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DANGEROUS GOODS PANEL (DGP)

TWENTY-NINTH MEETING

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Agenda Item 4: Managing safety risks posed by the carriage of lithium batteries by air ***(Ref: Job Card DGP.003.04)***

REPORT OF THE DANGEROUS GOODS PANEL WORKING GROUP ON ENERGY STORAGE DEVICES (DGP-WG/ENERGY STORAGE DEVICES)

(Presented by the Rapporteur of DGP-WG/Energy Storage Devices)

SUMMARY

This paper presents a summary of the activities of the DGP-WG/Energy Storage Devices and results of its analysis on the transport of lithium batteries packed with and contained in equipment.

Action by the DGP: Action by the DGP is in paragraph 4.

1. INTRODUCTION

1.1 The DGP Working Group on Energy Storage Devices (DGP-WG/Energy Storage Devices) was established to progress the work identified in ANC job card DGP.003.03: Mitigating safety risks posed by the carriage of lithium batteries by air. The twenty-eighth meeting of the Dangerous Goods Panel (DGP/28, 15 to 19 November 2021) requested DGP-WG/Energy Storage Devices to conduct a safety risk assessment on lithium batteries packed with or contained in equipment and vehicles under the guidance of ICAO safety management experts. One consideration the working group was asked to address within a safety risk assessment concerned extending the existing state of charge limit for lithium ion batteries on their own (UN 3480) to lithium ion batteries contained in and packed with equipment (UN 3481). This is particularly applicable to lithium ion batteries packed with equipment as these shipments were not considered much different than lithium ion batteries packed on their own. The working group examined lithium ion batteries packed with or contained in equipment recognizing that these configurations have similar characteristics and requirements while lithium ion battery powered vehicles comprise a broad range of products and sizes that may warrant special consideration.

1.1.1 During the 2022-2023 biennium, DGP-WG/Energy Storage Devices met during the 2022 DGP Working Group Meeting (DGP-WG/22, Montréal, 21 to 25 November 2022), the 2023 DGP Working Group Meeting (DGP-WG/23, Rio de Janeiro, 15 to 19 May 2023) and several times virtually between in-person meetings.

1.1.2 DGP-WG/Energy Storage Devices first utilized the bowtie method to visualize the hazard, the risk, the resulting consequences, and the reactive and proactive controls/measures designed to prevent unwanted outcomes. A copy of the diagram is shown in DGP/29-IP/1.

1.1.3 The bowtie analysis identified that an increase in the energy density of lithium ion batteries over time and an inability for operators to fully identify and therefore effectively control the location of lithium ion batteries packed with or contained in equipment weakens barriers designed to reduce the likelihood and respond to potential thermal runaway events. The bowtie also identified that procedures and training were the primary means to detect and mitigate against damage to lithium ion batteries and equipment. In some cases, visible markings, labels, and information contained in transport documents aid in identifying lithium ion battery shipments. Finally, the bowtie indicated that fires involving lithium ion batteries create unique hazards that are not fully addressed by conventional fire suppression systems. Supplementary smoke/fire detection systems, fire resistant containers and fire containment covers could help mitigate these hazards, but it is not fully known the extent to which these mitigation strategies have been implemented globally.

1.1.4 The group next turned its attention to completing a safety risk analysis. Previous efforts to characterize lithium ion battery transport safety involved some type of probabilistic risk assessment that applies statistical or other analytical techniques to support decision making. The level of risk is typically defined as a product of severity of an event (e.g. a thermal runaway of lithium ion batteries in an aircraft cargo compartment) and the likelihood of that event or a specific series of events leading to that outcome. This is used to determine whether the risk is sufficiently controlled. Inputs including incident report data, cargo volumes, and aircraft cargo compartment capability are used to inform such an analysis. Where an identified risk is not sufficiently controlled, additional/redundant controls or barriers are created to prevent or mitigate potential failures. Although this is a well-developed process employed for many years, this method of risk assessment poses significant challenges when assessing lithium ion battery thermal runaway events. While the potential for a catastrophic event such as a fire in a cargo compartment involving lithium ion batteries is well established, the likelihood of such an event is impossible to predict with any accuracy based only on limited incident reports and cargo transport volumes. Additionally, past incidents do not necessarily predict future behaviour as this approach does not reflect the evolution of batteries, equipment, safety regulations, shipping configurations and business practices.

1.1.5 Considering these factors, ICAO identified an alternative risk assessment approach, System Theoretic Process Analysis (STPA), to evaluate the safety of air transport of lithium ion batteries packed with and contained in equipment. The STPA method follows a series of steps aimed to associate hazards with prioritized losses (Leveson & Thomas, 2018)[1]. This method emphasizes interactions between system components and identifying ways that interactions negatively impact safety. Further, unlike other methods, STPA is not limited to previously identified failures. The analysis identified many of the ways that lithium ion batteries either packed with or contained in equipment could result in loss of life, loss of aircraft, loss of cargo, and loss of ability to transport lithium ion batteries and equipment safely and efficiently. DGP-WG/Energy Storage Devices applied this method to the air transport of lithium ion batteries packed with and contained in equipment. A copy of the report is in DGP/29-IP/2.

1.1.6 DGP-WG/Energy Storage Devices identified many scenarios in which lithium ion batteries either packed with or contained in equipment could become a hazard in transport. Circumstances include offering for transport untested, non-conforming or damaged batteries or equipment, packaging batteries and equipment in such a manner that they become damaged in transport, using a packaging not suitable for transport, and damage to batteries or equipment during handling both prior to offering for transport and

[1] STPA Handbook: https://psas.scripts.mit.edu/home/get_file.php?name=STPA_handbook.pdf

during transport. The Technical Instructions include many requirements designed to mitigate these hazardous conditions. However, when the group reviewed these requirements, it became apparent that implementation of existing requirements still presents opportunities for system failures. Package markings and documentation, when applied, notify operators of the presence of batteries and equipment but this is not universally applied, and product damage or inadequate packaging are not readily detectable through physical inspection. Additionally, national authorities receive little by way of feedback to assess whether safety requirements are being observed and if so whether they are effective. The effectiveness of the regulations can be inferred by a reduction of incidents from a specific cause, but little can be said about overall system safety other than incidents continue to occur.

2. OBSERVATIONS

2.1 Using STPA, the working group identified several themes:

a) The information presented during previous DGP-Working Group meetings indicates a significant increase in lithium ion battery powered equipment air transport volumes, a demonstrated fire hazard when a lithium ion cell or battery goes into thermal runaway and incidents with lithium ion cells and batteries in air transport including handling prior to or after air transport (not limited to cargo shipments) [2,3,4].

b) The supply chain for lithium ion batteries and equipment is fragmented and has many interactions amongst supply chain participants that introduce the possibility of safety issues.

c) Provisions in the Technical Instructions designed to facilitate transport of lithium ion batteries packed with equipment and lithium ion batteries contained in equipment (i.e. Packing Instructions 966 and 967) limit the ability of supply chain participants to identify shipments and apply hazard mitigation measures.

d) Civil aviation authorities obtain most of their information on safety performance through incident reports and inspections. As a result, such information is obtained only after losses (e.g. thermal events) and non-compliance with safety requirements have been observed.

e) Acceptance checklists (for Section I shipments) and an external inspection of packages are the primary methods for operators to determine whether a package conforms to the regulations. However, acceptance checklists can only verify that the quantity is within limits, the packaging is undamaged, and the marks and labels accord with the dangerous goods transport document, and the external inspection of Section II

[2] U.S. Import-Export Data on UN 3480/UN 3481/UN 3090 Based on Harmonized Tariff System (HTS) and Harmonized Tariff Schedule of the United States, PRBA, November 2022, https://www.icao.int/safety/DangerousGoods/WG22IPs/DGPWG.22.IP.014.4.en.pdf

[3] Transport airplane cargo compartment fire suppression capabilities, requirements and dangerous goods assessment in three parts, U.S. FAA, November 2022, https://www.icao.int/safety/DangerousGoods/WG22IPs/DGPWG.22.IP.009.2.en.pdf

[4] Thermal Incident Data related to Cargo Operations reported through the Voluntary Thermal Runaway Incident Program (TRIP) RIP Cargo Data: Summary Of Data, UL Standards and Engagement, November 2022, https://www.icao.int/safety/DangerousGoods/WG22IPs/DGPWG.22.IP.010.4.en.pdf

shipments may be cursory. Damaged or improperly packaged lithium batteries and equipment are not readily identifiable through a physical inspection.

f) Design testing and quality control at the point of manufacture of cells and batteries are the primary proactive measures in the Technical Instructions aimed at controlling hazards of lithium batteries either packed with or contained in equipment.

g) A state of charge requirement is most practically implemented by the offeror or the original manufacturer. Verifying compliance with a state of charge requirement is impractical once packages are prepared and offered for transport.

2.2 The dangerous goods air transport system is based on trust whereby downstream supply chain participants rely on information provided by entities further up the chain. A shipment prepared for transport may pass through multiple intermediaries such as freight forwarders and logistics agents who may not actually see a consignment. As such, operators often have little relationship with the original offeror and face uncertainty of the condition of a package containing lithium ion batteries or equipment. Compliance with requirements is often assured only through the provision of suitable documentation and inspections immediately prior to loading.

3. CONSIDERATIONS

3.1 Through the STPA process, DGP-WG/Energy Storage Devices created various scenarios that identify the causes of hazardous conditions. These scenarios can be used to generate additional requirements and evaluate or revisit existing requirements and identify gaps. Safety requirements exist on a spectrum, from measures that prevent or significantly mitigate hazards, to measures that provide warnings of potential hazards enabling personnel to respond, to training and procedures that standardize processes. Assessing existing and potential new safety requirements could employ a scale that differentiates between requirements that eliminate the hazard from those that only detect and mitigate the hazard. Strategies that eliminate or reduce hazards regardless of the cause are ranked higher than those that utilize training and procedures. The appendix to this working paper contains a scale (Table 1) to assess the strength of mitigation measures and applies this scale to various existing requirements (Table 2) and potential new requirements (Table 3).

3.1.1 When considering additional requirements, they should be targeted at eliminating or reducing hazards posed by batteries and equipment thereby mitigating many of the problems associated with mishandling or damage that can occur during preparation for transport and transport. Additionally, fire containment devices such as fire-resistant packages, fire containment covers, and fire-resistant containers are potential strategies that mitigate hazards. Uncertainty can be reduced by increasing supply chain transparency through methods such as validation of products by trusted sources, vetting of sources of shipments and developing methods to detect unacceptable or unidentified shipments. Working with battery and equipment manufacturers to ensure that all batteries and equipment meet rigorous testing and quality assurance practices and introducing additional protections for battery powered equipment would mitigate many hazards associated with poor quality equipment. While these are all important mitigation measures, they are largely beyond the scope of the Technical Instructions or require actions from regulatory authorities, manufacturers, operators, freight forwarders and standards development organizations to implement.

3.2 Potential new requirements identified through the bowtie and the STPA that are within the scope of the Technical Instructions include:

a) Prohibit certain shipments from air transport. A method employed in the Technical Instructions in limited circumstances;

b) Identify and accept only low energy batteries;

c) Require a reduced state of charge for lithium ion batteries as a condition for transport;

d) Eliminate provisions that allow consignments to be transported without identifying marks and documentation (i.e. Section II of Packing Instruction 967 where there are a limited number of lithium ion cells or batteries in a package);

e) Enhance training requirements for shippers/packers preparing battery powered equipment for transport.

4. ACTION BY THE DGP

4.1 The DGP is invited to review the bowtie diagram and the STPA report found in DGP/29-IP/1 and DGP/29-IP/2, and consider the following:

a) What the assessment provides — how does the assessment aid the DGP in determining potential new requirements?

b) What the assessment does not provide — what are the limitations of the assessment to influence decisions within the scope of the DGP?

c) Of the identified potential new requirements, which ones provide the most value, keeping in mind the scope of the DGP?

d) Table 2 and Table 3 in the appendix to this working paper describe existing safety requirements and identify potential new requirements. What other risk mitigation measures could the DGP discuss with the view of an implementation strategy that leverages partnerships within applicable functional entities (not DGP members)?

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APPENDIX

MITIGATING MEASURES

The Technical Instructions identify the acceptability of lithium ion batteries packed with and contained in equipment for transport by air and under what conditions. As such, the Technical Instructions include many requirements intended to prevent and mitigate hazardous conditions. DGP-WG/Energy Storage Devices utilized a mitigation order of precedence to assess existing and potential new requirements outlined through the following tables:

a) Table 1 displays a mitigation order of precedence scale consistent with MIL-STD-882 and various other safety standards. Mitigations that design for minimum risk or eliminate the risk are ranked higher than those mitigations that provide only warnings or rely on procedures and training.

b) Table 2 applies the mitigation order of precedence scale from Table 1 to various requirements identified in the Technical Instructions.

c) Table 3 applies potential new requirements identified through the STPA using the mitigation order of precedence scale from Table 1. The group identified battery manufacturers, shippers/packers, and ground handlers as those whose actions most directly led to hazards and losses.

Table 1. Mitigation order of precedence

Mitigation level	Mitigation description	Mitigation effectiveness score
Design for minimum risk	The causal factor can be eliminated through design to eliminate risks.	5
Reduction through design	If the identified risks cannot be eliminated, reduce it to an acceptable level through design selection e.g., safety design features or safety devices. The occurrence of the casual factor can then be reduced or controlled through system design (proactive)	4
Provide warning devices	When neither design nor safety devices can eliminate identified risks or reduce risk, devices shall be used to detect the condition and to produce an adequate warning signal. The causal factor can be detected and requires a response to mitigate (reactive).	3
Develop training and procedures	Where it is impractical to eliminate risks through system design, training and procedures are used. Causal factor can be mitigated through additional training and procedures (reactive)	2

Mitigation level	Mitigation description	Mitigation effectiveness score
None	No possible mitigation exists, or mitigation is never applied	1

Table 2. Existing requirements identified in the Technical Instructions scored against the mitigation order of precedence

Description	Mitigation effectiveness score
UN 38.3 testing and quality management system	4
UN 38.3 test summary	3
Strong rigid outer packaging. Acceptable package types and performance qualities identified	4
Requirements to protect equipment against short circuits and damage	4
Package/overpack marks, labels, and documentation indicate the presence of lithium batteries in a consignment	3
Initial acceptance check	2
Inspection prior to loading	2
Handling procedures and personnel training	2

Table 3. Potential additional requirements scored against the mitigation order of precedence

Causal scenario ID	Causal scenario description	Recommended mitigation description	Mitigation effectiveness score
CS 1.1	Manufacturers do not conduct UN38.3 tests.	National authorities conduct inspections and surveillance on battery/equipment manufacturers to identify flawed assumptions in the battery testing and equipment environment and conditions that violate assumptions about usage conditions.	~~4~~3
		Develop detailed requirements to identify acceptable design changes.	2
		Reduce the state of charge for rechargeable batteries.	4
CS 1.2	Manufacturers do not develop and adhere to a quality management system.	Develop detailed requirements for quality assessments including third-party verification.	2

Causal scenario ID	Causal scenario description	Recommended mitigation description	Mitigation effectiveness score
		Develop safety features for battery powered equipment	4
		Reduce the state of charge for rechargeable batteries.	4
CS 1.3	Shipper does not utilize lithium battery test summary information to make a classification decision.	Require shippers to produce lithium battery test summaries as a condition for carriage	2
CS 2.1	Shipper does not protect the battery from short circuits or damage prior to placement of the battery in the package with equipment.	Increase awareness of shipping and transport requirements	2
		Require training for all shippers	2
		Reduce the state of charge for rechargeable batteries	4
		Design equipment to protect installed batteries	4
CS 2.2	Shipper/packer does not secure equipment within the outer packaging when offering for transport	Increase awareness of shipping and transport requirements	2
		Require training for all shippers	2
		Reduce the state of charge for rechargeable batteries	4
		Design equipment to protect installed batteries	4
CS 3.1	Shipper/ packer selects a package of insufficient strength leading to damage of the contents during handling.	Increase awareness of shipping and transport requirements	2
		Require training for all shippers	2
		Reduce the state of charge for rechargeable batteries	4
		Design equipment to protect installed batteries	4
CS 3.2	Ground handling service provider damages packages during handling	Require quarantine or inspection of all packages subject to suspected damage	3
		Reduce the state of charge for rechargeable batteries	4
		Design equipment to protect installed batteries	4

Causal scenario ID	Causal scenario description	Recommended mitigation description	Mitigation effectiveness score
		Review training and procedures for package handlers	2
CS 4.1	Shipper does not apply appropriate marks, labels, or indicate the presence of lithium batteries in a consignment.	Eliminate provisions that allow consignments to be transported without identifying marks and documentation	3
		Require training for all shippers	2
		Reduce the state of charge for rechargeable batteries	4
		Design equipment to protect installed batteries	4
4.2	Operator accepts a consolidation of multiple consignments of lithium batteries contained in equipment in a mail sack without marks, labels, and declaration.	Eliminate provisions that allow consignments to be transported without identifying marks and documentation	3
		Require training for all mailers	2
		Reduce the state of charge for rechargeable batteries	4
		Institute requirements for mailers to indicate the presence of electronic equipment or items containing batteries or attest to the absence of electronic equipment containing lithium batteries.	2

— END —