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Committee of Experts on the Transport of Dangerous Goods and on the Globally Harmonized System of Classification and Labelling of Chemicals

Sub-Committee of Experts on the Transport of Dangerous Goods

Fifty-first session
Geneva, 3-7 July 2017
Item 4 (b) of the provisional agenda
Electric storage systems:
hazard-based system for classification of lithium batteries

Report of the informal working group on lithium batteries on its first session of the biennium 2017-2018

Transmitted by the expert from France on behalf of the informal working group*

1. The informal working group (IWG) met in Montreal in the premises of the International Civil Aviation Organization (ICAO) from 27 to 29 March 2017 under the chairmanship of Mr. Claude Pfauvadel (France). A list of participants is reproduced in informal document INF.3.

2. The purpose of the meeting was to discuss the inherent hazards associated with lithium batteries. Based on lessons learned and experience gained, the Sub-Committee had mandated the IWG to consider a hazard-based system to classify lithium batteries and cells for transport. Such a system might include determining the inherent hazards represented by lithium batteries and the types of reaction that may result. Destructive testing should be considered. Overall questions to guide the discussions included:

(a) Look at all available data that can already be useful to analyse the effects produced by lithium batteries when they react;

(b) Identify the additional data needed;

(c) Prepare plan for getting all the necessary data and the way to use them.

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* In accordance with the programme of work of the Sub-Committee for 2017–2018 approved by the Committee at its eighth session (see ST/SG/AC.10/C.3/100, paragraph 98 and ST/SG/AC.10/44, paragraph 14).

3. Presentations had been circulated to the group prior to the meeting and are available from the PRBA Website: http://www.prba.org/lithium-battery-transport-information/un-lithium-battery-working-group-on-classification/

4. The IWG discussed what would be reported to the Sub-Committee and which questions were the most important to answer.

5. The Chairman explained that the Sub-Committee needed to know the feasibility of the mandate and what information was needed to meet the intended goals. It was not expected that final decisions would be reached at this first session. Instead, the goal of the meeting was to determine the magnitude of the effort.

6. Specifically, the following questions were to be discussed:

(a) What risk/type of reactions have to be assessed?

(i) fire

(ii) gas emission

(iii) toxic fumes

(iv) projections

(b) How to initiate the reaction in the test?

(i) exposure to fire (bonfire test)

(ii) exposure to heat radiation

(iii) exposure to heat through short circuit

(iv) overcharge

(c) What is the item to be tested for classification?

(i) a whole battery (independently from the size);

(ii) a cell;

(iii) a "module" or battery part;

(iv) several of the above mentioned items;

(v) can the reactivity of the bigger battery be assessed by testing some of the elements.

(d) Other issues

(i) testing packed or unpacked items (going toward a classification related to the transport packaging);

(ii) use of the tests to be defined;

(iii) assessing the violence of the reaction only as a classification factor versus assessing the violence of the reaction and the sensitivity.

INERIS Presentation

7. INERIS provided a summary of the testing it conducted on various types of lithium batteries. It had reviewed the variety of effects that resulted from lithium battery incidents/fires and compared those effects de pending on battery chemistry. It identified:

(a) Toxic effects: great variability depending on battery chemistries;

(b) Thermal effects: great variability depending on battery chemistries;

(c) Mechanical effects: not enough data to make significant comparisons.

8. INERIS had also compared the effects noted above with those resulting from tests on other common materials including aerosols, DVDs, plastic drums, and a pallet of containerized salad (food):

(a) Thermal effects: INERIS had concluded that one battery pack tested represented a risk higher than a pallet of aerosols, while a second battery pack tested represented a risk of the same magnitude as for DVDs, plastic containers of salads, and plastic drums. The results indicated two clear groupings of thermal power levels one above 140 megawatts (MW) and a second one below 70 MW.

(b) Flame emittance and height: the results were similar to those for thermal effect tests.

(c) Toxic effects: INERIS reviewed the concentration of gaseous effluents and compared the toxicity level in ppm. Lithium batteries presented a mid-level hazard compared to other materials. Plastic drums represented the highest toxicity, a magnitude greater than lithium batteries.

9. The results of the study indicated great variability on toxic and thermal effects between different battery types with many of the effects being lower than other commonly shipped goods. INERIS concluded that a classification system based on toxic and thermal effects would be relevant.

10. Participants discussed whether it was important to look at the specific hazards represented by the lithium batteries or whether those effects should be compared to other goods. Some suggested the unique properties of lithium batteries should be accepted as the basis and a system had to address known concerns, regardless of how those values compared to other materials. But the group recognized that a first step should be to determine the different hazards represented and that then, in a later step, risk-mitigation factors that may reduce or eliminate those hazards should be determined. A multi-modal approach should be considered. The group was reminded of the efforts being conducted by the SAE G-27 Lithium Battery Packaging Performance Committee ("G-27") reviewing lithium battery packagings for transport by air. The Chairman reminded the group that the issue would not be solved during this meeting and that it would take more than one biennium to reach a final result. Hazards had to be identified first, and tests had to be defined to collect data. But it was also important to understand how to identify representative samples (size, battery/cell chemistry, design).

11. Some indicated that industry battery performance was governed by the intended use of the cell/battery and existing government regulations. Marketability and profitability were key drivers in industry. It was important to ensure that new tests would not lead to unintended consequences (e.g. new designs would pass the tests but the hazards would still exist).

RECHARGE Presentation No.1

12. RECHARGE discussed the potential hazards of lithium batteries identifying:

(a) Electrical

(b) Thermal runaway

(c) Chemical (electrolyte leakage)

(d) Mechanical

13. In the case of thermal runaway:

(a) Gas emission -toxicity and volume

(b) Flame and heat emission

(c) Rapid disassembly

(d) Electrolyte leakage

14. RECHARGE explained that thermal runaway was actually a series or chain of chemical reactions, several of which produced heat and gas. The process was not a single reaction but several reactions in a feedback loop. Event propagation occurred because of heat transfer, flames, and burning of flammable gas within the battery, casing, or high unit density in packaging. Cooling systems could dissipate heat across cells or out of the battery. Thermal insulation could also reduce heat transfer to other cells. RECHARGE had studied insulation properties with different materials (i.e. vermiculite, sand). It had also reviewed event probability – risk of battery resulting in a thermal event based on the status of the battery and battery design. Acknowledging the fact that a high severity of hazard would have a low acceptance in transport but a low severity hazard might have a higher acceptance, RECHARGE concluded a system could be developed to mitigate or eliminate severe hazards in transport while permitting lower hazards to exist if controlled.

15. The IWG discussed the difficulty in determining the probability of an event. How was this determined in all cases? The group also considered the fact that various hazard properties could be mitigated in multiple ways. Participants were generally supportive of developing new classification criteria but had differing opinions on whether packaging or battery design needed to be considered as mitigating factors for classification. The Chairman and others felt strongly that mitigating factors should be set aside for the short term and that the group should focus on identifying intrinsic hazards, developing tests to identify relative hazards, and deal with mitigating factors at a future session.

RECHARGE Presentation No.2

16. RECHARGE gave a second presentation discussing factors that may be used to categorize hazards. The approach included reviewing the maximum hazard (effect) produced by a battery and the susceptibility that a battery would present the maximum hazard. Propagation ability could be considered as one of the factors of susceptibility. RECHARGE suggested a 3-step approach to classification:

(a) Determination of maximum potential hazard effect;

(b) Characteristics of susceptibility;

(c) Consideration of mitigation factors.

17. The proposal included concepts of testing for maximum potential hazard and susceptibility, and identification of relative hazard levels based on the hazard and susceptibility data. Once test data had identified the relative hazard, mitigating factors could be used to reduce the hazard or susceptibility. The presentation gave a high overview of the philosophy of a new lithium battery classification system but did not detail the specific hazards that should be tested. RECHARGE concluded the presentation with a proposed scope of work for future work.

18. The IWG requested expansion on how susceptibility would be tested. Examples given included considering the temperature at which a battery may begin a thermal event, or whether cells would propagate within a battery. The Chairman suggested that, at present, the work discussed in the IWG should be in parallel and in addition to the work on section

38.3 of the Manual of Tests and Criteria (“UN 38.3”), but that changes to UN38.3 could be considered at a future session. The proposed scope of work was generally supported as a basis for moving forward.

19. The question was raised whether changes to the UN38.3 testing requirements could also be discussed. The Chairman explained that the current mandate of the IWG does not include the review of the UN38.3 requirements. Concerns about the existing UN38.3 could be considered as a separate work item. The work of the IWG might not be directly related to UN38.3, but the result of discussions might have consequences on UN38.3 and could be considered in the future. UN 38.3 is a pass/fail condition. If a design type passes, it is acceptable for transport as Class 9. If it fails, it is not acceptable for general transport as Class 9. The new method would consider the worst case situation and as a result, all cells and batteries would likely “fail” the test. Therefore, identifying the key factors to be monitored was more relevant in the new process than passing UN38.3.

20. The Chairman suggested that the group discuss the worst case condition, review the hazards that should be measured, and consider test methods that may be used to quantify the hazard. He reiterated that all recommendations that would come from the IWG would have to be discussed by the Sub-Committee eventually. Therefore the work had to be justified by data in the IWG.

21. The group questioned which hazards were not currently identified through testing under UN38.3. UN38.3 verifies the safety of the cell and battery design for transport, but the hazards are not quantified. The current test methods result in a wide range of reactions from very low dangers to very significant dangers. The new method should identify the reactions that are of concern, measure the reaction, and provide a method for relating the danger. Packaging should be considered after the hazards and test methods are established. Some participants questioned whether the efforts of the G-27 should be considered *in lieu* of complete changes to classification. They voiced concern that, as hazards of lithium batteries are identified in the IWG, the group as a whole would consider all hazards as “worst case” to be mitigated, when in reality hazardous effects may already be confined to the package or through battery design under the current system. Others explained the current system is not capable of applying to new technologies, and based on information from modal bodies, does not contain enough granularity to allow for proper characterization of relative danger. Therefore new processes needed to be considered. While the air mode had been the most vocal for change and raised the issue because all hazards represented by lithium batteries were not fully identified under the current system, the current system presents problems in all modes. Once the IWG had decided on a course of action and this cause of action had been endorsed by the Sub-Committee, the modal bodies might consider how they would address the hazards through packaging, hazard communication, or exceptions.

22. The IWG discussed the importance of defining the hazards and identifying acceptable criteria for each of the hazards before moving to testing and mitigation taking into account the possibility of future technologies. The Chairman agreed and indicated the system should be independent of technology.

FAA Presentation

23. The FAA gave an overview of lithium battery testing that had been conducted at the FAA Fire Safety Branch in Atlantic City, New Jersey, USA. In Report TC-16/37, Primary tests were to determine if Halon or existing packagings prevent propagation of thermal runaway in Class C cargo compartments. Results indicated that existing packaging do not prevent cell to cell propagation, and Halon was inefficient in extinguishing lithium ion fires completely. In these tests the FAA demonstrated that propagation of thermal runaway did

not occur for the majority of cells tested when the State of Charge (SOC) was reduced to 30%.

24. Other reports issued included TC-TN 16/22 and TC-16/17 which determined thermal heat production and cell failure effects.

25. Some members questioned why the aviation industry uses Halon as an extinguishing agent. The FAA explained alternate solutions are being researched but have not been adopted yet. The group questioned whether there was a clear relationship between the energy released in a thermal runaway and the stored electrical energy. The FAA noted their testing confirmed more energy was released in the thermal runaway than the total energy stored electrically in the battery.

26. All three reports are available from the FAA Testing Center Website:

(a) Report DOT/FAA/TC-16/37 titled: Summary of FAA Studies Related to the Hazards Produced by Lithium Cells in Thermal Runaway in Aircraft Cargo Compartments, (July 2016), is a compilation of test data and results from projects conducted by the Fire Safety branch over the past 15 years.

(https://www.fire.tc.faa.gov/pdf/TC-16-37.pdf)

(b) Report DOT/FAA/TC-16/17 titled: Fire Hazard Analysis for Various Lithium Batteries, (March 2017), is a report of fire test conducted on lithium ion cells (pouch, cylindrical) and lithium metal cells (cylindrical) of various cathode chemistries and sizes to evaluate their failure effects.

(https://www.fire.tc.faa.gov/pdf/TC-16-17.pdf)

(c) Technical Note DOT/FAA/TC-TN16/22 titled: Energy Release by Rechargeable Lithium-Ion Batteries in Thermal Runaway (April 2016), and its publication: Richard E. Lyon, Richard N. Walters. “Energetics of lithium ion battery failure.” Journal of Hazardous Materials 318 (2016) 164-172. It is on the energy released by failure of rechargeable 18650 cylindrical lithium ion cells/batteries measured in a bomb calorimeter for four different commercial cathode chemistries over the full range of charge using a method developed for this purpose.

(https://www.fire.tc.faa.gov/pdf/TC-TN16-22.pdf)

(http://www.sciencedirect.com/science/article/pii/S0304389416306008)

(d) Additional information, videos and data are available from the FAA Test Center website. www.fire.tc.faa.gov.

SAE G-27 Presentation

27. General Motors provided an update on the ongoing effort within the SAE G-27 to develop a minimum performance standard for packagings used to transport lithium batteries by air. Two concerns directed the effort:

(a) Uncontrolled fire in cargo compartment

(b) Critical overpressure in cargo compartment

28. G27 was continuing to develop test methods to determine whether packagings would ensure that hazardous effects are limited to the package (i.e. no flame emitted, no projection hazards, no ignition of vapours, limits to maximum external package temperature, and package integrity). G-27 is also considering a test that would indicate the cell is completely safe. Current draft testing methods were discussed.

29. Participants discussed the concerns over the vapour or gases that are produced from thermal runway events. The testing currently did not distinguish between vapour or gas production. They indicated there were multiple ways of failure including ejection of a cell or flame from the package. SOC was also being considered requiring testing at 110% of the SOC of batteries as offered for transport. The group questioned whether heat-absorbing or dissipating materials were being reviewed in the effort. Others explained that the packaging industry was actively developing new packaging designs, and some of those designs included heat dissipating materials.

30. Concerns were voiced on how the G-27 results would be integrated into the regulations and implemented into industry. The results could be very complicated and could lead to shipper confusion as to which packagings had been tested and approved for which types of batteries. The group was reminded that the G-27 effort was to test packagings designed to contain a battery, whereas the IWG was looking at how to classify the relative dangers presented by lithium batteries. The IWG discussed the fact that test methods being considered start with a failure of a cell that then propagates, not necessarily heating or causing an entire battery to start the event. Could tests be developed to use short circuits as the event initiator? The discussion concluded with the indication that the G-27 planned to complete the standard in late 2017.

Hazardous effects brainstorming

31. The IWG conducted an open, brainstorming event to collect and discuss hazardous effects that should be considered as part of the classification process. The Hazard Table (see annex) lists identified hazards, reasons for concern, parameters to be measured, and general notes on the issue.

32. The IWG recommended that participants should continue to obtain and submit information on open questions to determine appropriate tests associated with different hazard categories.

Initiation discussion

33. The IWG discussed the challenges with initiating the reaction. Using an external short-circuit approach to define conditions that would lead to a worst-case thermal runaway reaction would be very difficult. The current short circuit in UN38.3 would not give the intended worst-case result. The short circuit test is a misuse condition and does not reach the goal of a destructive test. Others felt a reaction was needed in all cases, and short circuit might not be readily reproducible. A bonfire test might be too severe but a flame source could be used (flammable liquid fire, etc.). Heat appeared to be more reproducible than short circuit. Some felt cells and batteries might have different initiation solutions. The probability of more than one cell having a reaction was far greater than two or more. Thus, it was suggested perhaps only one cell reaction in a battery needed to be simulated.

34. The IWG agreed that the test procedure should ensure that thermal runaway or thermal reaction was certain. Electrical initiations are not certain. The test investigations should study whether the reactions are different with different initiation methods (fire, radiant heat, electrical). The amount of energy released during an event should be compared to the amount of energy used to initiate the reaction. Since some test methods were more stressful than other test methods, screening tests could be considered. Some participants felt it important for tests to be flexible to accommodate various designs and chemistries. It was noted that the G-27 discussed the same issue and came to the conclusion that a heating cartridge was the preferred method. The Chairman recalled that the mandate from the Sub-

Committee was to determine the hazards presented by lithium batteries and identify possible tests to measure the severity of the hazards. Tests had to be meaningful or practical in reality. Such tests would then become the basis for classification of lithium batteries in the future. Therefore, understanding the difference between reactions initiated by different methods would impact how the tests would be designed. Participants discussed the fact that every cell and battery represents both chemical and electrical hazards, but electrical initiation methods were more difficult to impose. Some participants confirmed from experience that pressure, heat, gas composition, and reaction vary greatly depending on the initiation method.

35. Some felt propagation was of critical concern, and therefore the initiation method for the first cell might not be as critical as long as thermal runaway began. If a cell was resistant to heating and thermal runaway, the cell became a safer cell. But it was also important to design a test that represents real life initiation methods.

36. The Chairman summarized the discussion by indicating the question of how the different initiation methods impact the results. Research could be done through review of literature and existing test methods. If the data suggested a difference existed, additional investigative tests could be conducted. If the data confirmed that some methods created bias, the eventual test methods could be adjusted to address the bias.

Discussion on what needs to be tested

37. The IWG discussed what should be tested (the cell, the battery, modules, several of each). Participants shared the opinion that the reaction on the cell level was the critical element. Opinions were divided as to whether the test results on the battery would be equivalent to those conducted on the cells alone. After some discussion, it was generally agreed that it would be dependent on the hazard to be assessed, the nature of the abuse and the design of the battery. But if disassembly occurred or heat generation occurred batteries composed of such cells might also need to be tested. If testing of batteries became independent, cost associated with testing might become unreasonable. The IWG debated whether a package containing 1000 cells was equivalent to a battery containing 1000 cells. Some recommended conducting “investigative” tests to determine if a battery made of benign cells would result in a benign battery (does the reactivity of cells equate to the reactivity of the battery). The group acknowledged there might be situations where reactive cells might be protected in a battery case or pack. Several participants felt any testing scheme should include considerations for scaling up or scaling down testing based on cell/battery design and protections. Others pointed out that heat generation in a battery pack independent of cells may lead to the thermal events. Large batteries containing benign cells would have additional considerations including high voltage that may overpower any safety systems present. The presence of plastics or other materials in the pack/case might create smoke, vapor, etc.

38. The Chairman added that experience with the current UN38.3 testing indicated there were conditions that the battery could experience that could lead to a thermal event and that are not addressed when testing the cell alone. Some pointed out the definition of “benign” is critical in this argument. A cell may not experience a thermal event but if it creates enough heat or leaks, it might create other hazards already observed in incidents. Others argued that even benign cells could be placed into a battery in a “less safe” design. Thus, the battery or pack should be subject to some testing requirements. One participant suggested to compare the case of lithium cells and batteries with that of dangerous goods packed in limited quantities. By limiting the amount of material per package, derogations can be granted in relation to hazard communication and packing. Additional requirements may be applicable for transport by sea or air, but the concept remains. Could such a system

apply to lithium batteries as well? It was noted the situation was not exactly the same when cells are connected together in batteries to create a new article, which is not the case when inner packages containing dangerous goods are contained in an outer packaging.

39. Participants added that testing should consider whether cells would push electrical charge to cells that are beginning to enter a thermal runaway. This also raised the question whether cells in parallel each at a 30% SOC should be considered as a single cell at 60% SOC. Others confirmed their experience supported this concern.

40. The IWG recommended that participants should share testing experience with benign cells and battery packs. Additionally, the group considered including such testing in an investigative testing plan. Some noted emergency responders would have a different perspective on the issue and recommended they be invited to participate in the discussion.

Investigative test plan

41. Based on the discussion, the Chairman indicated that France would prepare an informal paper for the July session of the Sub-Committee recommending an investigative testing plan to answer some of the questions raised during the week.

42. The Chairman noted that France would ask for a lunchtime working group at the July session. Discussion topics for the session would include:

(a) Tests to be conducted;

(b) What would be a satisfactory representative sampling;

(c) Who would be able to participate in the investigative testing;

(d) Ensuring confidentiality when necessary and appropriate.

43. Opinions were expressed that battery chemistry may have a significant impact on testing results. Therefore, concepts of equivalency had to be considered. PRBA indicated it would work with BAJ and other battery associations around the world to bring additional resources to the testing efforts. It was reiterated that confidentiality would be an important aspect of the testing to ensure that participation would not be limited.

44. The Chairman noted that the representative of RECHARGE offered to host the next session of the IWG in Europe. The date and location would be decided after the July session of the Sub-Committee.

Conclusion

45. The Sub-Committee is invited to take note of this report and of the questions raised in the Table in the Annex, and to take action as appropriate, including development of revised terms of reference for future work

Annex

Hazard Table

Hazards	Characteristic	Measurable parameter	Concern	What needs to be investigated?	How do we investigate/ intitiate it? [is a precise measurement tool needed?]	Notes/Questions
Thermal	Fire	Flame duration	flame may lead to fire in package, CTU or cargo compartment/ all of the other hazards	range/duration/ temp of flame		
		Flame power	Heat energy			IWG suggested removing this condition
		Flame length/height				
	Heat Production	Heat release rate	heat may initiate fire or reaction with other LB	heat energy available		
		Max energy released	evolution of heat flow rate over time and duration	max energy (MW/kg), how long it lasts (sec)	heat flow meter in given distance	
		Max temp increase	temperature at surface or from a distance, or temperature of gaseous emissions	what is the heat produced by the battery? What is the heat production of combustibles in the battery? Is the presence of O2 a limiting factor?	IR camera	

Hazards	Characteristic	Measurable parameter	Concern	What needs to be investigated?	How do we investigate/ intitiate it? [is a precise measurement tool needed?]	Notes/Questions
Smoke/vapor	Smoke/fog/opacity		reduction in visibility	opacity of vapor or gas generated	Opacity meters, light source, what volume should be considered?	Should be investigated to determine if it a real threat and whether it is a distinguishible characteristic for classification.

Hazards	Characteristic	Measurable parameter	Concern	What needs to be investigated?	How do we investigate/ intitiate it? [is a precise measurement tool needed?]	Notes/Questions
Mechanical	Explosion/projection		expulsion of materials or complete failure of the cell/battery casing	weight and distance of parts ejected		May already be addressed in UN38.3, other UN test series, or industry standards. evaluate for inclusion or expansion, significance
	Pressure pulse		immediate release of gas or combusion of gas creates pressure pulse that may damage seals, packaging, vehicle	Quantity of gas, concentration of combustible gases, volume of packaging, CTU, cargo compartments	measure rate of gas release from sealed cell/battery or packaging, pressure released from combusion of gases	1-2 psi pressure pulse can create issues in air transport, determine if it is an issue in other modes, different battery chemistries
	Leakage		release of electrolyte	Assessment of hazard depending on nature of the characteristic of the electrolyte and the quantity (flammable, corrosive, toxic electrolyte)	disassembly leads to release of electrolyte	May already be addressed in UN38.3. evaluate for inclusion

Hazards	Characteristic	Measurable parameter	Concern	What needs to be investigated?	How do we investigate/ intitiate it? [is a precise measurement tool needed?]	Notes/Questions
Chemical	Toxicity		toxic substances may create a toxic effects to humans	composition, concentration, duration of exposure		Might not be separate as it may be covered by leakage
	Flammability		flammable liquids may create an ignitable atmosphere	composition, concentration, ability to ignite		

Hazards	Characteristic	Measurable parameter	Concern	What needs to be investigated?	How do we investigate/ intitiate it? [is a precise measurement tool needed?]	Notes/Questions
Electrical	Total energy in system		energy in the system may lead to event initiation,	Determine how energy level impacts initiation and level of reaction		Related to initiation of reactions, SOC for testing conditions. Relation to energy level and reaction may be investigated. Not a separate hazard
	High voltage		Impact of high voltage on reaction, possible ignition of flammable gases or adverse interaction with fire extinguishing materials.	Determine if high voltage creates additional hazards		Electro-shock hazards are addressed by other standards and are not covered in this test parameter.