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

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Sub-Committee of Experts on the Transport of Dangerous Goods
Fifty-eight session
Geneva, June 2023
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 expert from France on behalf of the informal working group[1]

1. Following the last physical meeting of the UN IWG, the following recommendation are proposed for a future hazardous based classification of lithium batteries. This document describes the achievement of the IWG so far. It contains the presentation of 9 categories and the decision diagram associated as well as the test procedure and criteria to assess in which category a cell/battery belongs. However tThe IWG wishes to present the principles agreed so far in order to get an did not drafted this text formally approval of the subcommittee to continue the drafting of more formal proposals. in a suitable way to be include in the regulation.

2. The proposed classification aims to classify cells and batteries according to their intrinsic hazards. It complements current transport condition and does not aim to replace current transport condition and testing requirement according to the UN MT&C 38.3.

2. The UN existing classification of lithium batteries still apply (UN 3090 and UN 3480) based on 38.3. The new scheme would allow in addition to differentiate 9 categories according to their intrinsic hazard in case of thermal runaway.

3. By As a result of the testing performed by the UN IWG members, the following hazards have been identified. In case no test is performed, the cells will be considered as category 9, as presented in the diagram below . The following default values may be assumed: By default, the hazards

[1] In accordance with the programme of work of the Sub-Committee for 2019–2020 approved by the Committee at its ninth session (see ST/SG/AC.10/C.3/108, paragraph 141 and ST/SG/AC.10/46, paragraph 14).

are identified as the one of representative products (worst case) of typical Li-ion or Li-metal batteries with common chemistries, represented by the category 9 according to the classification tree presented below: For such default classification, it is assumed that : - (measured for li-ion cells)

- the propagation occurs from cell to cell with a speed of1 min 8s for [100 mm/8s]
- the gas emissions can contains 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.,
- the fire risk is applicable [and maximum temperature related to fire]

4. The classification tree would be presented in the model regulation vol 1, 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.

5. In order to determine a specific classification of the cell or battery, 3 similar 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/battery hazard measurement criteria. If one of the tests can not be completed and makes the hazard evaluation impossible, additional tests shall be run, until a total of 3 valid tests are completed.

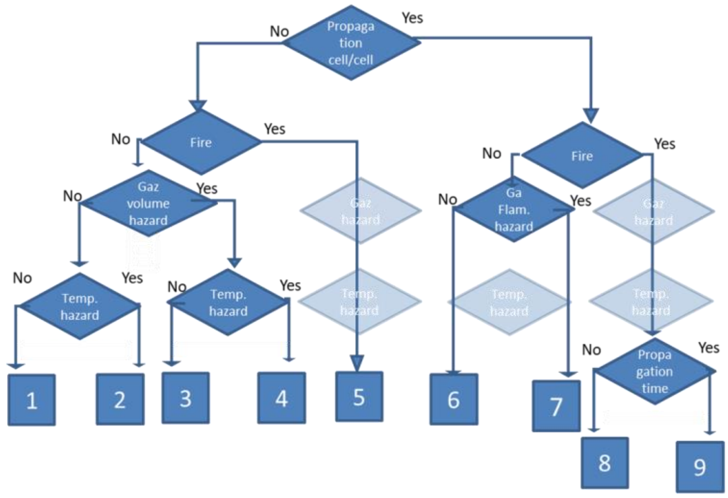
6. **Introduction of the new classification proposal for cells**

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

- 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 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.
- The capability to produce high temperature.

The possible combinations of these hazards have been considered, and a proposal for a classification of the cells, according to these hazards, has been agreed upon a classification tree, enabling to clarify the presence or absence of each hazard relative to a product, has been proposed.

This classification tree represents on its last line the potential grouping of hazards, applicable to the various lithium batteries chemistries.



In this tree, light blue diamonds are representing hazards that are always applicable in this class, and therefore are not submitted to test verification. The hazard level of each class is not corelated to the value of the class.

This classification is applicable for 100% SOC cells, without considering the packaging.

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

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

7.1 Principle for the initiation of the thermal reaction

The proposed tests for the hazards classification are based on the initiation of the thermal runaway of the initiation cell 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 is the application of heat on the surface of the cell or battery by a controlled heater in order to abuse a localized zone until the thermal runaway reaction is initiated inside the cell or that the cell surface temperature has reached 400°C 350°C for 1 min. 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 of the commercially available fully charged lithium cell will go into thermal runaway. reaction initiation makes that most of the current commercially available Li batteries technologies are expected to react into a thermal runaway , when fully charged or at intermediate SOC. All the batteries tested during the test protocol study, reacted below this temperature.

For the potentially future cells or batteries that would not initiate a thermal runaway at a fully charged state when applying the test protocol,

it may also be appropriate that if no reaction occurs at the maximum temperature (350 oC), the working group considers two possibilities:

- the cell could be assigned to the relevant category according to the test result (category1 to 3).
- Alternatively, such cells may be eligible for transport under conditions authorized by competent authorities, until the regulation is amended to address these new technologies (e.g solid state batteries)..

7.2 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 from cell to cell.

The propagation test is applicable to 4 cells in a row, with the initiation cell 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 cells will be placed inside a thermally insulated container designed to tightly maintain the 4 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 and flame exhaustion. Each cell will be equipped with a thermocouple.

The initiation cell shall be heated at a rate of [15+-10°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 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 350°C. The data are recorded for 6h 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 case of propagation, the time difference between two successive thermal run-away 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 could be expressed as :

-No propagation, or

- propagation (Propagation rate below [1000] mm per min) , or

~~[Propagation rate between [100-10] mm per min~~

- rapid propagation (Propagation rate above [1000] mm per min)

~~[rationale: inspired from MTC 33.2.4.4.1 Powdered, granular or pasty substances should be classified as flammable solids when the time of burning of one or more of the test runs, in accordance with the test method described in 33.2.4.3.2, is less than 45 s or the rate of burning is more than 2.2 mm/s. Powders of metals or metal alloys should be classified relatively to the time for first responders to be on site]~~

7.3 Test and criteria for evaluation of fire

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

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

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 cell property: generate fire or do not generate fire.

7.4 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. 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…). It is considered by default that all lithium battery cells generate toxic gas (see §4). The test to demonstrate the absence of toxicity of a gas is therefore not proposed in this classification.

On the contrary, the flammability hazard of the gas is not applicable to all lithium batteries.

The working group is working on a supplementary option, an additional test or determination method, with the purpose to determine whether the gas is flammable or not.]

On the contrary, 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 applied to determine the quantity of gas generated by a single cell in thermal runaway is based on the capture of the gas generated inside an enclosure, equipped either with a gas pressure and temperature measurement, or with a volumetric gauge.

The thermal run-away is initiated in similar way as for the propagation test, except that is 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 homogeneity inside the chamber.

Test criteria: the result of the test will be expressed as a volume of gas 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.

Option B:

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 between the UN
IWG testing laboratories. The ISO 10156 standard allows determination based on testing or calculation.

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

7.5 Test and criteria for evaluation of temperature hazard

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

The testing method applied is the one used for the determination of the thermal runaway propagation (§ above). The determination is based on the use of the thermocouple on the first cell of the row, to capture the maximum
temperature during the test. The thermocouple will be placed on the cell surface, opposite side of the row, and insulated from any container 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.

8. **Introduction of the new classification proposal 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.
- 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.

The testing protocol for batteries may consider the battery boundary similar to how packaging may protect a battery under the packaging test according to P911.

~~The testing protocol is similar to the one applicable to a package test according to P911~~, Measuring the intensity of the effect at the battery ~~casing as a~~ boundary would enable to define criteria related to the propagation risk. ~~in the same way as a packaging~~. The tests enable to measure the hazards as required for the 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 hazardous properties, a battery test can be run to determine propagation risk, fire risk and actual quantity of gas.

[A battery test would not be necessary and the tested cells classification would be applicable, when 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, [for discussion]).

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 gaz 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. [~~Possibility to test as well one cell in the battery, when more practical ?]~~.

9. Introduction of the testing requirements to support battery classification

9.1 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.
- 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.

9.2 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.

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 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,

-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]

9.3 Test and criteria for evaluation of fire

The test purpose 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 (§ 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.

9.4 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:

- ~~When a single cell can be separated~~ from the battery, ~~or a similar single cell than the one used in the battery can be supplied, then~~ 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.
- 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. ~~This method is not recommended for large batteries~~ with internal propagation~~, as the quantity of gas generated during the test may be very~~ .

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.

10. If the subcommittee validate this approach, the IWG will work on

- Drafting amendments proposal to translate the presented hazard classification and test protocol for the model regulation MTC. The test protocol in the annex used by the labs can be used for this purpose.

- Explain the transport conditions of each category.

10.11. 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 subcommittee 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 batterie 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 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
- 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.

~~Several option may be considered:~~

~~Option a :~~

~~If a cell at reduced SOC shows no initiation, the cell is classified as the cell at the lowest SOC where an initiation was observed.~~

~~Option b :~~

~~If a cell at reduced SOC shows no initiation. To evaluate initiation, the “initiation cell” of the test shall be at the lowest SOC where an initiation was observed, and the rest of the cells (witness) shall be at SOC under evaluation. To evaluate presence of fire hazard, fume hazard and temperature hazard, the effect observed on the test at reduced SOC shall be considered.~~

~~Option c :~~

~~If a cell at reduced SOC shows no initiation and has been classified at a higher SOC, it is classed in category 1~~

~~Option d: applicable in case the Sud-committee accept classification as 1 2 or 3 in absence of reaction at 100% SOC: use the same method as decided by the subcommittee at 100% SOC.~~

The IWG invites the subcommittee 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. The IWG invites the subcommittee 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 packagings.

Annexe 1 :

Draft of the detailed testing protocol.

Commented [BA1]: Je ne sais plus quelle est la dernière version, je te laisse l'inclure ?

Cells and batteries test protocol

Draft following Jan 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 run-away 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 MoT&C 38.3.
The SOC shall be verified at 100% SOC or undischarged primary cells or batteries, less than 72h before 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 2s. 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 [5] °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, in order to avoid local cell wall failure. (the description of the effect is not sensitive to the heater technology change or available products. A exemple 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.

~~3.2.4. Equipment to detect flammability of gas (for all tests)~~

~~Labs can propose an equipment for the testing of the gas flammability (by test instead of composition). Usage of a sparkling system, burner of gas, installed on a gas exit of the thermally insulated container. To be defined. To be preferred to the chamber test, which will be applicable in the gas volume test. Issue of gas velocity at the gas exit: may require an additive “dilution and accumulation chamber” to conduct the gas and test flammability.~~

~~Sparkling in a chamber SAE AS6413 std ? the chamber should be smaller than in the std , because limited number of cells? The sparkling system can be communicated.~~

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

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

The chamber for gas volume measurement shall be a tight enclosure, filled with inert gas (nitrogen or argon ~~in case of already demonstrated flammable gas), or air (to demonstrate absence of flammability~~) 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 stabilze and homogenized must be allowed before making the pressure and temperatre measurements.

A fan may be necessary to avieve 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 case of cells, the test is applied to [6] [4?]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 cyclindrical 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 to 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 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 +-3mm of the side of the heater, or 3mm for small cells (18650 or smaller).
The cell shall be placed vertically in the chamber, and the chamber filled with inert gaz (or air if non flammable 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 [5] °C/min between the initial a temperature and 250°C minimum
Option test 3: ~~additive test setup conditions for the gas composition measurement (postponed)?~~ Not described in this protocol.

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+-5°C[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. ~~the total energy used by the heater is exceeding the heated cell electrical energy content (with a potential margin to be discussed).(or check what 's happening in case of continuous heating as another option).~~
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.
• Use the change in pressure caused by venting to calculate the volume of gas emitted (assume ideal gas).
~~Gas test conduct: Optional test 3: additive conditions for the conduct of the gas composition measurement to be defined later?~~
~~• proposal: fill the chamber with nitrogen to 20 psia.~~
~~• Once the chamber again cooled to its initial temperature, vent the chamber into a gas sample bag or analyzer.~~
~~• Convert gas concentrations to determine the concentrations of the gases if they had not been diluted.~~

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 run-away 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 oC or a momentary spike above 200 oC meaqsured 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 gaz volume test:

3.7.4 The gaz volume hazard.

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

~~Option 2: additive list of criteria and methods for the calculation of the gaz composition?~~