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DANGEROUS GOODS PANEL (DGP)
WORKING GROUP ON LITHIUM BATTERIES

SECOND MEETING

Montréal, 7 to 11 April 2014

Agenda Item 1: Mitigating risks associated with the carriage of lithium metal batteries

A SAFETY MANAGEMENT REVIEW OF THE PROVISIONS FOR THE TRANSPORTATION OF LITHIUM METAL BATTERIES ON PASSENGER AIRCRAFT

(Presented by B. Firkins)

SUMMARY

This working paper reviews the current provisions for the carriage of lithium metal batteries on passenger aircraft using Safety Management Principles espoused in ICAO *Safety Management Manual (SMM)* (Doc 9859). The paper considers some risk mitigation strategies, new preventive controls and new escalation controls, particularly in light of emerging materials and technologies. The paper also considers some of the advantages and disadvantages of a global prohibition on transporting lithium metal batteries on passenger aircraft.

Action by the DGP-WG/LB: The DGP-WG/LB is invited to consider the paper and discuss the issues that have been raised. Options include developing appropriate text for inclusion in the Technical Instructions during the working group meeting; generating effective safety promotion and education outreach strategies; producing guidance material for regulatory authorities to engage with lithium battery manufacturers, testing laboratories, shippers, forwarders and airline operators; and tasking the Secretariat to engage with the UN Committee of Experts.

1. INTRODUCTION

1.1 At the twenty-fourth meeting of the Dangerous Goods Panel (DGP/24), the panel considered the paper submitted by the Secretary that proposed a prohibition on the carriage of lithium metal batteries as cargo (DGP/24-WP/9) on all aircraft. The paper was subsequently amended to propose

a ban of lithium metal batteries as cargo on passenger aircraft only. The proposal would not extend to lithium metal batteries packed with equipment nor contained in equipment (UN 3091).

1.2 The rationale for a ban stemmed from testing by the United States' (USA) Federal Aviation Administration (FAA) which indicated that existing Halon fire suppression systems in Class C Cargo compartments were ineffective in suppressing or extinguishing lithium metal battery fires.

1.3 A multi-disciplinary working group; which included 10 members of the ICAO Dangerous Goods Panel, was held at the FAA's test facility at Atlantic City from 4 to 6 February 2014.[1]

1.4 The classification of lithium batteries is set out in the 38.3 series of tests in the UN's Manual of Tests and Criteria. There are over 20 different lithium battery chemistries, yet classification distils them into one of two forms – either UN3480 - **Lithium Ion** - and sometimes referred to as rechargeable or secondary batteries; or UN3090 **Lithium Metal** - which may be referred to as non-rechargeable or primary batteries.

UN Number	Proper Shipping Name	Generic Properties	Alternative Nomenclature
UN 3090	**Lithium Metal**	Non-Rechargeable	Primary batteries
UN 3480	**Lithium Ion**	Rechargeable	Secondary batteries

1.5 There are two further UN numbers and 4 proper shipping names associated with lithium batteries.

UN Number	Proper Shipping Name	Examples
UN 3091	**Lithium metal batteries, packed with equipment**	Small toys with disposable button cell style batteries.
	Lithium metal batteries, contained in equipment	Hearing aids, defibrillators
UN 3481	**Lithium ion batteries, packed with equipment**	New mobile phones where the battery is contained in the same packaging material, but not in the mobile phone
	Lithium ion batteries, contained in equipment	Watches, tablet computers, iPod

1.6 One State, the USA, and about 30 airlines associated with IATA, either have a total prohibition or some other form of restriction on lithium metal batteries, as cargo, on passenger aircraft; and about half that number do not apply the same form of restriction to UN 3091 (packed with, or contained in equipment). Many of the airline variations have commonalities that reflect a regional approach or strategic commercial partnerships. The remaining countries and IATA airlines outside of the USA permit the carriage of dangerous goods (including lithium metal batteries) in cargo. There are also a large number of airlines which are not directly affiliated with IATA, but will carry dangerous goods in accordance with the IATA Dangerous Goods Regulations. There are a number of non-IATA airlines, which have a policy of not carrying dangerous goods in cargo (will-not-carry-DG) and a few airlines that only offer a passenger service and who do not offer a cargo service at all.

[1] The report of the first international multidisciplinary lithium battery working meeting, held in Atlantic City, can be found at http://www.icao.int/safety/DangerousGoods/Working%20Group%20of%20the%20Whole%20on%20Lithium%20Batteries%2020/DGPWGLB.2.WP.001.1.en.pdf

1.7 As there is already a ban in place on lithium metal batteries as cargo on passenger aircraft in the United States, the United States and the FAA have nothing to gain from the safety management review and implications of extending the ban to a global scale. Accordingly, it is all the more appropriate to acknowledge and respect the work of the FAA and the expenditure of time and resources in raising a greater awareness of this as an aviation safety issue. The donation of the test airframe by Federal Express and the work and expense borne by the FAA in respect of lithium metal batteries and the hosting of the first multidisciplinary lithium battery working group is appreciated and acknowledged.

2. ATLANTIC CITY MULTI-DISCIPLINARY LITHIUM BATTERY WORKING GROUP - TEST DEMONSTRATIONS[2] AND FINDINGS:

2.1 The cells and batteries in the demonstrations were heated into thermal runaway by two methods. For some demonstrations, a small alcohol fire was used to heat the cells and initiate thermal runaway. This method simulates the temperature generated by a cell in thermal runaway as well as supplying an ignition source for the vented electrolyte. It is also a proxy for the heat that could be expected to be generated by a cargo fire which has been suppressed, but not extinguished, by the on-board Halon systems found in passenger aircraft.

2.2 For other demonstrations, an electric heater was used to raise the cell temperature to the point where thermal runaway was initiated (190 ^{o}C approximately for lithium metal batteries).

2.3 **Different batteries, similar battery size:** lithium metal, lithium ion and nickel metal hydride cells. The fire propagation and pattern, including the emission of particles, was substantially different between the lithium metal and lithium ion; a normal burning, with nil particle emission was observed for the nickel metal hydride

2.4 **Different manufacturers, same battery chemistry and type**: (lithium ion - 18650) The fire propagation and pattern was substantially different. A better quality battery construction resulted in stronger flame and particle emission but with a lower propensity to cause thermal runaway and sympathetic ignition in adjacent batteries. Whilst the test was on lithium ion and not lithium metal batteries; the objective was to demonstrate the issue with differing fire pattern properties that introduced by different manufacturing methods and materials.

2.5 **Different chemistry, same battery type and size:** (lithium manganese dioxide (Li-MnO_2) and lithium sulphur dioxide (Li-SO_2) – both are lithium metal, D size battery): The fire propagation and pattern of the two battery chemistries was substantially different. The lithium manganese dioxide had a significant fire propagation pattern, while the same battery type with a different chemistry (lithium sulphur dioxide) did not have significant fire propagation and bore similarities to the nickel metal hydride batteries when burnt.

2.6 **Varying sizes of "button" cells** (2032 and 2450). The hazardous characteristics of these button cells appeared to be proportionate to the size; with the cells disassembling; some smoke, and no fire or particle emission. The batteries were not positioned adjacent to each other, therefore no conclusions could be drawn in respect of whether packages of button cells will provide sympathetic initiation to adjacent cells.

[2] Available for viewing at http://www.fire.tc.faa.gov/temp/ICAO/ICAO_Test.zip

2.7 **Battery containing "non-flammable" electrolyte** (lithium thionyl chloride ($Li\text{-}SOCl_2$)) – which is still identified as a lithium metal battery. The battery was induced by heating into a runaway state and the results were a violent explosion and significant smoke. This was from one single D-cell battery. Lithium thionyl chloride batteries are generally for military or industrial purposes; are very stable; have a good operating temperature range and a long shelf life. The lithium content of the battery would result in a classification as a Section IA battery within the relevant packing instruction. Having witnessed the destructive intensity of one battery; heated to a point that was within the normally expected range for a suppressed and unextinguished fire; leads to an inclination that shipments of these batteries (D-size battery of Lithium Thionyl Chloride) should not be on passenger aircraft without further testing and risk mitigation.

2.8 The FAA's video[3] of the full scale testing of 4800 lithium metal cells (lithium manganese dioxide batteries), prepared for shipment in a manner consistent with the ICAO requirements, in a B727 airframe, provides compelling evidence of the need for action in respect of bulk shipments, particularly of of lithium manganese dioxide batteries, on passenger aircraft.

3. STATISTICAL DATA

3.1 Lithium metal batteries are a portable source of stored electrical energy that not only store more energy when compared to other similar sized batteries; they also have a long shelf life and better operating-temperature range. Lithium manganese dioxide batteries are the most common consumer type of lithium metal batteries in use and account for over 2/3rd of the non-rechargeable lithium metal batteries in the retail-consumer market. Other common-usage lithium-format primary batteries include lithium-iron disulphide oxide, lithium sulphur dioxide and lithium silver chromate.

3.2 Lithium metal batteries are credited with a shelf-life of 10-20 years and statistically, the 13 hours of transit flight time is a very small fraction of that battery life. One argument is that the risk of a potential failure can be considered as the probability of a lithium metal battery spontaneously going into thermal runaway and self-destructing multiplied by the percentage of flight time duration spent in air transportation as a fraction of total shelf life.

3.3 One line of thinking is that this is not a reasonable statistical comparison as there is a difference between the bumps, shocks and temperature changes experienced in transport and flight, compared to being static on a factory floor or warehouse shelf for a number of years. The alternative view is that the lithium battery has been designed and type-tested against a UN standard which does take into account the normal rigours of air transportation, including aviation transportation measures such as the low pressure environment that might be encountered during a depressurisation event or being carried at high altitude in an unpressurised cargo hold.

3.4 Some data was presented at the multi-disciplinary working group in Atlantic City; to the extent that approximately 2.5 billion lithium metal batteries were produced each year and about 10% were shipped by air. However, this only addressed cells and batteries that were shipped from Japanese manufacturers and could not be usefully extrapolated to other manufacturers or companies which were conducting subsequent shipments by air transport.

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

3.5 In reviewing the safety case for the safe transport of lithium metal batteries, one set of arguments turns to the different sources of a fire and the ability of aircraft, which meet certification standards to manage a situation involving a cargo fire whilst carrying lithium metal batteries. The fire may have originated either from the other cargo, or co-located passengers' checked-in baggage, or from an electrical or other aircraft-equipment source to cause a fire in the cargo hold.

3.6 The worst-case argument continues to pre-suppose that there is a fire on board the aircraft; that appropriate procedures have been followed; that Halon has managed to suppress the fire; however, the fire has not been fully extinguished and continues to burn, without spreading at an uncontrolled rate to further threaten the aircraft; and the heat from the suppressed fire is raising the temperature of the lithium metal batteries in the hold to a point where they will enter thermal runaway, vent, eject flammable electrolyte and the auto-ignition of adjacent packaging material which in turn will ignite the flammable electrolyte.

3.7 Cargo fires, particularly on passenger aircraft, are extremely rare occurrences. There are some statistics on aircraft smoke, fume and fire events; with the sequence of likelihood for the source of the event being cabin, followed by toilet, cockpit, cargo, then the galley[4]. Further useful statistical data on the frequency of cargo fire occurrences on passenger aircraft has been sought. Data has been extracted where there are indications of smoke or fire events, related to the cargo hold, on air transport category aircraft, which have been reported to Australian authorities.

3.8 There were 15 reported events in the years from 1 January 1999 through to 2014. False alarms by faulty detectors were identified in six of the cases, a further five events originated from aircraft components and there was insufficient detail in the remaining four to determine whether that had been an actual cargo fire. As an example, the report has words to the effect of "The aircraft was returned for a landing without incident." Rather than assume that if there had been an actual cargo fire, then that fact would have been reported; the absence of any positive statement to the effect of a false alarm or indication of an aircraft malfunction, the conclusion has been left as a worst case situation. None of the fifteen events presented any indication that they involved a suppressed, but unextinguished, fire. Nevertheless, it is best to take the worst case statistical positioning; which would be one smoke/fire indication event, per year, related to Australian Air Transport category operations.

3.9 The Bureau of Infrastructure, Transport and Regional Economics advises that in 2013, there were almost 800,000 Regular Public Transport flights involving Australian registered aircraft or foreign aircraft arriving into or leaving Australia.

3.10 The current rough statistic would therefore be that an average of one smoke/fire event per year, across 800,000 flights, would give rise to the probability of 1 in 800,000 or 1.25×10^{-6}.

3.11 The alternative source of fire is posed as originating from one defective or damaged battery within a package of batteries, causing sympathetic heating of adjacent batteries and the triggering of an uncontrollable fire.

3.12 Spontaneous self-ignition of lithium metal batteries, with long shelf-storage or operational usage life are also very rare occurrences, particularly moreso since the introduction of the UN 38.3 tests for lithium batteries.

[4] Royal Aeronautical Society and Guild of Air Pilots and Air Navigators – "Smoke Fire and Fumes in Transport Aircraft", February 2007 - http://aerosociety.com/Assets/Docs/Publications/SpecialistPapers/SAFITA_Paper.pdf

3.13 Usually when lithium metal batteries fail – it is a quality control issue where they do not produce a charge (i.e., they fail safe). Most anecdotal reports on when primary, non-rechargeable, lithium metal batteries fail unintentionally, and produce smoke, heat or promote combustion, it is usually due to misuse, abuse or short-circuiting within the circuitry of associated equipment. There has been a recent fire involving an ELT on an aircraft at Heathrow, London, UK which is being investigated by the AAIB; however, a report had not been produced at the time of preparing this paper. Nevertheless, the type and configuration of the lithium metal batteries and particularly how they have been wired together may help to lead to a statistical number for the reliability of the battery type and its configuration in an ELT, albeit UN3091 (lithium metal batteries contained in equipment) and aircraft componentry reliability.

3.14 One operator has provided some basic details of lithium metal battery shipments over a 12 month period. The data indicates that there were 325 sectors carrying a UN3090 consignment on passenger aircraft on a network of over 200,000 flights. The pitfall with statistics is then marrying sectors with flights. Nevertheless equating "sectors" with "flights" will, for the purposes of this paper, provide a higher probability of carrying lithium metal batteries on an aircraft. Therefore, at best, the probability of there being lithium metal batteries in the cargo hold of a passenger aircraft operated by that operator was therefore of the order of $1.5x10^{-3}$. Simplistically, if that number is multiplied by the probability for an aircraft to experience a cargo hold fire - which will be suppressed, but not extinguished; then we can arrive at the likelihood of a bulk consignment of lithium metal batteries causing the consequential catastrophic loss of an aircraft. Unfortunately for statistical purposes, data on suppressed but unextinguished fires are unique events.

3.15 Continuing with worst case considerations, the probability of an aircraft experiencing an indicated smoke/fire event in the cargo hold of a passenger aircraft (including false alarms and smoke/fires from aircraft equipment and systems as $1.25x10^{-6}$), whilst that aircraft is carrying declared shipments of lithium metal batteries ($1.5x10^{-3}$), is of the order of $1.9x10^{-9}$.

3.16 It should also be noted 204 of the 325 sectors involved a total load of lithium metal batteries of 10 kg or less; and therefore probably not even close to being of a "bulk" quantity to endanger the aircraft in the event of a cargo fire.

3.17 In planning for aircraft single point failures, the goal is to reduce the likelihood to below $1x10^{-9}$. Better still, it is incumbent upon the entire interconnected aviation transportation system to bring it down to as low as reasonably achievable for all measures where the benefits continue to outweigh the costs.

3.18 At the multi-discipinary lithium battery working group in Atlantic City, the battery industry representatives also provided a short presentation on an analysis of the incidents associated with lithium metal batteries identified to the FAA, which showed no incidents since 2011. Others will suggest an alternative argument and postulate that lithium batteries may have been one of the factors in the loss of two Boeing 747 freighters. As this review paper is focused on passenger aircraft, any further discussion regarding the inclusion of these two events in the statistical population may have to be deferred until the ICAO Dangerous Goods Panel meets in November 2014 to review the carriage of lithium metal batteries on cargo aircraft.

4. SAFETY MANAGEMENT

4.1 The ICAO Safety Management Manual[5] refers to the concept of safety

> *"2.1.1 Within the context of aviation, safety is —the state in which the possibility of harm to persons or of property damage is reduced to, and maintained at or below, an acceptable level through a continuing process of hazard identification and safety risk management.*
>
> *2.1.2 While the elimination of aircraft accidents and/or serious incidents remains the ultimate goal, it is recognized that the aviation system cannot be completely free of hazards and associated risks. Human activities or human-built systems cannot be guaranteed to be absolutely free from operational errors and their consequences. Therefore, safety is a dynamic characteristic of the aviation system, whereby safety risks must be continuously mitigated. It is important to note that the acceptability of safety performance is often influenced by domestic and international norms and culture. As long as safety risks are kept under an appropriate level of control, a system as open and dynamic as aviation can still be managed to maintain the appropriate balance between production and protection."*

4.2 Whilst this paper will take a brief look at the hazard risk presented by self-heating and combusting lithium metal batteries, the main risk to aviation will be presented through a fire in the cargo hold which impacts upon a consignment of lithium metal batteries which were not the source of the fire.

4.3 The ICAO Safety Management Manual contains examples on Hazard Identification and Risk Mitigation (HIRM) process. The assumptions in working through the HIRM process for Lithium Metal Batteries in the cargo hold, is that there is a bulk consignment of those batteries in the cargo hold and the unsafe event is a suppressed, but unextinguished, fire.

4.4 **Safety Risk Severity:** Based on the testing performed by the FAA, the outcome of any analysis of a fire taking hold on a large consignment of lithium metal batteries will produce a Safety Risk Severity (SRS) of "catastrophic".

4.5 The **Safety Risk Probability** (SRP), depending on individual viewpoints, is either "Possible/Remote (i.e. might occur at some time)" or "Unlikely/Improbable (could occur at some time)". Whilst some may view the SRP as being "Exceptional (may only occur in exceptional circumstances)", the crew and passengers on the aircraft and those attending the subsequent coronial enquiry are likely to conclude that the causal linkage between a suppressed, unextinguished cargo fire and the subsequent trigger of a lithium metal battery fire is not so exceptional and that the outcome was more than likely (will probably occur at some time).

4.6 During its discussion of lithium batteries in the DGP/24 report, the ICAO Air Navigation Commission (ANC) had emphasized the importance of obtaining quantitative data in support of an SMS approach and that in the absence of quantitative data, worst case scenarios must be assumed for the likelihood and severity of an occurrence/exposure[6].

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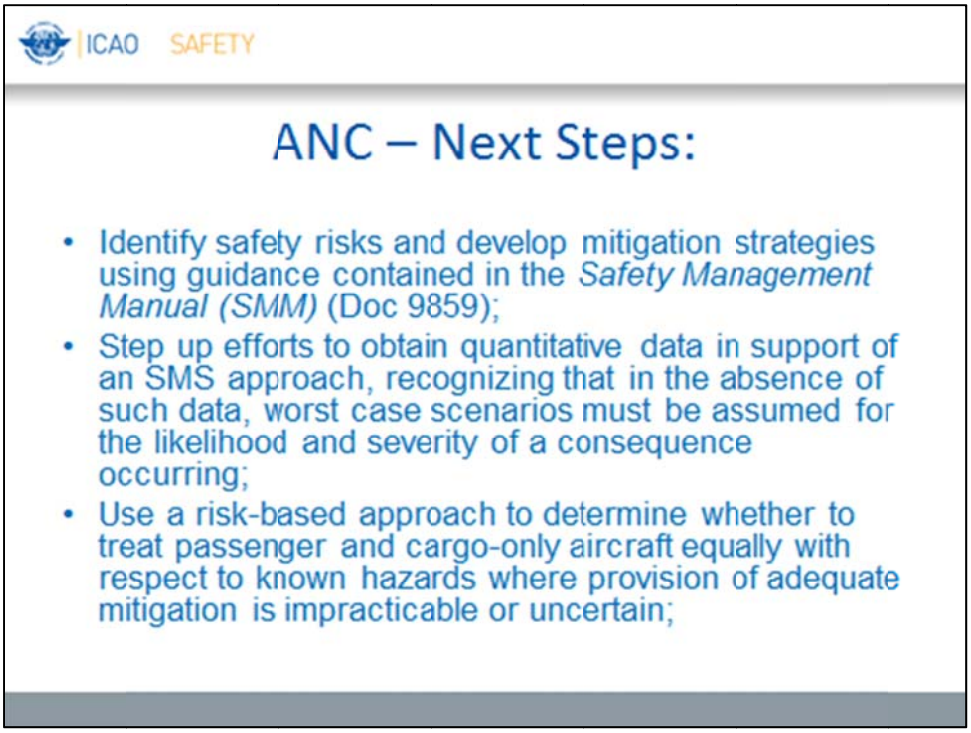
[5] ICAO DOC 9859 AN/474 - ISBN 978-92-9249-214-4

[6] Report From ICAO's International Multidisciplinary Lithium Battery Transport Coordination Meeting - Atlantic City, 4 To 6 February 2014 – Appendix D, Slide 20.



4.7 Irrespective of whether the SRP is exceptional or probable, the resulting **Safety Risk Tolerability** (SRT) will be either High or Moderate Risk and in either case it is prudent to re-evaluate the current Preventive Controls, the Escalation Factors and the Escalation Controls; and then to clearly and cogently question whether there are new preventive controls that can be introduced; whether there are newly created or existing Escalation Factors that may gain more prominence and whether new additional Escalation Controls can be identified and implemented.

4.8 The work in reviewing the various Preventive and Escalation Controls and Factors and developing mitigation strategies is consistent with the directions of the Air Navigation Commission.

5. EXISTING PREVENTIVE CONTROLS

5.1 There are a number of preventive controls already in existence including classification, testing, regulatory oversight, security measures, ICAO's Technical Instructions and procedures for shippers and operators.

5.2 **Classification.** Lithium batteries are classified and tested in accordance with subsection 38.3 of the United Nations Economic and Social Council's Committee of Experts on the Transport of Dangerous Goods and on the Globally Harmonised System of Classification and Labelling of Chemicals' (UN COE) Recommendations on the Transportation of Dangerous Goods – Manual of Tests and Criteria (ST/SG/AC.10/11/Rev.5).

5.3 The current 38.3 Series of tests, set by the UN COE for lithium batteries include:

- Altitude Simulation – to simulate transport under low-pressure conditions – 11.6kPa or less

- Thermal – to assess cell and battery seal integrity and internal electrical connections; the test is conducted using rapid and extreme temperature changes between -40 and +75 ^{o}C
- Vibration – to simulate vibration during transport – 7-200Hz.
- Shock – to simulate possible impacts during transport
- External Short Circuit – to simulate external short circuit – battery temperature must not exceed 170^{o}C when short-circuited at 55^{o}C.
- Impact – to simulate a direct impact onto a battery – large object is dropped onto it and the battery is not to exceed 170^{o}C.
- Overcharge – (relevant only for rechargeable batteries)
- Forced Discharge – a test to evaluate the ability of the battery to withstand a forced discharge – no disassembly or fire within 7 days of the test.

5.4 The requirements for successfully passing each test varies, and generally include no rupture, venting, disassembly or fire. The tests have been constructed around the conditions to be expected during normal use and transport with a degree of tolerance for abnormal circumstances.

5.5 **Regulatory oversight.** The regime and framework that regulatory authorities have in place for the subsequent manufacturing of those batteries and testing by Government or quasi-Government appointed/accredited agencies to ensure that the lithium batteries meet the set UN Standards are another preventive control. A subset of this preventive control is the relevant regulatory authority surveillance, compliance and audit functions and State-based enforcement and prosecution.

5.6 **ICAO packaging and shipping requirements.** At the level of the Shipper, there are packaging, marking, labelling requirements which are set down in the ICAO Technical Instructions. Furthermore employees are required to be trained in how to package the dangerous goods.

5.7 **Security.** The security environment around the cargo supply chain is strengthening with a "know-your-customer" ethos. Dangerous goods and security awareness training of employees of freight forwarders is becoming stronger; particularly in respect of inspecting consignments of dangerous goods with additional vigilance towards careful handling and inspection for damage and contamination. Similarly Freight Forwarder awareness training of the types of things that may contain hidden dangerous goods is also on the rise.

5.8 **Operator's procedures.** The Operator is the last entity before the goods are accepted for carriage and once again, packages of dangerous goods are inspected. This inspection takes place as part of the process for formal acceptance against a checklist, by a trained employee. The dangerous goods will be usually be stored in a specific area, pending allocation to a particular flight. When allocated onto that flight, the dangerous goods will again be inspected by a trained employee for evidence of damage or leakage, prior to stowing the goods on the aircraft and ensuring that they are restrained, not adjacent to any incompatible dangerous goods and not able to be damaged or broken by other items in the cargo compartment. The captain is then notified of the dangerous goods one board and a drill code is allocated which indicates the nature of the risk to the aircraft, passengers and personnel dealing with the package and appropriate considerations that ought to be taken into account when managing any emergency involving those goods.

6. EXISTING ESCALATION FACTORS

6.1 **Packaging and aircraft certification.** The aircraft manufacturers' certification assumptions for cargo fire protection do not specifically address the risks posed by the carriage of dangerous goods. The process for carrying dangerous goods is not within the scope or control of aircraft manufacturers. It is preferred that there be an assumption that normal restrictions placed on dangerous goods provide an acceptable level of safety and will not have an adverse impact upon the survivability of the aircraft.

6.2 The general approach employed by DG Panel members was that if an article or substance was so dangerous that it could self-ignite, self-explode, or be lethal to passengers or crew (i.e. toxic gas) then it was too dangerous to be carried and was classified as either "forbidden unless exempted" or Forbidden under any circumstance". The process for determining restrictions on dangerous goods, including lithium metal batteries, tended to be evaluated on a package level and not evaluated if the aircraft fire protection features were capable of controlling fires involving dangerous goods.

6.3 There are two existing performance standards for an article of dangerous goods and the packaging – these are explosives in Division 1.4S and Chemical Oxygen Generators in accordance with Packing Instruction 565. In both cases, even if the item somehow manages to activate itself, any hazardous effects will be substantially contained within the package. Setting a packaging standard for lithium metal batteries could be an effective preventive/escalation control when considering dangerous goods and aircraft certification issues.

6.4 **Bulk quantities.** Part of the issue is trying to identify at what point a shipment becomes a "bulk" shipment. It is not just a number of batteries but also the battery type (i.e. AA, AA, 18650, C, D, etc); the battery chemistry (i.e. Li-MnO_2 vs Li-SO_2) and the manufacturer/quality of battery construction.

6.5 **Counterfeit** or non-UN specification batteries will always continue to be a problem for as long as there continues to be manufacturers who are prepared to take short cuts and a willing market to purchase batteries not tested to UN 38.3 requirements.

6.6 **Difficulty in obtaining tests reports.** Some battery manufacturers regard reports of evidence that batteries meet the UN 38.3 tests as being material that is of commercial confidence. Some reports are available on the Internet; but others consider that there is no compulsion to produce reports. Then there is the problem where the reports are written in a foreign language.

6.7 **Outsourced manufacture.** Often the "Manufacturer" of a commodity outsources much of the manufacturing process. They rely on keeping scientific research and development and monitoring their intellectual property and quality assurance in-house, but outsource the actual act of manufacturing.

6.8 Producers of brand name products with expensive research and development and employing high level quality assurance want to maintain the commercial advantage that comes with charging a premium price for a premium product. Whilst they might use the same batteries from the same manufacturer and sell them with three different brandings (a "premium marketing" brand, a standard brand and a "low-cost, mass-market brand", yet all being produced by the same factory from the same raw materials, by the same equipment and built to the same standard); they do not want their particular products and research & development efforts to be white-labelled (sold with whatever brand label that a different retailer asks to be placed on it), without their knowledge. It erodes the brand-name products' market share and profit/commercial return. Furthermore, some battery manufacturers may have several

factories. This introduces the difficulty in ensuring that the consistency of batteries across the factories are of the same standard as the batch which was tested to and passed the UN 38.3 series test.

6.9 **Packaging**. Where Li-MnO_2 batteries have entered thermal runaway; then existing ICAO packing instructions will not impede sympathetic thermal runaway in adjacent batteries and an uncontrollable fire. Where deficient packaging can be an escalation factor is where the battery terminals are not adequately protected to take into account moisture which could initiate a short across several batteries thus potentially triggering a thermal runaway.

6.10 **Hidden lithium metal batteries.** This is the situation where the batteries are not declared as being lithium metal batteries and are not declared at all, possibly consigned as dry cell batteries or another innocuous description such as "spare parts". In these cases, the efforts are in the making of deliberately false declarations.

6.11 **Lack of resources.** Regulatory authorities may not have the legislative grounds, technical resources to undertake surveillance and compliance program oversight of lithium metal battery manufacturers, shippers and testing laboratories. In some cases, there may even be industry centric or political opposition to undertaking that safety oversight function.

7. EXISTING ESCALATION CONTROLS

7.1 Currently, aviation security screening X-ray equipment does not differentiate between lithium metal and lithium ion batteries. The only in-situ escalation control to hidden and misdeclared lithium metal batteries lies in the actual opening of packages by security screening agencies.

7.2 There are various reactive mechanisms which facilitate examination of preventive controls and escalation controls. These include; the reporting of occurrences where regulations are being flouted or instances where there has been a dangerous goods accident, incident or other occurrence. Reporting; investigation by relevant regulatory authorities; enforcement and prosecution as a general deterrence to others; and oversight of those regulatory authorities by internal Risk and Quality Assurance teams, Government Agency Audit Offices and ICAO-level Universal Safety Oversight and Audit Programs.

8. UNSAFE EVENT

8.1 The relevant unsafe event is a fire in cargo bay which also contains a bulk shipment(s) of lithium metal batteries.

8.2 At this point it is worth profiling the events that are likely to bring about the unsafe event. It will have started either as:

- a fire - which has started in other cargo or some part of the aircraft's systems which has shorted out and is in the vicinity of the cargo bay where a bulk load of lithium metal (i.e. $LiMnO_2$ or $LiSOCl_2$) is being externally heated towards thermal runaway; or,

- a consignment of general cargo which contains hidden lithium metal batteries; which has not been declared as containing either lithium metal or lithium ion batteries; which have been roughly handled, not carefully inspected; may not have been tested and confirmed as meeting UN 38.3

specifications; or have not had the terminals adequately protected and are able to short circuit each other and with the result that one or more batteries go into thermal runaway.

9. EXISTING RECOVERY MEASURES

9.1 In looking at recovery measures the first assumption that the unsafe event has happened. As this paper is dealing with shipments of lithium metal batteries in cargo on aircraft engaged in passenger transport in a Class C cargo compartment.

9.2 The cargo compartment will be equipped with on board smoke/fire detection systems which alert the pilot/flight engineer at their station.

9.3 There will be an approved built-in fire-extinguishing system controllable from the pilot/flight engineer station. Often this will be a Halon fire suppression system. Similarly, there are effective means to control ventilation and draughts within the cargo compartment to keep the extinguishing agent within the compartment and thus, once the fire has been suppressed; to prevent oxygenated air from re-entering the cargo compartment and allowing an unextinguished fire to flare up.

9.4 The flight crew will have been trained and are provide with Emergency Procedures Training.

9.5 There are Airfield Rescue and Fire-Fighting Services (ARFFS) maintained at licenced airfields which will be suitable for the category of aircraft rated to operate to that aerodrome.

10. EXISTING ESCALATION FACTORS TO RECOVERY MEASURES

10.1 **Human factors.** Indications are that crews are taking longer to respond to cargo fires than was presupposed by Aircraft Certification Standards. Research is currently indicating that the time between the start of a fire, the detection of that fire, and the commencement of suppressing that fire by the crew, is twice as long as that which had been thought likely and planned into aircraft design standards. This period of delay has tended to reinforce the desire for further restrictions on lithium metal batteries. Safety education and communication to operators is clearly another mitigating issue which should be explored as the issue is broader than lithium batteries and relates to fires generally. Contrary to the safety promotion communication of “follow your training and act” is the high probability that the fire/smoke indication is a false alarm.

10.2 **Volatility of batteries as a function of temperature**. The warmer a lithium battery is, the more volatile it is likely to be. Like a car left parked in direct sunlight, batteries in a Unit Load Device (ULD), which has been stored in a hot environment and in direct sunlight, may heat up to a temperature that is well above the external dry-bulb temperature. It would be appropriate to see if ULDs, containing general cargo and positioned in direct sunlight in hot, arid regions of the world, reach or exceed 75 ^{o}C.

10.3 **The batteries themselves**. Battery chemistry, size and the quality of the componentry and manufacture will all play a role in the escalation factors that affect the recovery mechanisms. The only generic type of lithium metal batteries which are not likely to contribute to a fire are the coin cells, which tend to disassemble when heated.

10.4 **"Bulk" shipments.** One issue with bulk shipments is trying to quantify at what point they are of sufficient bulk to prevent the effective work of the fire suppression systems for the complete duration of the post-emergency event flight, until a safe landing and evacuation.

10.5 **Fire or Smoke Detection.** Current aircraft certification standards have, as a minimum, that there be either fire detection or smoke detection; but do not require both detection methods. Some operators and aircraft may have both detection methods and may have more than the minimum number of detectors as well. However, where an aircraft is only equipped with one detector and only one method of detection; then the flight crew's response will not be as timely or effective as one where the aircraft is fitted with multiple detectors and differing detection means, especially when there are independent communication means from those detectors to the flight crew station, reducing the likelihood of a delay whilst the possibility of a false alarm is evaluated and ruled out.

10.6 In the event that the fire/smoke detection/communication/suppression systems are unserviceable; then many Aircraft Operating Handbooks and mandated Minimum Equipment Lists will stipulate that cargo cannot be carried in the cargo compartment.

10.7 **Re-invigorating a suppressed fire**. This scenario presumes that a fire has started (either from general cargo or an external aircraft short but spread into the cargo bay and penetrated existing firewalling); the crew have followed procedures; activated the fire suppression systems, quelling the fire; but that when on descent – oxygenated air may re-enter the cargo compartment and cause a suppressed fire to flare up. The procedure of maintaining altitude as long as possible in order to minimise the flow of fresh oxygen into the fire will not buy much more time for the flight crew and aircraft. Usually the amount of oxygen carried and available as emergency oxygen for passengers is of the order of 15 minutes; long enough short delay before initiating a descent to an altitude where there is sufficient oxygen for passengers to breathe normally. The flight procedures of maintaining altitude for as long as possible and then committing to an emergency descent at the latest possible time is really only applicable for cargo aircraft flight crew and not one that is available for aircraft carrying passengers.

10.8 **Extended Time Diversion Operations** (ETDO). Extended Time Diversion Operations are where the required flight time of an operational diversion to a suitable aerodrome for a landing may be extended beyond the normal mandated 60 minutes. Aircraft may be certificated to operate with longer ETDO parameters and are applicable to both passenger and cargo aircraft. ETDO operations are usually encountered on long over-water flights. It has been suggested that fire suppression abilities are one critical system contained within FAA and EASA requirements. It has been implied that when transporting consignments of lithium metal batteries, an operator should have to be able to demonstrate an ability to extinguish a fire involving those batteries. Naturally, deliberation of this Escalation Factor this can only be limited to shipments of declared lithium metal batteries. It holds no value when considering the scenario of lithium metal batteries that have been unlawfully declared as being lithium-ion batteries, or which are hidden in general cargo.

10.9 **Suitable landing areas.** From the tests by the FAA; where there is a lithium metal battery fire (or rather, a $LiMnO_2$ battery fire or a suppressed, unextinguished cargo or other fire which threatens an onboard shipment of Li-$SOCl_2$ batteries) then crews ought to be descending and landing as soon as possible. Within Continental USA, Europe and Asia, there are numerous airfields available from altitude, but there are far fewer options for South America, Australia or trans-Pacific/Atlantic over-water flights.

10.10 **Other dangerous goods**. In considering the potential for other goods which may be co-stowed and which may have an adverse impact in the event of a fire; it is necessary to reflect that **lithium**

batteries (lithium metal and lithium ion) are within Class 9 (Miscellaneous dangerous goods) and may be co-stowed with dangerous goods of all other classes/divisions of dangerous goods. It may well be that the co-stowed dangerous goods (i.e. oxidisers, organic peroxide, flammable solid, etc) could be caught up in an unrelated cargo fire and generate sufficient heat such that the adjacent shipments of lithium metal batteries are triggered into a thermal runaway event. In that case, the co-stowed dangerous goods have been the genesis of turning a survivable outcome into an uncontrollable fire and catastrophic loss.

11. EXISTING ESCALATION CONTROLS TO RECOVERY MEASURES

11.1 It is at this point where the aspect of systems and a single point of failure sits.

12. MOVING FORWARD AND THE MANDATE FROM THE AIR NAVIGATION COMMISSION

12.1 Despite currently sitting (very roughly) at $2x10^{-9}$ of an alerted smoke/fire event in the hold whilst carrying a declared shipment of lithium metal batteries; it is necessary move beyond just debating between whether this is an exceedingly unlikely event or if it could in fact be another "Black Swan[7]" event. Similarly, the work in the paper thus far in documenting the existing preventive and escalation controls and measures; and attempting to define most of the relevant escalation factors is only part of the job in improving aviation safety.

12.2 So far, this review paper has looked at some statistical data; however, it is data that is for one State and in respect of one Operator. That State is not a manufacturer or major distribution point for lithium metal batteries; it is an intermediate transit point en-route to South America or Africa as well as a significant end-user State. It would not be a useful proxy for other States nor for all operators. For example a low cost operator involved in flying only passengers and their baggage will not have any cargo at all. An operator involved in passenger transportation to/from/within the US and therefore subject to US State Variations 2 or 13 will not have any declared shipments of lithium metal batteries and a maximum of 25 kg of dangerous goods within the cargo hold. Statistically there will be a different probability for operators with aircraft departing from those States where lithium metal batteries are manufactured; and for States where there are less stringent quality assurance, safety and regulatory oversight.

12.3 Likewise looking for accident and incident data involving lithium metal batteries on passenger aircraft from the FAA is not a useful exercise either. The US is the only country with a prohibition on lithium metal batteries on passenger aircraft. The US also has a widespread cargo aircraft operation and a well-functioning, integrated surface transportation infrastructure.

12.4 **Moving Forward**. It is necessary to build upon the work of the work of the FAA's Fire Test Centre and the First Aviation Multi-Disciplinary Lithium Battery Working Group's efforts in Atlantic City. This includes looking at where new preventive and escalation controls can be introduced and to identify risk mitigation strategies and measures that are cost effective in implementation.

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[7] Black Swan event – an event which
(1) is an outlier, as it lies outside the realm of regular expectations, because nothing in the past can convincingly point to its possibility;
(2) carries an extreme 'impact'; and,
(3) in spite of its outlier status, is rationalised in hindsight, as an event that should have been explainable and predictable.
The term stems from a long-held belief that all Swans in the World were white; until the discovery of the Black Swan of Western Australia by Dutchman Willem de Vlamingh.

12.5 During its deliberations of the DGP/24 report on lithium batteries, the ANC emphasised that the dangerous goods panel was to "identify safety risks and develop mitigation strategies"

13. POTENTIAL NEW PREVENTIVE AND ESCALATION CONTROLS

13.1 **The case to involve the UN's Committee of Experts on the Transport of Dangerous Goods**. An option is to request the creation and requirement for additional tests, at the UN level, which relates to a lithium battery's propensity for an abnormal fire pattern, such as emitting projections or fragments, or producing an excessive audible report, smoke, fumes, dust or excessive surface temperature rise.

13.2 Similarly it may assist the UN if ICAO were to specify for the tests what would be the reasonable maximum external temperature (for a battery) envisaged and met by current aircraft certification standards. This will enable the UN and ICAO dangerous goods panel to set objective standards for packaging and substance/articles that will be automatically applicable for current substances (chemicals such as magnesium, potassium etc.) and for the future development of articles which may have explosive/dangerous properties.

13.3 The risk and hazards presented by lithium metal batteries involved in a fire, and which had been presented to the group was also considered by a number of those in the group as being something which would be worthy of referral to the UN COE and the International Maritime Organization (IMO) so that appropriate tests and guidance and contributions could be provided by road, rail and maritime transport modes.

13.4 There are currently over twenty different chemistries for lithium batteries, with the classification ultimately falling to only one of two entries, either lithium metal batteries or lithium ion batteries. The battery involved in test demonstration 5, - lithium thionyl chloride ($Li\text{-}SOCl_2$) is considered under the lithium metal battery classification, as the battery is a primary (non-rechargeable) battery.

13.5 Lithium sulphur dioxide ($Li\text{-}SO_2$) was not substantially different to other batteries in its burning characteristics (albeit the FAA did not get into different battery sizes of $Li\text{-}SO_2$). An option is for the UN to create a separate classification for $LiSO_2$. This option would result in new chemistries being automatically entered into the lithium metal battery category, and when they are proven to be suitably safe – for a separate UN number and proper shipping name to be created and allocated.

13.6 An alternative option is to create entry for $LiMnO_2$ and manage the risks presented by this popularly produced battery chemistry. A third option is to develop a test for "dry cell batteries – not otherwise restricted".

13.7 Whether there should be additional, or different, lithium battery classifications is a subject which ought to be discussed further and whether there is merit in having the subject matter referred to the UN Committee of Experts on the Transport of Dangerous Goods.

13.8 **Emerging packaging options.** It is open for ICAO to require a similar performance standard for lithium metal batteries in their packaging. Some packaging manufacturers are already in an advanced development stage. However the volumetric space/weight cost currently precludes regular bulk commercial usage and would be marketed for specific purpose usage, such as transportation for testing in

accordance with Special Provision A88 or analysis testing for faulty batteries under an Exemption issued by relevant States.

13.9 Another innovation being pursued is the addition of liquid gel pouches packed above the batteries. Initial testing is that when a lithium metal battery is triggered into thermal runaway, the gel pouch ruptures and the gel cools the battery below an auto-ignition point. The gel pouches are estimated to add 20% to the weight/cost of the batteries. Naturally further testing may be required to determine how a package of such batteries and gel pouches behaves when the entire package is subjected to external heat and or fire.

13.10 **Developing a performance standard for lithium metal battery packages.** It has been suggested that the ICAO should consider the development of a performance standard which could be used for both batteries and batteries within packaging. The risk posed by the batteries themselves would dictate the level of mitigation needed.

13.11 Where a battery, or package of batteries, pose no additional risks in the event of a fire, then they could be shipped in any manner or form. A separate argument is that because a bulk shipment of lithium metal batteries could be disastrous to road-trucks, rail carriages and sea-going vessels, this test should be at the UN level as the outcome will be relevant and germane to all modes of transport. Irrespective of which organisation sets the test standard, the battery itself, because it is unlikely to start a fire and does not adversely contribute to a fire, would not be dangerous any more. In essence, it would be displaying similar fire propagation properties to that of dry cell batteries.

13.12 If the battery, or group of batteries posed risks, such as sympathetic reactions, emission of molten, flaming or incandescent material or projectiles; then a battery+packaging standard could be set by ICAO/UN and have to be met before the item could be consigned for carriage on air transport.

13.13 Where there was no ability for a lithium battery+packaging combination to meet self-containment criteria; then operators could still offer a service to carry them, providing there was the ability of the operator to manage and control a fire that started in an area near the batteries. One example is new Unit Load Devices which contain their own fire detection and suppression systems and an operator might further mitigate the risks by insisting that no other cargo co be co-loaded in the same ULD at the bulk shipment of lithium metal batteries.

13.14 Developing such standards would then automatically take into account new battery types or chemistries developed in the future.

13.15 **Aviation Security**. The UK CAA has commenced work on researching security scanning technology and whether lithium metal batteries could be easily detected though simple modification of existing scanning equipment. If successful, then trials have been proposed at two airports. This is a potentially significant and far-reaching development in preventing hidden and mis-declared shipments of lithium metal batteries.

13.16 If the adjustment or refinement of algorithms within the security screening equipment is not possible; then shippers may continue to deliberately ship lithium metal batteries and lithium ion batteries with near impunity. The risk to aviation safety will not have been eliminated or reduced; it will have been made less safe.

13.17 **Safety Education and Promotion.** It is important that effective safety education and promotion campaigns are developed by regulatory authorities and targeted towards relevant industries and

entities. For example, this would include battery manufacturers on conducting UN tests and making of those test reports available on the internet as a service to their end-user customers who want to cary those batteries on aircraft and need to satisfy the airline operators that the batteries have in fact met and passed the UN 38.3 tests.

13.18 The message to shippers should be of the risks associated with sending lithium batteries (metal and ion) as not restricted items and the safety controls that are effectively circumvented and the international co-operation of aviation regulatory authorities to prosecute etc.

1.1 Freight forwarders could be reminded that they are dealing with the open-system of the cargo-supply chain and continually evolving security supply chain requirements of "knowing your customer"; as well as encouraging freight forwarders to also ensure supply chain continuity, cargo integrity, safety, security and customer knowledge with their up-stream and down-stream shippers, forwarders and cargo consolidators.

13.19 Operators should be encouraged to conduct their own safety assessments, and to explore additional means to cost effectively mitigate some of the risks presented by batteries; without rushing to unilateral prohibition and increasing the likelihood of those batteries becoming illegal and hidden or misdeclared shipments.

13.20 There is also a path for States which are the consumers and end-users of lithium metal batteries. The issue is not just within the shippers and States which are unable, unwilling or unresourced to enforce the manufacture, production and transportation of batteries to UN and ICAO requirements; there is an implicit obligation upon States who are net receivers of these products and services to examine the role that end consumers play in creating the demand. States which are of final destination need to look at it from the perspective of their role in the demand-side economic pull. There is a safety promotional message to be made to citizens regarding the quality, reliability and durability of original equipment manufactured products.

13.21 **Emerging new materials design in ULDs**. One operator has invested significantly in new ULD materials which will contain a smothered fire for an extended duration. This has the significant effect of reducing the likelihood that a fire involved in general cargo in one of those ULDs will cause a shipment of Lithium Metal Batteries in an adjacent ULD from entering thermal runaway. Similarly, it also promises to prevent a fire from an external source, such as a defective and burning aircraft system/component, from creating a large enough rise in temperature to penetrate a ULD containing a declared shipment of lithium metal batteries and triggering them to enter thermal runaway.

13.22 **Emerging self-contained fire detection and suppression devices**. One operator has been researching and investing in self-contained fire-detection and suppression devices. These small devices are contained within one transportable module and attached to the ceiling of a ULD. When the device is activated by heat, it automatically floods the ULD with a suppression agent. Again this will reduce the potential for a fire in general cargo from rising to the point where it triggers a sympathetic fire and thermal runaway reaction

in an adjacent ULD containing lithium metal batteries.

13.23 **Regulatory Authorities**: **Effective regulation, oversight and enforcement.** There needs to be an effective regime of oversight of testing laboratories; the availability on the internet and traceability and identification of battery products and associated test reports verifying that lithium metal batteries have been tested to and meet UN 38.3 tests. Similarly enhancement measures which strengthen the ability of regulatory authorities in assessing and confirming the effectiveness of battery manufacturer's quality assurance programs will be an effective safety development; especially when coupled with an enforcement program.

13.24 One issue for regulatory authorities are that technical and numerical resources are required, yet they are operating with limited budgets or lack the capacity to target all manufacturers and testing laboratories. This is an opportunity for ICAO States to learn from the lessons gained by their State aviation regulatory authorities in reviewing and approving designated postal operators.

13.25 This included a targeted program of finding out the size of the industry they are really dealing with; conducting exercises to establish degree of compliance and areas of significant non-compliance; communication of those results so that all segments of the industry within that State can learn from the lessons of others and accept that everyone is being treated equally; followed by a program of follow-up compliance checks; and a further grace period to achieve adequate compliance. Afterwards, the the enforcement program can commence with the aviation regulatory authority focussing its limited resources on those manufacturers, shippers and operators who deliberately choose not to comply with UN, ICAO and State-based requirements.

13.26 **Operators.** There are some additional measures that Operators can start looking towards. Some examples are: not accepting bulk shipments from freight forwarders or shippers; not accepting overpacks containing Section II batteries from unknown shippers; requiring Section 1B batteries to be accompanied by a shipper's declaration (IATA has already mandated this to take effect from 1 April 2014 and the experience in Australia is that there has been no resistance, complaints or push-back from training organisations and operators); not stowing lithium batteries (lithium metal or lithium ion) with other dangerous goods; not storing lithium batteries in direct sunlight or hot environments.

13.27 **ICAO dangerous goods panel**. In support of the mitigation measures above, it is open to the ICAO dangerous goods panel to amend table 7-1 "Segregation between packages" and corresponding text at 7;2.2.1. to include lithium metal batteries (and possibly lithium ion batteries) as being items which should not be co-stowed with goods of hazard divisions 2.1, 3, 4.1, 4.2, 5.1 and 5.2.

13.28 Similarly, in an effort to convey that lithium metal batteries (and possibly lithium ion batteries too) should not be stored in hot, confined areas, the dangerous goods panel could require that individual packages and overpacks of lithium metal batteries also be labelled with the relevant "Figure 5-29 – Keep away from heat" label.

13.29 There are many other initiatives which the ICAO DG Panel can consider, either from the perspective of encouraging a voluntary and measured lifting of aviation safety through targeted outreach and education programs and guidance material to other State Aviation Regulatory Authorities via the Supplement to the TIs; or by making mandatory improvements which will be of a universal nature; by amending the Technical Instructions..

14. ADDITIONAL POTENTIAL NEW ESCALATION CONTROLS

14.1 **Aircraft certification and the carriage of lithium metal batteries - Passenger Vs Cargo Aircraft.** Annex 6 to the Chicago Convention covers commercial airplanes – no distinction is made between international passenger and cargo-only operations. When referencing Annex 6 standards for Extended Time Diversion Operations (ETDO), where the required flight time of an operational diversion to a suitable aerodrome for a landing may be extended, it has been suggested that fire suppression is one critical system contained in FAA and EASA requirements. It has also been suggested that the risk level deemed to be acceptable for a cargo aircraft would be higher than that for a passenger aircraft; and that a distinction between forbidding lithium metal batteries on passenger aircraft but permitting them on cargo aircraft is somehow justified.

14.2 Ultimately, any propensity for an aircraft's systems or procedures not to be able to reasonably withstand a fire involving dangerous goods, is one that should not be permitted to continue into the unforeseeable future; irrespective of whether the aircraft is operating in a passenger carrying or cargo-only operation.

14.3 Whilst the ICAO Dangerous Goods Panel will be meeting again in November 2014 to review the carriage of lithium metal batteries on cargo aircraft; it would be prudent to put in place a limiting timeframe whereby lithium metal batteries and their associated packaging, will not be in a position to affect the aircraft with a catastrophic outcome on cargo aircraft.

14.4 **Multi-disciplinary Approach to Cargo Safety.** There was agreement that the multi-disciplinary approach adopted by the first multidisciplinary lithium battery working group in Atlantic City, involving aircraft designers, battery manufacturers and members of the DG Panel, was worthwhile and was likely to lead to greater awareness, understanding and cooperation. It was also commented that if the focus was to tackle all facets of the risks presented by lithium metal batteries, then the disciplines involved should also include Security and Airport Fire and Rescue Services.

15. COST BENEFIT ANALYSIS

15.1 Unfortunately, this paper is just an overview and does not contain all the current and relevant preventive and escalation controls; has not identified all the escalation factors nor all of the recovery measures. Furthermore, whilst a number of new controls have been identified, there may be additional new preventive and escalation controls that are being developed.

15.2 Any of the measures mentioned in this paper will come with some form of cost, whether it is a direct one (such as new ULD materials, additional labelling,) or indirect costs (such as new storage procedures prior to loading, additional segregation from other DGs). Some measures are easy to implement whilst others will prove to be more intractable. And then any cost benefit analysis has to consider the actual tangible benefits to aviation safety measured against the comparative costs and ease of implementation.

15.3 The cost benefit analysis also has to consider the potential for litigation; particularly should there be an otherwise survivable cargo hold fire yet resulting in an unsurvivable accident because a consignment of co-stowed and properly packed, marked, labelled, declared, accepted consignment of lithium metal batteries were triggered into a condition of thermal runaway, venting and ejection of flammable electrolyte. Unfortunately, the nature of a litigious society is such that even when a sequence

of events is exceedingly unlikely, including the prospect that the batteries did not meet UN specifications and had been unlawfully consigned and shipped as not hazardous; aircraft manufacturers and governments will continue to be targeted.

15.4 **Timing of new changes.** The companies involved in the battery manufacturing, testing and shipping industries which have complied with the spirit and intent of the ICAO Technical Instructions to date, will continue to evolve in order to meet any new standards or requirements that might be introduced; particularly where there is a strong foundation of an aviation safety rationale and realistic benefit to the additional cost. However, the introduction of any new requirements has to incorporate an appropriate period of time for transition.

16. IMPLEMENTING A BAN – THE EXPERIENCE OF THE USA; WHY THE PROHIBITION MODEL DOES NOT EXPORT TO OTHER STATES AND OTHER ANTICIPATED CONSEQUENCES.

16.1 The United States has had a prohibition on the carriage of lithium metal batteries on passenger aircraft for a number of years and the absence of accident and incident data on lithium metal batteries in more recent years would tend to indicate that there have not been any occurrences. Two postulations have been represented: (1) that a ban is effective and should be replicated across the globe; and, (2) there are no issues with counterfeit, non-UN 38.3 specification lithium batteries.

16.2 The USA is well served with extensive cargo aircraft networks, and an extensive surface transportation network of road, rail and maritime. The prohibition of lithium metal batteries on passenger aircraft has not been an impediment as there are numerous alternative and timely transport options. The experience cannot be carried easily to other States with large landmass but small population centres and little surface infrastructure. There are no US operators that fly both passenger aircraft and cargo aircraft. This means that the operators simply need to place barriers on lithium metal batteries at the point of acceptance. Outside the USA, a number of operators operate a mixed fleet of cargo freighters and passenger aircraft; with cargo and DG being carried on both aircraft types to facilitate cargo distribution across the whole network. Dedicated cargo-only freighters are only being deployed when freight volumes have risen to the economic levels necessary to make that dedicated cargo aircraft a viable and economic proposition; until then cargo is transported across the passenger network in order to have goods reach regional and remote locations and service those communities in a timely manner.

16.3 The US has a very large contiguous area which is served (in theory) by one regulatory authority. The FAA is the relevant jurisdiction from Seattle to Maine to Florida and California. Whilst EASA may be conceptually similar and across a correspondingly sized landmass; there are still numerous State-based regulatory authorities with differing national legislations. South America and Asia have the same general problem with small State landmass areas and differing national regulatory authorities and jurisdictions to their near neighbours.

16.4 **Individual operators with lithium metal battery restrictions**. There are approximately 30 IATA-member operators which have notified Operator variations or restrictions in respect of lithium metal batteries but not on lithium ion batteries. A number of those operators have similar geographic dispositions, operator groupings or common DG Technical committees. There are another 200+ IATA affiliated airlines; although a number of those would be US based/registered and because of the US ban, would not need to notify a variation in respect of lithium metal batteries on passenger aircraft. There is

also a large number of non-IATA affiliated airlines – operators which may only fly locally, domestically, to nearby international ports or otherwise choose not to affiliate with IATA.

16.5 The majority of the operators with notified lithium metal battery variations do not apply any restriction in respect of lithium ion batteries. In States where the shippers are generally law-abiding, or there are strong regulatory compliance, oversight and enforcement agencies or there are sufficient alternative operators or infrastructure networks to carry those batteries; then individual operators bans provide a veneer of being effective. However, should there be a global ban; then the reality is that those operators will find more people trying to unlawfully ship lithium metal batteries as hidden or misdeclared goods. The rationale is expanded on further in the next few paragraphs.

16.6 **The further effects of a ban as a new preventive control.** Introducing a ban on lithium metal batteries from being carried on passenger aircraft would result in a significant reduction of the shipments of such batteries on passenger aircraft; however, it would not be a complete reduction. Intuitively, implementing a ban is a new preventive control and should reduce the Safety Risk Probability to "could never happen"; similar to the US experience. Furthermore, the only lithium metal batteries carried on passenger aircraft would be those where a Competent Authority has given an approval or exemption and therefore knows where, when and with whom they are being carried.

16.7 A ban or prohibition is a very blunt instrument; particularly when there are no other corresponding measures or additional resources allocated to education, safety promotion, detection, compliance and general and specific enforcement and deterrence. The outcome will be in an increase of shipments of undeclared and mis-declared lithium metal batteries. – either as lithium ion batteries, or as "not restricted" batteries.

16.8 It is necessary to explore these two outcomes separately – first mis-declaration as Lithium Ion Batteries; secondly undeclared and shipped as non-hazardous cargo.

16.8.1 **Mis-declaration as Lithium Ion Batteries**. In the event of lithium metal batteries being deliberately misdeclared as lithium ion batteries; the outcome is still likely to be the uneventful transportation of the batteries; with the extant and continuing risk posed by those mis-declared and hidden batteries in the event of an external fire. Even with the lithium ion battery handling label and the training of ramp staff and cargo handlers, providing awareness to persons handling the package, that if the package is damaged, that it should be removed from the air transportation system. Declared dangerous goods, even those which have been misdeclared, are handled more carefully than general cargo and the risk arising from such misdeclared batteries being the initiator of a fire is still very unlikely.

16.8.2 From an ideological statistical viewpoint, the worst case outcome is the elimination of all properly packaged and declared lithium metal battery shipments from passenger aircraft, leaving only the existing volumes of hidden and misdeclared shipments. In theory as there would be fewer bulk shipments of lithium metal batteries, the potential likelihood of lithium metal batteries being involved in a fire will be correspondingly lower, although the outcome involving the catastrophic loss of the airframe would still be the same. However, without the appropriate controls of effective detection of unlawful shipments and regulatory oversight and enforcement, there will be an increase in lithium metal batteries shipped as lithium ion batteries. The opportunity of drastically improving aviation safety will have been lost as unscrupulous shippers will continue to meet customer and consumer needs and gain a greater competitive advantage at the expense of law-abiding businesses.

16.8.3 The author of this paper has been involved in dangerous goods incident investigations, surveillance and compliance programs and undertaken enforcement activity for twenty years. The

following two photographs are an actual situation where a pallet load of lithium metal batteries, ostensibly packed in compliance with Section II of Packing Instruction 965 and labelled as "Lithium Ion Batteries", did in fact contain lithium metal batteries and which was declared on the shrink-wrapped overpack with a lithium metal battery label. Given the State of Origin of the consignment, it considered very likely that it was labelled as lithium-ion in order to enable the carriage on an operator which has a variation that states it does not carry lithium metal batteries on any of its aircraft. Whether the consignment was landed outside the US and then moved by surface transport to be re-shrink-wrapped and- relabelled and imported; or was landed in the US in contravention of US State Variation 2 is a moot point. The issue is that shippers do not go to special effort to package to purported packing instructions yet "inadvertently" affix the wrong label.

16.8.4 Operators and geographic areas where it is too hard to get the consignment legally into the air, are going to become more prevalent with sending the lithium metal batteries by illegal means.

16.8.5 **Undeclared Lithium Metal Batteries - shipped as general cargo**. The preventive controls of packing, marking, labelling and declaration are removed. Similarly when the preventive control of labelling is removed, so too the preventive controls of inspection, acceptance, stowage, notification to crew also evaporate. Worse still, the absence of labelling also removes the careful handling that usually accompanies the treatment of dangerous goods. With less careful handling, the consignment will be more susceptible to abnormal shocks and treatments.

16.8.6 **In applying the Reason Model of Accident causation**, a prohibition, without additional measures to secure compliance with the ban, is just removing the slices of swiss cheese and increasing the likelihood of a catastrophic accident.

16.9 **Expanded individual operator bans**. If Operators with "No lithium metal battery" policies decide to expand their unilateral prohibition to all lithium batteries; then it will only exacerbate the move of the unscrupulous shippers move to consigning their lithium metal batteries as "dry cell batteries" or even just non-hazardous goods.

16.10 **Opportunity cost of a global ban**. The contrary view is that the potential loss of an airframe and lives of crew and passengers is such that a "ban-first; then work out what can be safely allowed" approach should be adopted. Unfortunately, a ban not only removes many existing preventive controls, it also removes the opportunity to introduce some/many of the new potential preventive and

escalation controls and risk-mitigation strategies and thus make cost-effective improvements in aviation safety.

16.11 **UN3091 - Lithium metal batteries packed with….** Another widely-anticipated consequence of a prohibition on just lithium metal battery consignments, shipped as UN 3090 (and a new escalation factor) is attributable to the inventiveness at interpreting other provisions of the Technical Instructions in order to complete the act of shipping bulk quantities of lithium metal batteries. Two existing provisions are "Lithium batteries packed with equipment" (i.e. new torch in retail packaging with new lithium metal batteries, which the retail purchaser inserts themselves) and "Lithium Metal batteries contained in equipment" (i.e. a key-fob torch which already contains the battery and the torch and battery are thrown away when the battery is flat). Any general restriction on lithium metal batteries must take into account the provisions for those batteries when "packed with" and "contained in" equipment; otherwise, within two years of prohibiting lithium metal batteries as UN 3090, the ICAO dangerous goods panel will be revisiting the topic of lithium metal batteries packed with or contained in equipment as UN 3091.

16.12 **The Air Navigation Commission's message to the ICAO Dangerous Goods Panel** could be paraphrased as **"Recognise the problem – identify the solutions"**. One opinion is that the role for the dangerous goods panel is to focus on aviation safety and the paramount risk and potential catastrophic loss of an airframe presented by lithium metal batteries being involved in a fire. Deliberate non-compliance by manufacturers and shippers is a separate matter for the relevant law enforcement organisations. The contrary position is taken by those who would argue that a healthy safety culture actively seeks improvements, vigilantly remains aware of hazards and utilizes systems and tools for continuous monitoring, analysis and investigation.

16.13 At the opening of DGP 24, the President of the Air Navigation Commission, made some statements which provided insight into the Secretariat's growing concern with cargo safety and how the mandate of the DG Section would be expanded. Dangerous goods could no longer be thought of in isolation but would need to involve other parts of the aviation system such as operations, airworthiness and security.

16.14 Continuous improvement in safety performance is possible when safety becomes a value within the organization as well as a priority at the national or professional level. The dangerous goods panel is the representative body for the safe transport of dangerous goods by air. However, it is only one part of the total transportation system for moving dangerous goods from manufacturer, through shippers, forwarders and onto factories, warehouses, retail venues and end consumers. It is incumbent upon the DG Panel to acknowledge the human factors that are in place within this open system; and the factors which may lead to deliberate violations and normalised deviance presented by commercial opportunism. This is particularly so where there is a lack of effective deterrence against non-compliance.

16.15 Until there are more effective and efficient methods of detecting unlawful shipments, then shippers may continue to deliberately ship lithium metal batteries and lithium ion batteries with near impunity.

16.16 The attractiveness of a prohibition on lithium metal batteries will have not eliminated the risk to aviation safety. It penalise those who comply with the ban; and it will encourage others into commercial opportunism and deliberate flaunting of the legislative requirements.

17. ACTION BY THE DGP-WG/LB

17.1 The DGP-WG/LB is invited to consider the paper and discuss the issues that have been raised. Options include: developing appropriate text for inclusion in the Technical Instructions during the working group meeting; generating effective safety promotion and education outreach strategies; producing guidance material for regulatory authorities to engage with lithium battery manufacturers, testing laboratories, shippers, forwarders and airline operators; and tasking the Secretariat to engage with the UN Committee of Experts.

17.2 Additional activities could include identification and examination of risk mitigation strategies that have not be brought out in this paper; and furthering the work of a cost:benefit analysis in order to deliver the best improvements in aviation safety for the least financial and resourcing costs.

— END —