runaway events create an explosive atmosphere when contained inside an enclosed space (such as load devices (container, covered pallet) or cargo compartments) (see Appendix C, Reference 4).

3.5 Occurrences of lithium battery thermal runaways (due to production or design defects, poor manufacturing quality, improper packaging, mechanical impact, etc.), as listed in the FAA incident data base and other published reports, need to be considered in the failure case analysis (see Appendix C, References 5 and 6).

3.6 By applying the tenets of the ICAO *Safety Management Manual (SMM)* (Doc 9859) to the knowledge that lithium batteries have been involved in aircraft fires in the past and uncontrolled fires have hazardous or catastrophic consequences, this safety process requires immediate action due to the unacceptable risk under the existing circumstances. Appendix B to this working paper provides a description of how this conclusion is reached using the *Safety Management Manual (SMM)* (Doc 9859).

4. MITIGATION STRATEGIES

4.1 A layered protection sequence should be employed that is focused at the source of the threat and then expanded outward as necessary: Battery – packaging – cargo unit load device – cargo compartment – aircraft level.

4.2 Preventing propagation of thermal runaway from batteries in one package to batteries in adjacent packages is a basic necessity for adequately controlling the effects of a fire involving lithium batteries. Current packaging requirements do not reflect this need.

4.3 Potential packaging solutions are actively being developed by other sectors of the aircraft transportation industry (loose fill intumescent packing material, cooling pouches, intumescent plastic matrix materials, etc.)

5. CONCLUSIONS

5.1 The known and unknown risks associated with transporting lithium batteries by air coupled with the knowledge that the volume of such cargo is continually increasing requires action to be taken.

5.2 ICCAIA recommends that appropriate packaging and shipping requirements be established to safely ship lithium ion batteries as cargo on aircraft and that high density packages of lithium ion batteries and cells (UN 3480) not be transported as cargo on passenger aircraft until such time as safer methods of transport are established and followed.

5.3 It is further recommended that appropriate packaging and shipping requirements are established to more safely ship lithium metal and lithium ion batteries as cargo on freighter aircraft.

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APPENDIX A

CARGO COMPARTMENT LIMITATIONS

1. The fire protection capabilities and certification of original equipment manufacturers' (OEM's) airframes and systems were developed considering the carriage of general cargo, and not the unique hazards associated with the carriage of dangerous goods, including lithium batteries.

2. The main classification of cargo compartments used for CS/FAR25 certified aircrafts (reference 25.857) are class C and Class E cargo compartments. Additionally, there are many older aircraft in service that have Class D cargo compartments.

   a) 25.857 (c) Class C cargo compartments need to be equipped with smoke/fire detection system, ventilation control, built-in fire suppression system, fire resistant linings that meet the test requirements of Part III of Appendix F to CS/FAR25 and it needs to be demonstrated that no hazardous quantity of smoke, flames or fire extinguishing agents are able to enter into occupied areas;

   b) 25.857 (d) Class D cargo compartments need to be equipped with ventilation control, fire resistant lining and it needs to be demonstrated that no hazardous quantity of smoke, flames or noxious gases are able to enter into occupied areas; and

   c) 25.857 (e) Class E cargo compartment (only allowed for freighter aircraft) need to be equipped with a smoke/fire detection system, ventilation control, critical systems need to be protected from fire damage (liners that meet the test requirements of Part III of Appendix F to CS/FAR25 is one means), and it needs to be demonstrated that no hazardous quantity of smoke, flames or noxious gases are allowed to enter into occupied areas. For fire suppression, there is a means for oxygen starvation via flight procedure (flight level 20,000 feet / 25,000 feet).

3. The qualification requirement for lining material according to Part III of Appendix F to CS/FAR25 is to withstand an oil burner flame of 927°C (1700°F) for 5 minutes, the temperature 10 cm (4 inches) above the upper surface of the horizontal test sample must not exceed 204 ºC (400ºF).

   a) the 5 minute requirement was based on the assumption that a fire will be under control after this time. The 5 minutes considers the time to detect the fire, pilot reaction, system effectiveness;

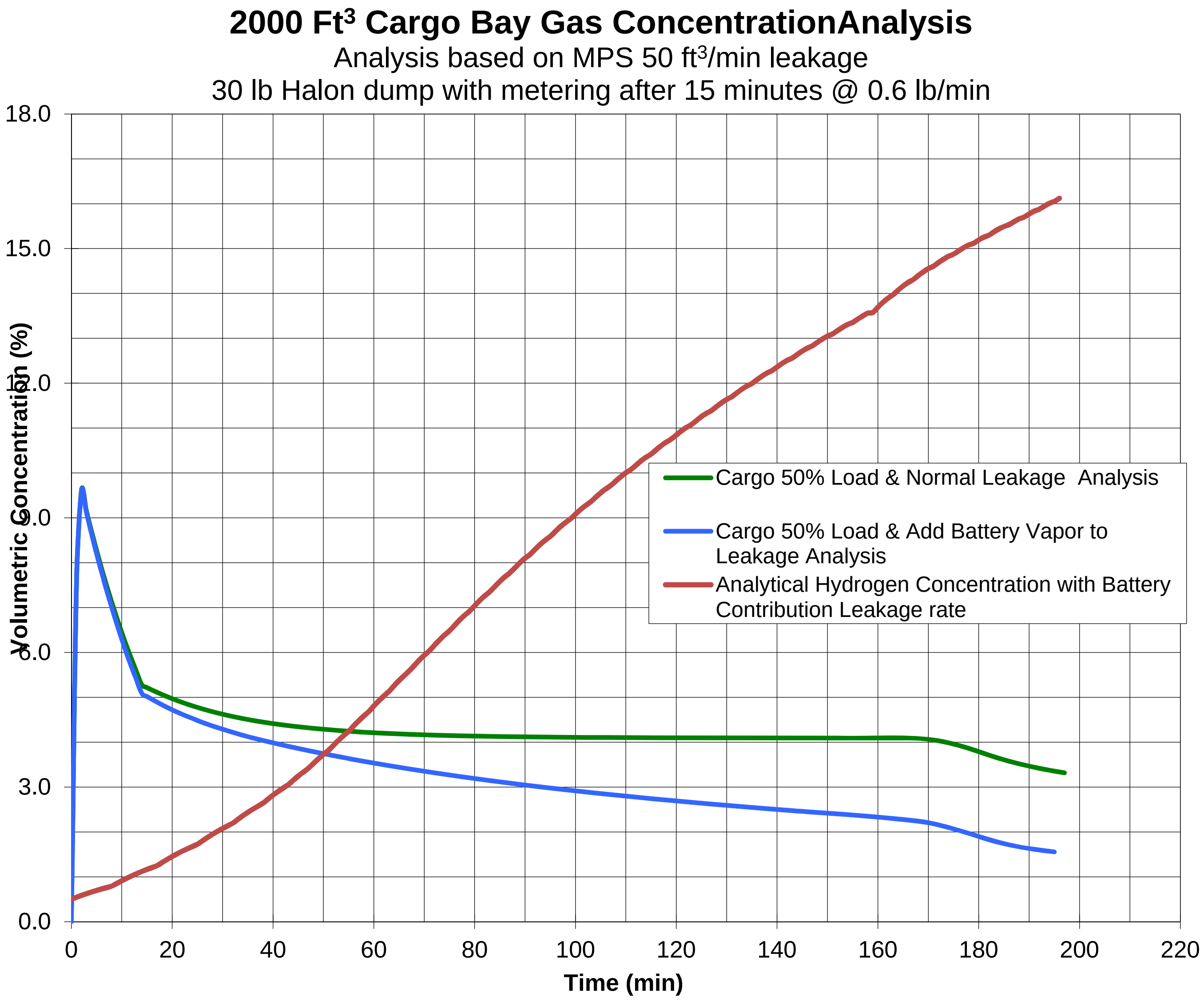
   b) investigations have shown that a significant number of lithium batteries involved in a fire will exceed the temperature of 927°C (FAA and Boeing report refers);

   c) the 927°C (1700 °F) requirement was based on FAA Tech Center testing of typical items carried in cargo compartment, specifically wood based products like paper, pallets, cardboard, etc.

4. Smoke detection systems must be demonstrated to detect small smoldering fires within one minute for newer aircraft (certified to CS/FAR 25.858(a)). Older aircraft generally have been demonstrated to detect fires within 5 minutes, while Class D cargo compartments do not have smoke detection systems.

5. Fire suppression agent: the current fire suppression systems for class C cargo compartments use Halon 1301. Halon 1301 is not expected nor designed to fully extinguish an aircraft fire. It is designed to suppress a fire, reducing the heat and energy intensity of the fire and to prevent re-ignition of the suppressed fire, to allow the aircraft to safely land at the nearest suitable airport. Halon is not effective for any type of metal fire, resulting in very limited effect for fires involving lithium metal batteries. Halon also has limited effectiveness on a lithium ion battery fire. This agent is not able to stop/prevent lithium ion- and lithium metal battery thermal runaway, nor does it prevent propagation of thermal runaway from one cell to the next. The primary protective capability it provides is through preventing the surrounding combustible materials from igniting and preventing the open flaming of the battery electrolyte. Although this reduces the heat intensity and thus the rate of thermal propagation from battery to battery, the accumulation of unburned hydrocarbons and other flammable gases may result in an explosive atmosphere within the cargo compartment.

6. The fire suppression system of a class C cargo compartment is designed for between 1 to 6 hours suppression time. To keep the required Halon concentration to prevent re-ignition of a suppressed fire, maintaining a defined cargo compartment leakage rate is required. Testing has shown that higher rates of smoke production, flammable vapor, pressure and temperatures happen with fires involving lithium batteries (metal and ion/polymer) than with ordinary Class A (i.e. paper, etc) products. Adding gasses into a cargo compartment will increase the pressure or will push out the Halon 1301, thus diluting the pre-existing Halon concentration in the atmosphere and increasing the compartment leakage rate. Different battery chemistry and types will vent different quantities of flammable gas during thermal runaway. One common chemistry of lithium ion 18650 cells will vent 0.25 moles (0.20 ft^3) of gases, with hydrogen making up 30% of the vented gas. With the expectation of not controlling a lithium battery fire and the known high quantity of smoke (burned battery material) and the significant quantity of flammable gas exhausted from the lithium batteries, it is expected that this will overwhelm the design target leakage rate of a cargo compartment. Therefore, the required Halon design concentration could no longer be maintained. At this point, the cargo compartment can develop an explosive atmosphere of CO, CO2, H_2, CH_4, and the ignition energy to set it off may be provided by the heat of a single battery cell in thermal runaway. The following graph shows how the battery vent gas volume quickly exceeds the cargo compartment leakage rate.



7. Cargo compartments are equipped with rapid decompression features to be prepared for an unexpected fuselage depressurization event. These decompression features maintain the integrity of fuselage structure. The special activation pressure of these features depends on the overall aircraft design, but in many cases the pressures needed to activate these features are less than one psid. Based on existing test results, it is likely that an explosion of the flammable vapors would activate rapid decompression features. One consequence of activating the decompression features will be that the leakage rate of Class C compartments will be increased, thus reducing the fire suppression agent concentrations within the compartment to a level below what is required for suppression and the fire would become uncontrollable.

8. The prevention of smoke penetration into occupied compartments must be demonstrated through flight testing (FAR/CS 25.855(h) and Advisory Circular (AC) 25-9A). This is typically accomplished by filling the cargo compartment under test with smoke to a visual obscuration density of 18 inches (i.e. cannot see one's hand 18 inches from one's eye) and then maintaining that density through a typical flight profile in response to a cargo fire while verifying no smoke penetration into the occupied compartments, such as the flight deck and the main cabin. Various commercial smoke generators that produce aerosol droplets with smoke-like properties and

heaters or other means of adding buoyancy to the smoke have been employed. As identified above, the smoke and pressure rates from fires involving lithium batteries is greater than for fires involving ordinary Class A combustibles and may overcome the aircraft design features that prevent smoke penetration into occupied areas. In addition, the potential for activation of decompression features by explosion of flammable battery vapors as described in (7), above, could allow hazardous quantities of smoke, flames, noxious gases or fire extinguishing agents to penetrate into occupied compartments.

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APPENDIX B

ICAO SAFETY MANAGEMENT MANUAL (DOC 9859)

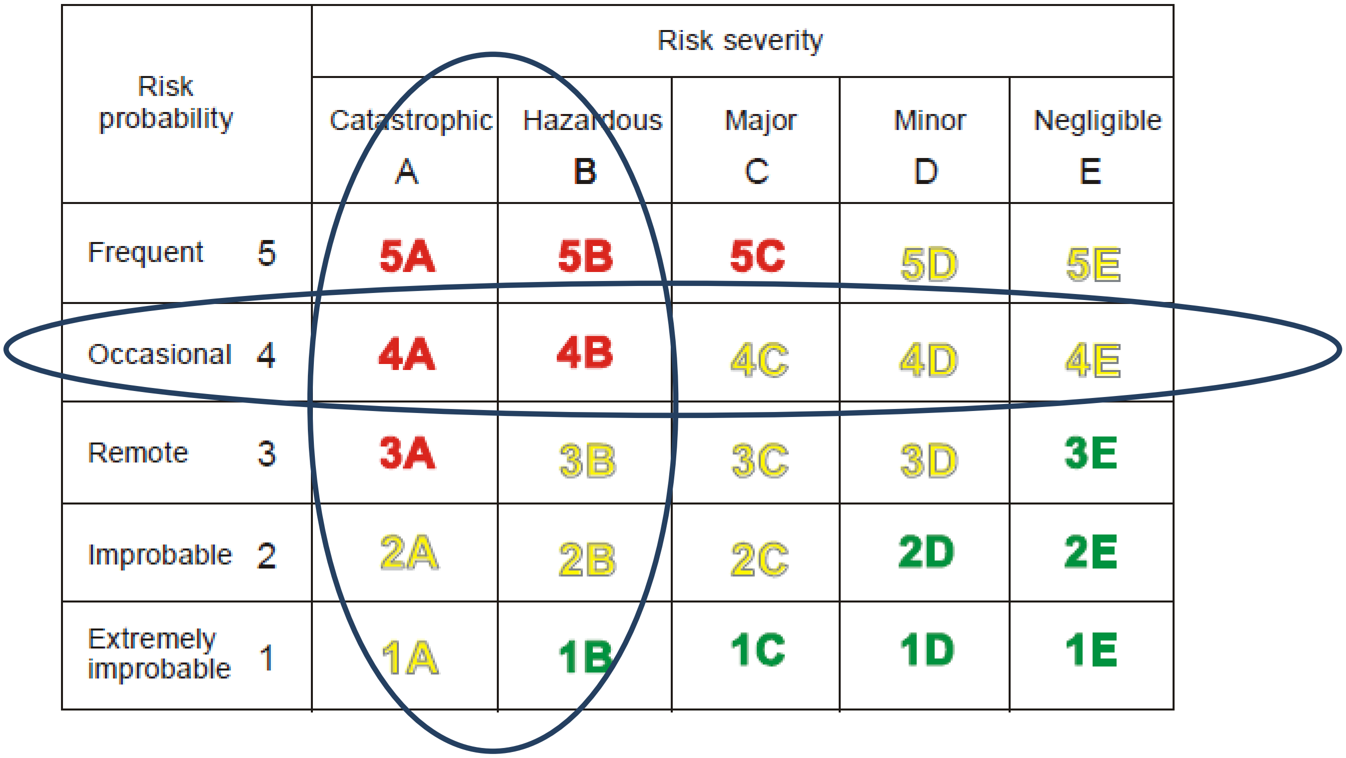
Applying the safety risk model provided in the *Safety Management Manual (SMM)* (Doc 9859) to the information provided in this paper, a scenario of a cargo fire involving lithium batteries has the following potential likelihood and severity (Figure numbers refer to Doc 9859):

Likelihood	*Meaning*	*Value*
Frequent	Likely to occur many times (has occurred frequently)	5
Occasional	Likely to occur sometimes (has occurred infrequently)	4
Remote	Unlikely to occur, but possible (has occurred rarely)	3
Improbable	Very unlikely to occur (not known to have occurred)	2
Extremely improbable	Almost inconceivable that the event will occur	1

Figure 2-11. Safety risk probability table

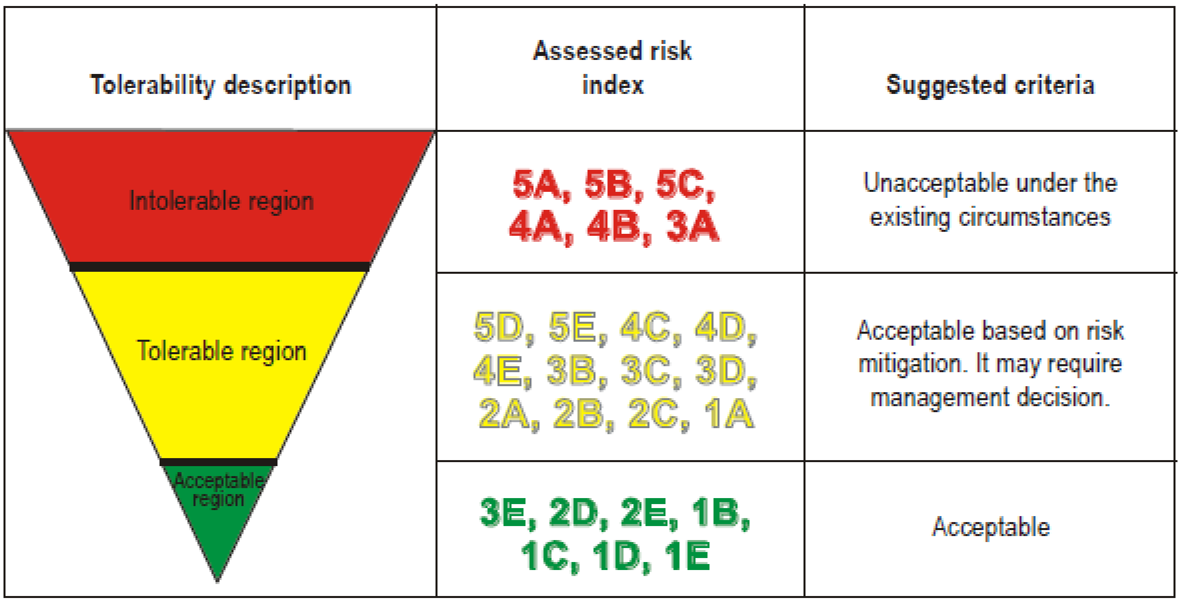
Severity	*Meaning*	*Value*
Catastrophic	— Equipment destroyed — Multiple deaths	A
Hazardous	— A large reduction in safety margins, physical distress or a workload such that the operators cannot be relied upon to perform their tasks accurately or completely — Serious injury — Major equipment damage	B
Major	— A significant reduction in safety margins, a reduction in the ability of the operators to cope with adverse operating conditions as a result of an increase in workload or as a result of conditions impairing their efficiency — Serious incident — Injury to persons	C
Minor	— Nuisance — Operating limitations — Use of emergency procedures — Minor incident	D
Negligible	— Few consequences	E

Figure 2-12. Safety risk severity table



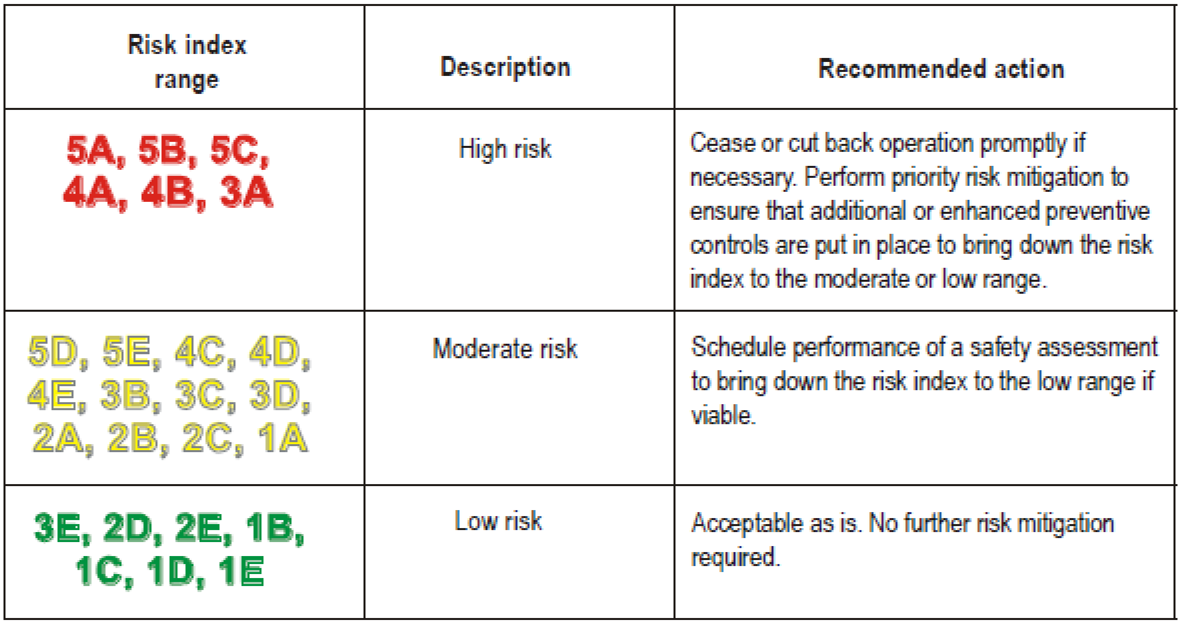
Risk probability		Risk severity				
		Catastrophic A	Hazardous B	Major C	Minor D	Negligible E
Frequent	5	5A	5B	5C	5D	5E
Occasional	4	4A	4B	4C	4D	4E
Remote	3	3A	3B	3C	3D	3E
Improbable	2	2A	2B	2C	2D	2E
Extremely improbable	1	1A	1B	1C	1D	1E

Figure 2-13. Safety risk assessment matrix



Tolerability description	Assessed risk index	Suggested criteria
Intolerable region	5A, 5B, 5C, 4A, 4B, 3A	Unacceptable under the existing circumstances
Tolerable region	5D, 5E, 4C, 4D, 4E, 3B, 3C, 3D, 2A, 2B, 2C, 1A	Acceptable based on risk mitigation. It may require management decision.
Acceptable region	3E, 2D, 2E, 1B, 1C, 1D, 1E	Acceptable

Figure 2-14. Safety risk tolerability matrix



Risk index range	Description	Recommended action
5A, 5B, 5C, 4A, 4B, 3A	High risk	Cease or cut back operation promptly if necessary. Perform priority risk mitigation to ensure that additional or enhanced preventive controls are put in place to bring down the risk index to the moderate or low range.
5D, 5E, 4C, 4D, 4E, 3B, 3C, 3D, 2A, 2B, 2C, 1A	Moderate risk	Schedule performance of a safety assessment to bring down the risk index to the low range if viable.
3E, 2D, 2E, 1B, 1C, 1D, 1E	Low risk	Acceptable as is. No further risk mitigation required.

Figure 2-15 An alternate safety risk tolerability matrix

APPENDIX C

REFERENCES

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http://www.fire.tc.faa.gov/2013Conference/files/Battery_Fires_I/WebsterFullScaleTests/WebsterFullScalePres.zip

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3) “**University of Science and Technology – China (USTC) and Boeing Test Results of Li-ion and Li-metal Batteries,**” Presented to the International Aircraft Systems Fire Protection Working Group by Doug Ferguson, Boeing, October 29, 2014

https://www.fire.tc.faa.gov/pdf/systems/Oct14Meeting/FERGUSON-1014-USTCBoeing.pdf

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5) **DOT/FAA/TC-13/2 “Freighter Airplane Cargo Fire Risk, Benefit and Cost Model (Model Version 5)”,** R.G.W. Cherry & Associates Limited, April 2013

6) **“Batteries & Battery-Powered Devices, Aviation Cargo and Passenger Baggage Incidents Involving Smoke, fire, Extremen Heat or Explosion,”** FAA Office of Security and Hazardous Materials Safety, As of 2/11/2015

http://www.faa.gov/about/office_org/headquarters_offices/ash/ash_programs/hazmat/aircarrier_info/media/battery_incident_chart.pdf

7) “**Thermal-runaway experiments on consumer Li-ion batteries with metal-oxide and olivin-type cathodes”** Andrey W. Golubkov*****[a], David Fuchs[a], Julian Wagner[b], Helmar Wiltsche[c], Christoph Stangl[d], Gisela Fauler[d], Gernot Voitic[e], Alexander Thaler[a] and Viktor Hacker, Royal Society of Chemistry, First published on the web 27th November 2013

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