

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

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Item 4 (b) of the provisional agenda

Electric storage systems:

Hazard-based system for classification
of lithium batteries

Work of the informal working group on hazard-based classification of lithium batteries and cells

Transmitted by the experts from France and RECHARGE on behalf of the informal working group

1. The UN Informal Working Group (IWG) on the hazard-based classification of lithium batteries met in Seoul, Korea from 24-26 April 2023. During the meeting the following recommendations were proposed for consideration by the Sub-Committee to further develop a hazard based lithium battery classification system. This document is intended to inform the Sub-Committee of the IWG's progress and proposed way forward. The IWG seeks the Sub-Committee's views and approval of a revised mandate and terms of reference to continue the IWG's work. The IWG is proposing 9 classification categories based on a decision diagram. The categories are intended to be based on defined test procedures and criteria to assess in which category a cell or battery would be assigned. Once the IWG receives approval of the Sub-Committee it is prepared to continue work drafting a formal proposal.
2. The proposed classification system aims to classify cells and batteries according to their inherent hazards. The current requirement for lithium batteries to be subjected to and pass the UN 38.3 tests is not intended to be replaced. The new tests and criteria are intended to provide a more granular classification system that takes account of how lithium batteries react when subjected to testing that assesses whether cell to cell propagation occurs and how much heat, fire, and gas are generated as a result of testing involving intentionally forcing a single cell including a cell that is assembled into a battery pack or module into thermal runaway.
3. As a result of the testing performed by the UN IWG members, 9 hazard categories have been identified as presented in the diagram below. If a cell or battery manufacturer or distributor chooses not to conduct testing they would be considered to fall into the most severe category 9.
4. The proposed propagation test involves placing 4 cells in a fixture and initiating a cell on either end of the fixture. This test method is more comprehensively described in paragraph 8.2 of this document. Based on the propagation test the following criteria were discussed and are provided for discussion:
 - the propagation occurs from cell to cell with a speed of [100 mm/8 s];
 - the gas emissions can contain up to 35%vol hydrogen, 30%vol CO and 30%vol organic carbonates (EC/DEC) and 4% HF, with a volume of 1.5 l/Wh of cell; and
 - the fire risk is applicable [and maximum temperature related to fire].
5. The classification tree would be presented in the Model Regulations Chapter 2.9, but also applied in the UN Manual of Test and Criteria, in the additive section describing the tests supporting the classification decisions of the diagram.

6. In order to determine a specific classification of the cell or battery, 3 repetitions of the tests corresponding to the decision tree shall be run. The more severe criteria measured over the 3 tests shall be reported as the cell or battery test results. If one of the tests cannot be completed and makes the hazard evaluation impossible, additional tests shall be run, until a total of 3 valid tests are completed.

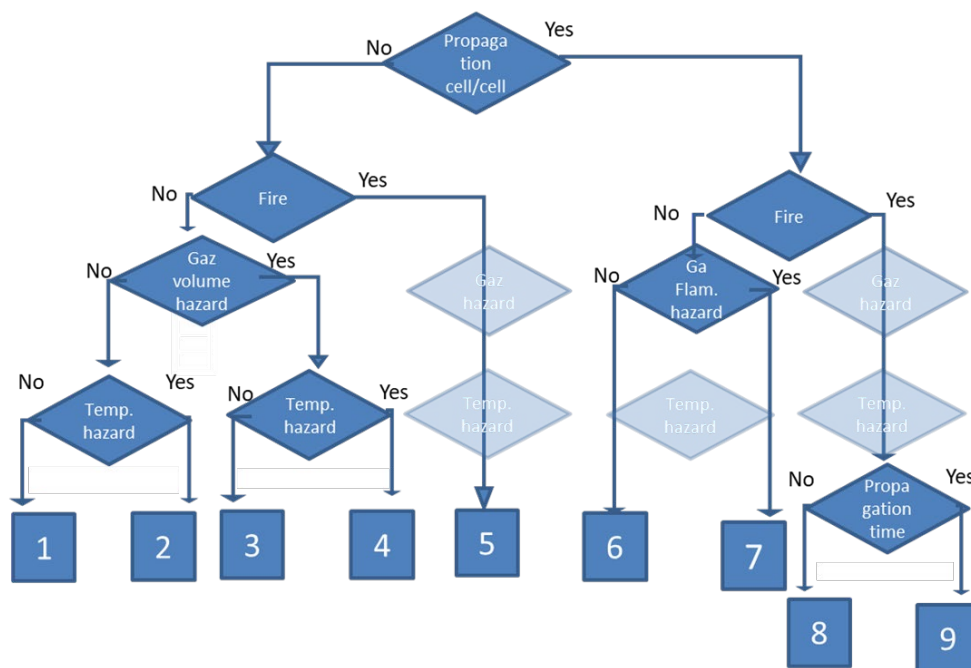
7. Introduction of the new classification proposal for cells

As presented in the previous report of the UN IWG, the hazards related to lithium cells have been identified and agreed upon:

- the capability for a thermal run-away to propagate from cell to cell;
- the capability to generate fire;
- the capability to generate significant quantities of gas. The gas composition may be toxic and/or flammable. However, the working group decided not to differentiate between these two properties in all cases but base the classification on the quantity of gas generated; and
- the capability to produce high temperature.

The possible combinations of these hazards have been considered, and a proposal for a classification system for cells, according to these hazards, was agreed upon. A classification tree, based on the test results was agreed and is proposed for consideration by the Sub-Committee.

This classification tree represents on its last line the hazard category that would result.



In this tree, light blue diamonds represent hazards that are always applicable for a category assignment, and therefore it would be unnecessary to conduct testing.

This classification is applicable for 100% SOC cells, without considering the packaging, or transport at a lower state of charge.

Each decision is based on a test result. For each type of hazard, the test method and decision criteria are described in paragraph 9 of this document.

8. Introduction of the testing requirements to support the cells classification

8.1 Principle for the initiation of the thermal reaction

The proposed tests for the hazard classification system are based on forcing the initiation cell into thermal runaway by an abuse method representing the best compromise between the simulation of the effect of an internal short circuit, the control of the

implementation and the reproducibility of the reaction. The selected method agreed by the IWG is the application of heat on the surface of a cell or a cell in a battery pack or module until the thermal runaway reaction is initiated inside the cell or the cell surface temperature has reached 350 °C for at least 1 minute. The surface of the heater shall be smaller than the minimal value between 10 cm² and 25% of the cell surface (except for button cells and cells with surface below 1 cm², where the heater can be as large as one face).

The maximum temperature selected (350 °C) for the test has been set on the basis that the majority of the commercially available fully charged lithium cell will go into thermal runaway at that temperature and because heating to a higher temperature could result in influencing the other cells due to the high temperature as opposed to assessing cell to cell propagation.

For the cells or batteries that would not initiate a thermal runaway at a fully charged state when applying the test protocol, the working group considers two possibilities:

- the cell could be assigned to the relevant category according to the test result (category 1 to 3); and
- alternatively, such cells may be eligible for transport under conditions authorized by competent authorities, until the regulation is amended to address these non-reactive technologies (e.g. solid state batteries).

8.2 Test and criteria for evaluation of propagation

The purpose of the testing is to create a worst-case testing condition to assess the risk of thermal runaway propagation from cell to cell.

The propagation test is conducted by placing 4 of the same cells inside a thermally insulated test fixture designed to tightly maintain the 4 cells in a row. The initiation cell shall be placed at one end of the row, with the heater on the side of the initiation cell that is not adjacent to the next cell in the row. All other cells will be placed side by side, with the larger side used as the contact surface, or the longer side for cylindrical cells. There shall not be any material inserted between the cells. The compression of the row shall be verified.

The test fixture must have 6 sides to maximize heat containment. The test fixture shall have the required mechanical robustness to contain all mechanical ejections, including through the lid, but allow for gas and flame exhaustion. Each cell will be equipped with a thermocouple.

The initiation cell shall be heated at a rate of $[15 \pm 10 \text{ °C}]$ per minute [ref to UN GTR/ISO 6469-1 to be checked if applicable to larger cells], based on the measure of the control thermocouple. The power of the heater shall be controlled manually or electronically to maintain the heating rate constant during the whole test duration. The heater power shall be cut off when a thermal runaway is detected (detection of an increase of temperature slope without increase of the heater power for more than [3 minutes]), or when the cell temperature has reached 350 °C for at least 1 minute. The data are recorded for 6 hours after stopping the heater.

Test criteria: The temperature of the cells in the row will be used to detect the propagation of the thermal run-away. The test will demonstrate the absence of propagation when the 4th cell in the row does not experience thermal run-away. In the case of propagation, the time difference between two successive cells experiencing thermal runaway in the row (based on the detection of the maximum temperature reached by each cell) will be measured. The propagation time will be calculated based on the average of all the time differences measured during the 3 repetitions of the test. The result is proposed to be expressed as:

- no propagation; or
- propagation (Propagation rate below [1000] mm per min); or
- rapid propagation (Propagation rate above [1000] mm per min).

NOTE: the IWG agreed to give this further review and welcomes the views of the Sub-Committee.

8.3 Test and criteria for evaluation of fire

The purpose of the test is to create a worst-case testing condition to assess the risk of flame generation in the case of thermal runaway of a cell or multiple cells.

The testing method applied is the one used for the determination of the thermal runaway propagation (as stated above). However, to detect flame the use of a video recording device is proposed to capture the potential appearance of flames at any of the gas exhausts of the thermally insulated test fixture.

Test criteria: the video recording of the test will be analyzed to detect the presence of flame.

The test result will be expressed as a cell property: generate fire or do not generate fire.

8.4 Test and criteria for evaluation of gas hazard

The purpose of the test is to determine the quantity of gas generated in the case of thermal runaway of a cell. To determine the hazards category attached to this quantity of gas the working group may consider the inclusion of some external factors such as the average volume where the gas is likely to create a hazardous atmosphere. It is considered by default that all lithium battery cells generate toxic gas. The test to demonstrate the absence of gas toxicity is therefore not proposed in this classification.

The flammability hazard of the gas is not applicable to all lithium batteries. Testing to determine gas flammability is optional for assignment to either category 6 or 7. If testing is not conducted then category 7 is the default.

The testing method used to determine the quantity of gas generated by a single cell in thermal runaway is based on capturing of the gas generated inside an enclosure, equipped either with a gas pressure and temperature measurement, or with a volumetric gauge.

The thermal runaway is initiated in a similar way as for the propagation test, except that it only applies to a single cell.

The chamber for gas volume measurement shall be a tight enclosure, filled with inert gas (nitrogen or argon) enabling to measure the gas volume released in absence of combustion. The chamber size will be determined based on the size of the cell, and the potential maximum volume of gas released.

The necessary time for temperature and pressure to stabilize and homogenize must be allowed before making the pressure and temperature measurements.

A fan must be placed in the enclosure to achieve good temperature homogeneity inside the chamber.

Test criteria: the result of the test will be expressed as a volume of gaz in liters, at ambient temperature and normal pressure.

The result could be expressed as:

- no gaz volume measured; or
- gaz volume below [XX] liters; or
- gaz volume above [XX] liters.

In addition, the determination of the flammability of the gas may be required to discriminate between the categories 6 and 7, applicable to potentially large quantities of gas. This classification may also be useful if the volume of gas generated by a single cell (see previous test) exceed the threshold defined in some specific transport conditions for flammable gas.

The testing method to verify gas flammability is under discussion amongst the IWG testing laboratory members based on their specific competency conducting such tests. Using standard ISO 10156 which specifies methods for determining whether or not a gas or gas mixture is flammable in air and whether a gas or gas mixture is more or less oxidizing than air under atmospheric conditions based on testing or calculation was suggested.

Test criteria: the result of the test will be expressed as a gas property for the cell tested: flammable or non-flammable gas.

8.5 Test and criteria for evaluation of temperature hazard

The purpose of the test is to create a worst-case testing condition to assess the maximum temperature of a cell or cells when the propagation test is conducted.

The determination is based on the use of a thermocouple on the last cell of the row. To capture the maximum temperature during the test the thermocouple will be placed on the surface of the cell that is furthest away from the initiation cell and insulated from any test fixture contact.

Test criteria: the temperature recording of test will be analyzed to detect the maximum temperature for a period of 3 minutes.

The test result will be expressed as a cell property: maximum temperature observed during the test:

- exceed a 150 °C increase above the temperature at the time the heater is stopped; or
- is below a 150 °C increase.

9. New classification system for batteries

The nature of the hazards relative to the lithium batteries have been identified as similar to the one relative to cells. They are:

- the capability for a thermal run-away to propagate inside the battery and from battery to battery;
- the capability to generate fire;
- the capability to generate significant quantities of gas. The gaz composition may be toxic and/or flammable. However, the working group decided not to differentiate between these two properties but base the classification on the quantity of gaz; and
- the capability to produce high temperature.

Additional components applied to batteries, such as plastic or metal casings, electric or electronic components, are not generating additional hazardous reactions.

Therefore, the proposed classification of the cells, according to these hazards, is also applicable to batteries.

The testing protocol proposed for batteries is differing from the one for cells. It is based on the principle of a single battery testing, with a criteria for maximum external temperature, assumed to demonstrate the impossibility of propagation from battery to battery or battery to environment, in all cases.

Measuring the intensity of the effect at the battery boundary would enable to define criteria related to the propagation risk.

Classification: detection of propagation, flames, gas volume, and maximum temperature.

In a similar way as for the cells, the battery classification by default when not tested is the same as the cells classification by default, which is category 9.

To assess the hazard category, a battery test can be run to determine propagation risk, fire risk and actual quantity of gas generated.

Furthermore, the working group is still considering the possibility to define a method clarifying when a battery test would not be necessary and the tested cells classification would be applicable, provided the battery design is recognized fulfilling specific design requirements (battery design criteria under development: description of battery design properties ensuring that the assembly of non-propagative cells results into a non-propagative battery).

The test 2 applicable to cells for the determination of the quantity of gas is also applicable to the batteries, with a total calculated quantity of gas obtained from the cell quantity times the number of cells in the battery. Alternatively, the complete battery could be used for the gas test.

The quantity of gas the emission of flames and the external temperature at the battery external surface would be sufficient criteria to determine the hazards of a battery.

10. Testing requirements to support battery classification

10.1 Principle for the initiation of the battery reaction

The tests for the hazards classification are based on the initiation of the thermal runaway of the battery, with the same method as for the cells, applied to one cell inside the battery.

The cell selected to be the initiation cell inside the battery cannot be identified based on a physical description, due to the multiple batteries design, but based on a guidance of general principles. The selected cell should be the one providing more risk of propagation. Particularly, the selected cell shall be fulfilling the following conditions, as far as applicable:

- the cell shall be on a battery side, in a position enabling the application of the heater,
- the cell shall be at the shorter distance of neighboring cells, considering the general battery design, and
- the cell shall not be closer or better connected to thermal masses or cooling systems when compared to other cells, considering the general battery design.

In the cases where the application of a heater on a cell is not technically possible, other equivalent ignition methods may be applied (overcharge of one cell, overcharge of a module, use a laser, use specially prepared cells with internal short circuit system, ...). This alternative method would only be acceptable in the case it generates a thermal run-away reaction on the initiation cell.

10.2 Test and criteria for evaluation of propagation

The test purpose is to create a worst-case testing condition to assess the risk of thermal runaway propagation inside the battery, and from battery to battery.

The propagation test is applicable to a single battery, with the initiation cell selected as indicated above, with the heater on the initiation cell, located closest to an external side of the battery.

Similarly to the cells test, the initiation cell shall be heated at a rate of [15 ± 10 °C per minute], based on the measure of the control thermocouple. The heater power shall be cut off when a thermal runaway is detected (detection of an increase of temperature slope without increase of the heater power for more than 3 minutes), or when the cell temperature has reached 350 °C for at least 1 minute.

The battery will be equipped with external thermocouples on each surface of the battery, except the surface with the initiation cell. For placing the thermocouples, representative positions for each side of the battery should be selected, to represent the maximum measurable temperature of the surface of the battery.

Test criteria: the temperature recording of test will be analyzed to detect the maximum temperature for a period of [3 minutes].

The result shall be expressed as a battery property: no surface temperature above 100 °C except momentary spike below 200 °C.

[Additional discussions are needed to clarify: Alternatively, a method using several batteries, similar to the cell propagation method, should be possible to verify the propagation risk between batteries in specific cases:

- in the case of batteries where the casing is hot or melting, but do not propagate the thermal runaway to a neighbor battery of the same type; and
- in the case of single cells batteries, or batteries without casing].

[Decision for the batteries without casing, where to place the thermocouples to be discussed].

10.3 Test and criteria for evaluation of fire

The purpose of the test is to create a worst-case testing condition to assess the risk of flame generation in case of thermal runaway of a cell in the battery.

The testing method applied is the one used for the determination of the thermal runaway propagation (see above). The additive requirement is the installation of a video recording device, to capture the potential apparition of flames at any of the gas exhausts of the battery.

Test criteria: the video recording of test will be analyzed to detect the presence of flame during the test or not.

The test result will be expressed as a battery property: generate fire or do not generate fire.

10.4 Test and criteria for evaluation of gas hazard

The test purpose is to determine the quantity of gas generated in case of thermal runaway of a cell(s) inside a battery. Similarly to cells, the determination of the hazards attached to this quantity of gas may depend on the transport mode and the external conditions of transport (packaging, quantities transported etc.).

Two protocols are proposed for the determination of gas quantities:

- the test protocol applicable is exactly the same as the one applicable to cells classification. In this case the determination of the number of cells that have reacted inside the battery during the propagation test will be required for the criteria calculation; and
- when a single cell cannot be separated or made available from another source, then the test protocol described for the gas volume determination is applied to the complete battery, the heater being applied to a single cell in the battery.

The chamber for gas volume measurement shall be similar to the one used for the cells classification test.

Test criteria: the result of the test will be expressed as a volume of gas in liters, at ambient temperature and normal pressure.

In the case a single cell has been tested, then the measured volume of gas shall be multiplied by the number of cells that have reacted during the thermal run-away propagation test of the battery, or the total number of cells in the battery in the case the result for the propagation test is not available.

11. If the Sub-Committee validate this approach, the IWG will work on:

- drafting amendments proposal to translate the presented hazard classification and test protocol for the model regulation Manual of Tests and Criteria. The test protocol in the annex used by the labs can be used for this purpose; and
- explain the transport conditions of each category.

12. Application to alternative SOC cells and batteries

By default, a cell or a battery is given a category at 100% SOC, defining its intrinsic hazard category. However, in the testing phase of the procedure, the IWG obtained results showing that cells or batteries at lower SOC are usually given another hazard category. The Sub-Committee has, in several occasions be confronted to proposal to transport batteries at lower SOC. This kind of transport at reduced SOC are already existing in ICAO regulation under the assumption that lower SOC leads to lower hazard. Up to now there is no clear method to assess such hypothesis. The IWG believes that this decision diagrams can also be used to assess the cell or batteries hazard at lower SOC. In practice, it can be used to categorize a cell or battery at a lower SOC as a different “object” and it can be a very good way to ensure the safe transport of cells and batteries.

To allow such a classification at reduced SOC, two conditions should be nonetheless verified:

- the sender should be able to guaranty through manufacturing process and quality management system that the transported cells/batteries have a controlled SOC; and
- a new series of test should be performed, to determine the hazards classification according to the classification tree applied to the cells at reduced SOC.

The IWG invites the Sub-Committee to include in the term of reference of the IWG the work on the demonstration and a method to assess that lower SOC leads to lower hazard category, as well as drafting amendments to introduce this in the model regulation. A method of control and identification of cells and batteries transported in such condition should also be part of the work.

13. Further developments concerning packaged cells and batteries

The IWG invites the Sub-Committee to also include in the term of reference of the IWG proposals for the use of this test method to assess the danger of cells and batteries inside a packaging and the definition of transport condition related to those packaging.

Indeed, the testing protocol for batteries may consider the battery boundary similar to how packaging may protect a battery and may be transposed to test batteries and cells in a packaging.

Annex 1

Draft of the detailed testing protocol

Note: This draft reflects the protocol as it was applied by the test labs on cells, previous to the UN IWG meeting in Seoul. It presents some differences with the document presented above. This protocol will be corrected and completed to define the final protocol.

Cells and batteries test protocol

Draft following the January 25th, 2023 meeting

1. Rationale

Description of a test protocol for the determination of the hazardous properties of lithium cells and batteries in case of thermal runaway initiation and propagation.

General chemical or electrical properties and related hazards (such as high voltage batteries hazards) are not considered in this protocol.

Abusive conditions rationale for thermal runaway initiation: The propagation and gas tests are based on the initiation of the thermal runaway of the cell (or cell in battery) by an abuse method representing the best compromise between the simulation of the internal short circuit, the control of the implementation and the reproducibility of the reaction. The selected method is the application of heat on the surface of the cell or battery by a controlled heater in order to abuse a localized zone of typically 1 cm³ (0.1 cubic inch) until the thermal runaway reaction is initiated inside the product.

2. Scope

All chemistries of lithium cells and batteries

3. Test procedure for cells and batteries

3.1. Device Under Test (DUT)

The DUT are cells or batteries, according to the definition of Manual of Tests and Criteria sub-section 38.3.

The SOC shall be verified at 100% SOC or undischarged primary cells or batteries, less than 72 hours before the test. The following IEC battery standards provide guidance in determining the capacity of secondary cell or battery: IEC 61960-3, IEC 62133-2, and IEC 62660.

The DUT shall be maintained at ambient temperature for a period of time necessary to reach a homogeneous stabilized temperature, as measured on the external casing of the cell or the battery, of 20 ± 10 °C.

3.2. Test instrumentation and equipment

3.2.1. Thermocouples (all tests)

The thermocouple shall be of type K or other suitable type to measure temperatures up to 600 °C.

The precision shall be equal or better than 2 °C, the time response below 2 s. The temperature recording system shall be used at a minimum frequency of 1 Hz.

3.2.2. Heater (all tests)

The heating source shall be capable to maintain a heating rate of 15 ± 10 °C/min between the initial a temperature and 250 °C minimum. (Rationale : the measure of the hazards will be mainly based on the consequences of the propagation, and less influenced by the initiation cell).

The size of the heater contact area shall be 20% of the cell surface or smaller, unless the heater induces a cell rupture under the heater. For button cells and cells with surface below 5 cm², the heater can be as large as the surface, to avoid local cell wall failure. (The description of the effect is not sensitive to the heater technology change or available products. An example of the practical solution is useful). More test data needed for cells with thick can to specify the maximum size of heating size).

3.2.3. Thermally insulated container (only for cell Propagation test)

A thermally insulated container shall be designed to tightly maintain the 6 cells in a row. The container must have 6 sides in order to maximize heat containment. The container shall have the required mechanical robustness to contain all mechanical ejections, including through the lid, but allow for gas exhaustion. See figure (typically holes or slits on the lid or on one side shall enable the gas exhaust).

The insulative material shall have a thermal conductivity below 0.3 W/m.K with a minimal thickness of 5 mm. Insulation material shall not melt or decompose below 800 °C.

The container shall be equipped with a system ensuring the compression of the cells in the direction of the row, with at least 1 kg force. This pressure shall be controlled before test initiation.

3.2.5. Chamber for gas volume measurement (only for gas volume test)

The gas volume can be measured by a static method (option 1) or a dynamic method (option 2).

Option 1: The chamber for gas volume measurement shall be a tight enclosure, filled with inert gas (nitrogen or argon enabling to measure the gas volume released in absence of combustion, thanks to a pressure gauge.

The chamber size will be determined based on the size of the device under test, and the potential maximum volume of gas released.

The chamber shall be equipped with a gas temperature measurement.

The necessary time for temperature and pressure to stabilize and homogenized must be allowed before making the pressure and temperature measurements.

A fan may be necessary to achieve good homogeneity inside the chamber.

Option 2: The chamber will be equipped with a valve with a volume measurement system, and a temperature measurement system. To be complete with technical information on the measurement system?

In all cases, the volume of gaz will be calculated at room temperature and ambient pressure, using when needed the ideal gas law ($PV=nRT$).

3.2.6. Camera for flame detection and recording (for the Propagation test)

3.3. Test set up

3.3.1. Propagation test set up

3.3.1.1. In the case of cells, the test is applied to 6 cells. (rationale: the hazards measured on the final 4 cells are more representative of the real self-propagation, and less influenced by the initial triggering conditions).

Each cell is equipped with at least one thermocouple. The position of the thermocouple shall allow to record the representative cell temperature increase, with minimal influence of temperature of cells having previously reacted, or influencing the heat transfer between cells. See figures for cylindrical and pouch/prismatic cell format.

One cell shall be equipped with a heater and a dedicated thermocouple for the heating rate control. The heater will be placed in the center of one main surface of the cell, with minimal influence on other cells. This thermocouple shall be placed at a distance of 5 ± 3 mm of the side of the heater, or 3 mm for small cells.

The initiation cell shall be placed at one end of the row, with the heater on the opposite side of the row. All other cells will be placed side by side, with the larger side used as the contact surface, or the longer side for cylindrical cells. The compression of the row shall be verified.

The video recorder shall be placed in a way to detect the potential emission of flame through the vents of the thermally insulated container.

3.3.1.2. In the case of batteries

[Rationale: Batteries will act similarly to packaged cells. For this reason, the battery could be considered a package, and testing is conducted in this manner. When the purpose is the demonstration that battery do not propagate to other batteries, this test would be sufficient].

The Battery test does not require a container.

One cell in the battery shall be equipped with a heater.

For placing the Heater: determination of the best appropriate place and method to heat 1 cell on a battery edge. The selected cell should be the one providing more risk of propagation. Other equivalent ignition methods may be applied if the heater cannot be applied (overcharge of one cell, use a laser, use a specially prepared cells with internal short circuit system,...).

Temperature measurements on the outside of the casing are acceptable.

For placing the thermocouples, representative positions for each side of the battery should be selected, in order to represent the maximum measurable temperature of the outer surface of the battery.

[The rationale is that even if cells propagate within the battery, the battery casing could prevent enough heat from escaping and igniting combustible materials or adjacent batteries. The battery test would be to determine if enough heat is generated on the external surface of the battery that could lead to propagation of adjacent cells or other packing materials. Provisions noted in packing instruction P911 for damaged/defective cells would be an acceptable pass criterion. The (no temperature above 100 °C or a momentary spike above 200 °C).].

The video recorder shall be placed in a way to detect the potential emission of flame through the vents of the battery.

As this is a propagation test, gas production would not be a consideration at this point in the protocol.

3.3.2. Gaz volume test set up

The test is applied to 1 cell.

The cell shall be equipped with a heater and a dedicated thermocouple for the heating rate control. The heater will be placed in a way to directly heat the cell internal active material. This thermocouple shall be placed at a distance of 5 ± 3 mm of the side of the heater, or 3 mm for small cells (18650 or smaller).

The cell shall be placed vertically in the chamber, and the chamber filled with inert gas (or air if nonflammable gas).

By difference to the propagation test, the conditions for heating should be closely followed to avoid influence on the amount of gas generated: heating rate of 15 ± 10 °C per minute between the initial a temperature and 250°C minimum.

3.5. Tests conduct

3.5.1. Propagation test

All equipment shall be set to register the required information for determination of the measured criteria.

The DUT shall be heated at a rate of 15 ± 10 °C per minute, based on the measure of the control thermocouple. The power of the heater shall be controlled manually or electronically in order to maintain the heating rate constant during the whole test duration. The heater power shall be cut off when a thermal runaway is detected (detection of an increase of temperature slope without increase of the heater power for more than 3 minutes), or when the cell temperature has reached 400 °C.

After cut-off of the heater, the DUT will remain under recording conditions for 3 hours (in case of absence of observed thermal runaway)

3.5.2. Gaz volume analysis

Seal and evacuate the test chamber to approximately 0.2 psia:

- add nitrogen (or air if non flammable gas) into the chamber to bring the pressure back up to 14.7 psia;
- activate the heater until thermal runaway occurs;
- allow the chamber to cool to its initial temperature; and
- use the change in pressure caused by venting to calculate the volume of gas emitted (assume ideal gas).

3.6. Tests repetition

3 similar test shall be runed. The more severe criteria measured over the 3 tests shall be reported as the DUT hazard measurement criteria.

3.7. Criteria measurement and recording

The following criteria will be measured and recorded:

For the propagation test:

3.7.1 Thermal run away propagation hazard

For cells: The temperature of the cells in the row will be used to detect the propagation of the thermal run-away. In case of propagation, the time difference between two successive thermal runaway in the row (based on the detection of the maximum temperature reached by each cell) will be measured. The average propagation time will be calculated based on the average of all the time differences measured during the 3 repetitions of the test.

For batteries: the propagation inside the battery will be measured in the same way as for the cells. Pass criterion: no temperature above 100 °C or a momentary spike above 200 °C measured on the surface of the battery.

3.7.2 Flame hazard

The video recording of DUT will be analyzed to detect the presence of flame during the test or not.

3.7.3 The temperature hazard

The maximum temperatures measured during the test for each cell shall be recorded. In order to avoid erratic measures (such as intermittent record of flame temperature), only the maximum temperatures presenting a consistent value during at least two seconds shall be recorded.

For the gas volume test:

3.7.4 The gas volume hazard

The pressure of gas and the temperature of the gas shall be recorded, and the volume of gas ejected shall be calculated.
