Single Cell Thermal Runaway Propagation

OICA comments and suggestions to modify the text are indicated by red colored fonts and, in some cases, explained in a directly following colored box.

The purpose of this document is to facilitate arrival at a common understanding among EVS IWG contracting parties on thermal runaway propagation. Several contracting parties are embarking on a thermal runaway propagation experimental research campaigns for Phase 2 and a common understanding is important to help focus research efforts especially considering the complexity of cost-intensive thermal propagation tests. This approach is expected to further facilitate coordination of contracting parties' research and to pave a path for effective round-robin testing.

For this purpose this document contains a non-exhaustive list of questions for discussion and agreement among experts.

EVS-GTR – Phase I

The EVS-GTR requires manufacturers to provide documentation that demonstrates their system design to provide a warning to vehicle occupants in the event of a single cell thermal runaway due to internal short circuit to allow safe egress from the vehicle.

EVS-GTR currently does not specify a thermal runaway propagation test procedure however it does describe, as an example, a test procedure that was developed jointly by China and Japan during Phase 1. The single cell thermal runaway initiation methods initially considered in this test method are: nail penetration, heating, and overcharge. The EVS Working group agreed that further research was needed on the topic of thermal runaway propagation to:

- Evaluate initiation methods and their feasibility, repeatability, and reproducibility,
- Investigate the effect of manipulation of the test device on test results,
- Investigate potential new methods for initiation, including methods which minimize manipulation of the test-device, and
- Evaluate appropriateness of pass/fail criteria.

The EVS-GTR was developed based on the following principles:

- Safety level is equivalent to conventional vehicles with internal combustion engine and to prevent EV specific hazardous events, assuming a reasonable level of robustness,
- Assess the potential safety risks during normal use (driving, parking, charging) and post-crash
- Safety validation of entire battery system of the vehicle,
- Performance based requirements without being design restrictive,
- Requirements and test procedures that are reasonable, practicable, and effective, and
- Test procedures that are repeatable and reproducible.

Considerations for Single Cell Thermal Runaway Propagation for EVS-GTR Phase II

Objective – The objective in Phase II is to ~~develop a repeatable and reproducible~~ **justify the need for a** test procedure that represents a single cell thermal runaway due to internal short circuit in a REESS and **to design and develop a repeatable and reproducible test procedure as well as** to assess the appropriateness of evaluation criteri**a**~~on~~ and pass/fail limits.

Special consideration**, in addition to the principles considered in phase I of the EVS-GTR development,** is given to:

- The relevance of the test in representing a single cell thermal runaway due to internal short circuit,
- The repeatability and reproducibility of the test, and
- The extent of manipulation of the test-device and its effect on the test results.

> OICA suggests that the language of "objective" should be modified to reflect the questions to address field data analysis. The principles agreed for phase I should also be applied for phase II for consistency.

The following questions were raised in the 14th EVS-GTR meeting regarding the development of a thermal runaway propagation test:

Is ~~thermal propagation due to~~ an internal short single cell thermal runaway ***or propagation of such thermal runaway*** *a problem in the field?*

1. *Does field data exist on this topic? Experience from different countries and industry.*
2. *Can industry provide cases of success where an internal short of a cell was detected in the field and appropriate intervention action was taken?*
3. *Does field data inform on a specific test condition or method?*

> OICA considers that collection, analysis and examination of relevant field data are essential for EVS-GTR IWG in developing a new test procedure. The scope of field data collection can be extended with the amendment proposed above.

Simulation of a single cell thermal runaway

1. What are we trying to simulate?
   - Should the test specifically simulate a single cell thermal runaway due to internal short (i.e. scenario specific)?
     - Is this a realistic internal short circuit scenario?
     - **Is there field data to verify the validity of this scenario as appropriate for demonstrating thermal propagation safety?**
     - *Does the test method consistently result in thermal runaway of the target cell?*

- **Is it a prerequisite of this approach that the test method must always succeed in initiating a thermal runaway in the targeted cell?**
- Would it be relevant to all technologies?
- Would it have acceptable repeatability/reproducibility?

For phase II development of EVS-GTR, the validity of such a scenario should be examined based on field experiences. With the growth of the EV fleet it should be possible to verify if this is an appropriate approach and, if this is the case, define the scenario addressed.

- Are we trying to initiate a single cell thermal runaway in the target cell regardless of type or format of cell or cause of thermal runaway, to assess thermal propagation response (i.e. scenario independent)?
  - Would this approach bypass the cell level safety?
  - Could this approach have acceptable repeatability/reproducibility?
  - **What consequences would a scenario independent approach have on future development of EV battery systems and their associated safety performance, e.g. thermal propagation preventive and/or mitigating technology and other safety enhancing functionality on the battery system?**

A scenario independent approach for EVS-GTR phase II assumes that thermal runaway must be an intrinsic characteristic of existing and future EV battery cell technology. The validity and the consequences of this assumption must be verified.

2. Are different methods of initiating single cell thermal runaway (nail penetration, ceramic nail penetration, slow heating, fast heating, overcharge, mechanical crush, etc) equivalent?
   - Would the different scenario independent methods of initiating single cell thermal runaway need to be equivalent?
     - Could non-equivalency of initiating method be addressed by modifying the evaluation criteria for each scenario independent initiation method?
     - **How can objective and accurate principles for matching initiating method with evaluation criteria be established to be certain that equivalency is achieved?**
     - **How can non-equivalency in safety performance requirements based on verification method be justified in an objective and comprehensive way?**

3. Which cells in a pack should be used to initiate a single cell thermal runaway?
   - Does it depend on the type of cells and pack design and feasibility of initiation?
   - Does it impact the outcome of the test?
   - **By what procedure or method should the target cell be identified/selected, e.g. by what standards is the “worst case” cell position selected?**

- **How should the feasibility of conducting the test on a specific target cell affect testing, e.g. prioritization between accessibility of a cell and selection of a cell representing "worst case"?**
- **Is "worst case" always the same cell position, regardless if a scenario dependent or a scenario independent approach is taken?**

4. Are the different methods of initiating single cell thermal runaway technology neutral (can be used on different types of cells and packs)?
   - Are some methods more suited for certain technologies?
   - Are there initiation methods that are technology neutral?
   - **What criteria or principles can be used to determine if a method is technology neutral?**
   - **What do we mean by technology neutral? Definition is needed~~,~~.**

Elimination of Detection and Intervention Technologies

1. *If thermal ~~runaway~~ propagation test is required, would this eliminate development of detection and intervention technologies?*
2. *Should battery systems that have internal short circuit detection and intervention technologies have the option of providing documentation of the operation of this system to prevent cell thermal runaway instead of conducting the thermal runaway propagation test?*
3. **What would be the long term effects of the thermal propagation test on the development of detection and intervention technologies?**
4. **Is there a risk that the test methodology "locks in" battery safety on the current state of the arts level and hinders/slows down expected safety performance progression?**
5. **Should it be possible to demonstrate the impossibility of thermal propagation in a prequalification test, and if so, what should the test conditions be?**

Ignition of vented gases

1. Is ignition of venting gases a necessity for a thermal propagation test or not?
2. Considering the potential of spark sources in close proximity in-situ, should ignition be caused intentionally during the test e.g. using a spark igniter?
3. **Is there field data to support the necessity of forced ignition of vented gases for the defined test scenario?**
4. **How would the test conditions take into account design features or functionalities in the battery system to prevent ignition of vented gases, e.g. systems designed to separate flammable gases from ignition sources?**

Evaluation Criteria

1. What should be the evaluation criteria (Pass/Fail conditions)?

- No propagation at all?
- Total containment?
- Egress test?
- **Other?**

2. Is the evaluation criterion in Phase I EVS-GTR (a warning be provided to vehicle occupants in sufficient time (5 minutes) for them to egress the vehicle safely) appropriate?

The evaluation criteria must be developed with respect to the safety of occupants and surrounding people. Additionally evaluation criteria must be appropriate for the test method.

3. Are the evaluation criteria feasible to quantify reliably with a single test? Should there be tolerances to the pass/fail limits?
    a. *One point made in the EVS-GTR meeting was that pass/fail limits should not have tolerances. The limits should be one value for enforcement purpose. The threshold limit selected should take into account the variability in test results.*
    b. ***If tolerances are applied, is it possible to develop a methodology to determine what the appropriate limits are?***

4. Is no thermal runaway after initiation a pass?

5. Should the evaluation criteria be different for different type of single cell thermal runaway initiation methods and for different types of cells?

6. **How do we ensure that the evaluation criteria are technology neutral and take appropriate account of the acceleration of test conditions?**

Repeatability and Reproducibility

1. How is repeatability of the test defined? The thermal runaway initiation of the target cell or the propagation results?
    a. *The ESV-GTR group recommends evaluating repeatability of thermal runaway initiation and repeatability of test results. Both are needed.*
    b. ***Battery pack variations, e.g. distance tolerances, should also be considered.***
2. How many tests need to be conducted to evaluate repeatability and reproducibility of the test? **Does this question apply to verification of the test procedure or verification of test compliance for certification?**
3. *The stochastic nature of the test and test results may require more than one test to be conducted (for example 5 tests are conducted in the flammability test in ECE R. 118). How many tests are needed? Are 3 to 5 tests sufficient? It would increase test cost. Should the pass/fail limits be selected to take into consideration the stochastic nature of the test results?*

Manipulation of test-device

1. Does the initiation method manipulate the test-device and would the test results be the same without manipulation of the test-device?
2. How do we assess if the manipulation of test-device has effect on the test results?
3. **What types of manipulation are acceptable?**
4. **Who is responsible for making the required changes to the test object, the Test House or the OEM?**
5. **How do we take effects of test object manipulation into account when determining appropriate evaluation criteria?**
6. **What conclusions can be drawn, and what consequences do these have on determining the validity of the test approach based?**

Specifics of initiation methods and environmental conditions

1. What are the test parameters for the choice of initiation method? For example:

   - For the heating method of initiation thermal runaway, what is the heating rate, heating area, maximum temperature of heater? What is the rationale for selection of these values?
   - For the nail penetration method, what is the size, shape, and material of nail? What is the rationale for the selection of these values?
   - *For nail penetration test – can the test be developed such that only one or two layers of the cell are penetrated instead of all the layers? This may result in a more realistic internal short circuit of the cell but such a test may not be as repeatable and reproducible. This issue may need to be investigated.*

IWG should not limit research to these initiation methods as it has not been determined that any of these methods is appropriate for the purpose of the test. Generally, the chosen initiation method should be representative of actual failure conditions and acceleration of test conditions should be avoided to minimize the risk of false failures and unrepresentative test results.

   - What are the ambient temperature conditions for the test?

- **How to take into account different geographic conditions and the possibility to carry out testing in a reasonable way (i.e. outdoor testing or non-climatized buildings for abuse tests)?**

Re-testing and re-homologation requirements

1. **In normal battery and vehicle development and lifecycle, changes are done. Which changes during the development or lifecycle process require a completely new testing and corresponding homologation and which changes can be considered to be so minor that a full retesting and re-release are not necessary?**