Submitted by the expert from Contracting Parties participated into SIG Thermal Propagation

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Model Regulation with respect to thermal propagation of REESS for electric power train

For comment by 30 April

Comment to be submitted to the Secretary (masaaaki_iwasaki@mail.toyota.co.jp) by 30 April 2024. Any technical and/or essential modifications should be accompanied with justifications.

Submitted by the expert from Contracting Parties participated into SIG Thermal Propagation

The text reproduced below was prepared by the expert from Australia, China, France, Germany, Japan, Republic of Korea, the Netherlands, the United Kingdom and the European Commission, aiming to improve implementation of thermal propagation requirements prescribed in the Global Technical Regulation No. 20 (ECE/TRANS/180/Add.20) with the view to introduce robust and practicable certification procedure.

The numbering of paragraph in this document corresponds to those of 03 series of amendments to UN Regulation No.100. Technical aspects of this model regulation may be adopted also for other national regulations based on Global Technical Regulation No.20.

I. Proposal

1. Scope

1.1. Part I: Safety requirements with respect to the electric power train of road vehicles of categories M and N[1], with a maximum design speed exceeding 25 km/h, equipped with electric power train, excluding vehicles permanently connected to the grid.

Part I of this regulation does not cover**;**

(a) Post-crash safety requirements of road vehicles.

(b) High voltage components and systems which are not galvanically connected to the high voltage bus of the electric power train.

1.2. Part II: Safety requirements with respect to the Rechargeable Electrical Energy Storage System (REESS), of road vehicles of categories M and N equipped with electric power train, excluding vehicles permanently connected to the grid.

Part II of this Regulation does not apply to a battery whose primary use is to supply power for starting the engine and/or lighting and/or other vehicle auxiliaries' systems.

2. Definitions

For the purpose of this Regulation the following definitions apply:

2.1. "*Active driving possible mode*" means the vehicle mode when application of pressure to the accelerator pedal (or activation of an equivalent control) or release of the brake system will cause the electric power train to move the vehicle.

2.2. "*Aqueous electrolyte*" means an electrolyte based on water solvent for the compounds (e.g. acids, bases) providing conducting ions after its dissociation.

2.3. "*Automatic disconnect*" means a device that when triggered, conductively separates the electric energy sources from the rest of the high voltage circuit of the electric power train.

2.4. "*Breakout harness*" means connector wires that are connected for testing purposes to the REESS on the traction side of the automatic disconnect

2.5. "*Cell*" means a single encased electrochemical unit containing one positive and one negative terminals, which exhibits a voltage differential across its two terminals and used as rechargeable electrical energy storage device.

2.6 "*Conductive connection*" means the connection using connectors to an external power supply when the Rechargeable Electrical Energy Storage System (REESS) is charged.

[1] As defined in the Consolidated Resolution on the Construction of Vehicles (R.E.3.), document ECE/TRANS/WP.29/78/Rev.6, para. 2 https://unece.org/transport/standards/transport/vehicle-regulations-wp29/resolutions

2.7. "*Connector*" means the device that provides mechanical connection and disconnection of high voltage electrical conductors to a suitable mating component including its housing

2.8. "*Coupling system for charging the Rechargeable Electrical Energy Storage System (REESS)*" means the electrical circuit used for charging the REESS from an external electric power supply including the vehicle inlet.

2.9. "*C Rate*" *of* "*n C*" is defined as the constant current of the Tested-Device, which takes 1/n hours to charge or discharge the Tested-Device between 0 per cent of the state of charge and 100 per cent of the state of charge.

2.10. "*Direct contact*" means the contact of persons with high voltage live parts.

2.11. "*Electric energy conversion system*" means a system (e.g. fuel cell) that generates and provides electric energy for electric propulsion.

2.12. "*Electric power train*" means the electrical circuit which includes the traction motor(s), and may include the REESS, the electric energy conversion system, the electronic converters, the associated wiring harness and connectors, and the coupling system for charging the REESS.

2.13. "*Electrical chassis*" means a set made of conductive parts electrically linked together, whose potential is taken as reference.

2.14. "*Electrical circuit*" means an assembly of connected live parts which is designed to be electrically energized in normal operation.

2.15. "*Electrical protection barrier*" means the part that provides protection against direct contact with the high voltage live parts.

2.16. "*Electrolyte leakage*" means the escape of electrolyte from the REESS in the form of liquid.

2.17. "*Electronic converter*" means a device capable of controlling and/or converting electric power for electric propulsion.

2.18. "*Enclosure*" means the part enclosing the internal units and providing protection against any direct contact.

2.19. "*Explosion*" means the sudden release of energy sufficient to cause pressure waves and/or projectiles that may cause structural and/or physical damage to the surrounding of the Tested-Device.

2.20. "*Exposed conductive part*" means the conductive part which can be touched under the provisions of the protection degree IPXXB, and which is not normally energized, but which can become electrically energized under isolation failure conditions. This includes parts under a cover that can be removed without using tools.

2.21. "*External electric power supply*" means an alternating current (AC) or direct current (DC) electric power supply outside of the vehicle.

2.22. "*Fire*" means the emission of flames from a Tested-Device. Sparks and arcing shall not be considered as flames.

2.23. "*Flammable electrolyte*" means an electrolyte that contains substances classified as Class 3 "flammable liquid" under "UN Recommendations on the Transport of Dangerous Goods – Model Regulations (Revision 17 from June 2011), Volume I, Chapter 2.3"[2].

2.24. "*High Voltage*" means the classification of an electric component or circuit, if its working voltage is > 60 V and ≤ 1500 V DC or > 30 V and ≤ 1000 V AC root mean square (rms).

[2] www.unece.org/trans/danger/publi/unrec/rev17/17files_e.html

2.25. "*High voltage bus*" means the electrical circuit, including the coupling system for charging the REESS that operates on high voltage. In case of electrical circuits, that are galvanically connected to each other and fulfilling the voltage condition specified in paragraph 2.42., only the components or parts of the electric circuit that operate on high voltage are classified as a high voltage bus.

2.26. "*Indirect contact*" means the contact of persons with exposed conductive parts.

2.27. "*Live parts*" means the conductive part(s) intended to be electrically energized under normal operating conditions.

2.28. "*Luggage compartment*" means the space in the vehicle for luggage accommodation, bounded by the roof, hood, floor, side walls, as well as by the barrier and enclosure provided for protecting the occupants from direct contact with high voltage live parts, being separated from the passenger compartment by the front bulkhead or the rear bulk head.

2.29. "*Manufacturer*" means the person or body who is responsible to the approval authority for all aspects of the approval process and for ensuring conformity of production. It is not essential that the person or body is directly involved in all stages of the construction of the vehicle or component which is the subject of the approval process.

2.30. "*Non-aqueous electrolyte*" means an electrolyte not based on water as the solvent.

2.31. "*Normal operating conditions*" includes operating modes and conditions that can reasonably be encountered during typical operation of the vehicle including driving at legally posted speeds, parking and standing in traffic as well as charging using chargers that are compatible with the specific charging ports installed on the vehicle. It does not include conditions where the vehicle is damaged, either by a crash, road debris or vandalization, subjected to fire or water submersion, or in a state where service and or maintenance is needed or being performed.

2.32. "*On-board isolation resistance monitoring system*" means the device which monitors the isolation resistance between the high voltage buses and the electrical chassis.

2.33. "*Open type traction battery*" means a liquid type battery requiring refilling with water and generating hydrogen gas released to the atmosphere.

2.34. "*Passenger compartment*" means the space for occupant accommodation, bounded by the roof, floor, side walls, doors, window glass, front bulkhead and rear bulkhead, or rear gate, as well as by the barriers and enclosures provided for protecting the occupants from direct contact with live parts.

2.35. "*Protection degree IPXXB*" means protection from contact with high voltage live parts provided by either an electrical protection barrier or an enclosure and tested using a Jointed Test Finger (IPXXB) as described in Annex 3.

2.36. "*Protection degree IPXXD*" means protection from contact with high voltage live parts provided by either an electrical protection barrier or an enclosure and tested using a Test Wire (IPXXD) as described in Annex 3.

2.37. "*Rechargeable Electrical Energy Storage System (REESS)*" means the rechargeable energy storage system that provides electric energy for electrical propulsion.

A battery whose primary use is to supply power for starting the engine and/or lighting and/or other vehicle auxiliaries’ systems is not considered as a REESS.

The REESS may include the necessary systems for physical support, thermal management, electronic controls and casing.

2.38. "*REESS subsystem*" means any assembly of REESS components which stores energy. A REESS subsystem may or may not include the entire management system of the REESS.

2.39. "*Rupture*" means opening(s) through the casing of any functional cell assembly created or enlarged by an event, large enough for a 12 mm diameter test finger (IPXXB) to penetrate and make contact with live parts (see Annex 3).

2.40. "*Service disconnect*" means the device for deactivation of the electrical circuit when conducting checks and services of the REESS, fuel cell stack, etc.

2.41. "*Solid insulator*" means the insulating coating of wiring harnesses provided in order to cover and prevent the high voltage live parts from any direct contact

2.42. "*Specific voltage condition*" means the condition that the maximum voltage of a galvanically connected electrical circuit between a DC live part and any other live part (DC or AC) is ≤ 30 V AC (rms) and ≤ 60 V DC.

Note 1: When a DC live part of such an electrical circuit is connected to chassis and the specific voltage condition applies, the maximum voltage between any live part and the electrical chassis is ≤ 30 V AC (rms) and ≤ 60 V DC

Note 2: For pulsating DC voltages (alternating voltages without change of polarity) the DC threshold shall be applied.

2.43. "*State of Charge (SOC)*" means the available electrical charge in a Tested-Device expressed as a percentage of its rated capacity.

2.44. "*Tested-Device*" means either complete REESS or REESS subsystem that is subjected to the tests prescribed by this Regulation.

2.45. "*Thermal event*" means the condition when the temperature within the REESS is significantly higher (as defined by the manufacturer) than the maximum operating temperature.

2.46. "*Thermal runaway*" means an uncontrolled increase of cell temperature caused by exothermic reactions inside the cell.

2.47. "*Thermal propagation*" means the sequential occurrence of thermal runaway within a REESS triggered by thermal runaway of a cell in that REESS.

2.48. "*Type of REESS*" means systems which do not differ significantly in such essential aspects as:

(a) The manufacturer's trade name or mark;

(b) The chemistry, capacity and physical dimensions of its cells;

(c) The number of cells, the mode of connection of the cells and the physical support of the cells;

(d) The construction, materials and physical dimensions of the casing and

(e) The necessary ancillary devices for physical support, thermal management and electronic control.

2.49. "*Vehicle connector*" means the device which is inserted into the vehicle inlet to supply electric energy to the vehicle from an external electric power supply.

2.50. "*Vehicle inlet*" means the device on the externally chargeable vehicle into which the vehicle connector is inserted for the purpose of transferring electric energy from an external electric power supply.

2.51. "*Vehicle type*" means vehicles which do not differ in such essential aspects as:

(a) Installation of the electric power train and the galvanically connected high voltage bus;

(b) Nature and type of electric power train and the galvanically connected high voltage components.

2.52. "*Venting*" means the release of excessive internal pressure from cell or REESS subsystem or REESS in a manner intended by design to preclude rupture or explosion."

2.53. "*Working voltage*" means the highest value of an electrical circuit voltage root-mean-square (rms), specified by the manufacturer, which may occur between any conductive parts in open circuit conditions or under normal operating condition. If the electrical circuit is divided by galvanic isolation, the working voltage is defined for each divided circuit, respectively.

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[3. Application for approval

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3.4. In cases where information is shown to be covered by intellectual property rights or to constitute specific know-how of the manufacturer or of their suppliers, the manufacturer or their suppliers shall make available sufficient information to enable the checks referred to in this Regulation to be made properly. Such information shall be treated on a confidential basis.

3.5. Documentation shall be made available in two parts:

(a) The formal documentation package for the approval, containing the material specified in Annex 1, Appendix 1 or Appendix 2 which shall be supplied to the Approval Authority or its Technical Service at the time of submission of the type approval application. This documentation package shall be used by the Approval Authority or its Technical Service as the basic reference for the approval process. The Approval Authority or its Technical Service shall ensure that this documentation package remains available for at least 10 years counted from the time when production of the vehicle/REESS type is definitively discontinued.

(b) Additional material relevant to the requirements of this regulation may be retained by the manufacturer, but shall be made open for inspection at the time of type approval. The manufacturer shall ensure that any material made open for inspection at the time of type approval remains available for at least a period of 10 years counted from the time when production of the vehicle/REESS type is definitively discontinued.]

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5. Part I: Requirements of a vehicle with regard to specific requirements for the electric power train

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5.2. Rechargeable Electrical Energy Storage System (REESS)

5.2.1. For a vehicle with a REESS, the requirement of either paragraph 5.2.1.1. or paragraph 5.2.1.2. shall be satisfied.

5.2.1.1. For a REESS which has been type approved in accordance with Part II of this series of Amendments to this Regulation, it shall be installed in accordance with the instructions provided by the manufacturer of the REESS, and in conformity with the description provided in Annex 1, Appendix 2 to this Regulation. [In case that the component based test is performed for the verification of thermal propagation, the additional test specified in paragraph 6.15.3.3.(a) shall be performed on the vehicle in accordance with Annex 9K, paragraph.7.]

5.2.1.2. The REESS including related vehicle components, systems and structure as applicable, shall comply with the respective requirements of paragraph 6. of this Regulation.

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5.2.3. Warning in the event of failure in REESS

The vehicle shall provide a warning to the driver when the vehicle is in active driving possible mode in the event specified in paragraphs 6.13. to 6.15.

In case of optical warning, the tell-tale shall, when illuminated, be sufficiently bright to be visible to the driver under both daylight and night-time driving conditions, when the driver has adapted to the ambient roadway light conditions.

This tell-tale shall be activated as a check of lamp function either when the propulsion system is turned to the "On" position, or when the propulsion system is in a position between "On" and "Start" that is designated by the manufacturer as a check position. This requirement does not apply to the tell-tale or text shown in a common space.

6. Part II: Requirements of a Rechargeable Electrical Energy Storage System (REESS) with regard to its safety

6.1. General

The procedures prescribed in Annex 9 of this Regulation shall be applied.

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6.12. Management of gases emitted from REESS

6.12.1. Under vehicle operation including the operation with a failure, the vehicle occupants shall not be exposed to any hazardous environment inside the passenger compartment caused by emissions from REESS.

6.12.2. (vacant)

6.12.3. For REESS other than open-type traction battery, the requirement of paragraph 6.12.1. is deemed to be satisfied, if all applicable requirements of the following tests are met: paragraph 6.2. (vibration), paragraph 6.3. (thermal shock and cycling), paragraph 6.6. (external short circuit protection), paragraph 6.7. (overcharge protection), paragraph 6.8. (over-discharge protection), paragraph 6.9. (over-temperature protection) and paragraph 6.10. (overcurrent protection).

6.13. Warning in the event of operational failure of vehicle controls that manage REESS safe operation.

The REESS or vehicle system shall provide a signal to activate the warning specified in paragraph 5.2.3. in the event of operational failure of the vehicle controls (e.g. input and output signals to the management system of REESS, sensors within REESS, etc.) that manage the safe operation of the REESS. REESS or vehicle manufacturer shall make available, at the request of the Technical Service with its necessity, the following documentation explaining safety performance of the system level or subsystem level of the vehicle:

6.13.1. A system diagram that identifies all the vehicle controls that manage REESS operations. The diagram must identify what components are used to generate a warning due to operational failure of vehicle controls to conduct one or more basic operations.

6.13.2. A written explanation describing the basic operation of the vehicle controls that manage REESS operation. The explanation must identify the components of the vehicle control system, provide description of their functions and capability to manage the REESS, and provide a logic diagram and description of conditions that would lead to triggering of the warning.

6.14. Warning in the case of a thermal event within the REESS.

The REESS or vehicle system shall provide a signal to activate the warning specified in paragraph 5.2.3. in the case of a thermal event in the REESS (as specified by the manufacturer). REESS or vehicle manufacturer shall make available, at the request of the Technical Service with its necessity, the following documentation explaining safety performance of the system level or subsystem level of the vehicle:

6.14.1. The parameters and associated threshold levels that are used to indicate a thermal event (e.g. temperature, temperature rise rate, SOC level, voltage drop, electrical current, etc.) to trigger the warning.

6.14.2. A system diagram and written explanation describing the sensors and operation of the vehicle controls to manage the REESS in the event of a thermal event.

6.15. Thermal propagation.

For a REESS [containing flammable electrolyte], the vehicle occupants shall not be exposed to any hazardous environment caused by thermal propagation which is triggered by an internal short circuit leading to a single cell thermal runaway. To ensure this, the requirements of paragraphs 6.15.1. and 6.15.2. shall be satisfied in accordance with the verification procedure described in paragraph 6.15.3.[3]

6.15.1. The REESS or vehicle system shall provide a signal to activate the warning specified in paragraph 5.2.3. in the event of a thermal propagation which is triggered by an internal short circuit leading to a single cell thermal runaway in order to allow egress. This requirement is deemed to be met if the presence of a hazardous situation as defined by pass/fail criteria in paragraph 6.15.3.4. does not occur within 5 minutes following the warning signal or if the single cell thermal runaway does not lead to thermal propagation in the REESS.

6.15.1.1. REESS or vehicle manufacturer shall make available the following documentation:

(a) The parameters (for example, temperature, voltage or electrical current) which trigger the warning indication.

(b) Description of the warning system.

6.15.2. The REESS or vehicle system shall have functions or characteristics in the cell, REESS or vehicle intended to protect vehicle occupants (as described in paragraph 6.15.) in conditions caused by thermal propagation which is triggered by an internal short circuit leading to a single cell thermal runaway.

6.15.3. The verification process of thermal propagation safety compliance

Recognizing that there are different REESS and vehicle designs on the market, and to ensure the technical neutrality of this requirement, the verification of thermal propagation safety compliance process follows a multi-step approach described in paragraphs 6.15.3.1. to 6.15.3.4.

Conformance with thermal propagation safety is either demonstrated by physical testing (as described in Annex 9K) or, when it is deemed that physical testing is not possible without compromising the REESS safety design, e.g. because REESS design precludes disassembly, by a systematic risk management analysis method (paragraph 6.15.4.). [The Type Approval Authority and the Technical Service shall determine, with the help of documentation provided by the manufacturer, whether the physical testing is possible without compromising the safety functionality and design of the vehicle/REESS.]

If the REESS is designed to be charged only by an energy source on the vehicle [and its capacity does not exceed 2 kWh], only the risk management analysis according to paragraph 6.15.4. needs to be performed.

6.15.3.1. Step 1: Initial documentation submission

The manufacturer shall provide technical documentation containing the followings:

(a) A system diagram of all relevant physical systems and components;

(b) A diagram showing the functional operation of the relevant systems and components, identifying all risk mitigation functions or characteristics;

(c) For each identified risk mitigation function of characteristic implemented, the physical system or component which implements the function shall be identified and the operating strategy described;

(d) The maximum temperature safety limit of the cell defined by the manufacturer; and

(e) If applicable, recommendations on the feasibility for conducting the physical testing and the most suitable trigger method including the preparation and instrumentation of the Tested-Device. Pre-instrumentation of the triggering and measuring devices may be allowed for this recommendation provided sufficient details of such pre-instrumentation are described.

Relevant systems and components are those which contribute to protection of vehicle occupants from hazardous situation caused by thermal propagation triggered by a single cell thermal runaway.

6.15.3.2. Step 2: Selection of trigger method

Localized fast external heating is the default trigger method for physical testing of thermal propagation safety performance. Alternative methods, e.g. localized internal heater, nail penetration or laser-based trigger, may be used if one of those methods is recommended by manufacturer and [recognized as the most suitable for the REESS design by the Technical Service to cause the single cell thermal runaway satisfying the criteria given in Annex 9K, paragraph 5. The decision of the Technical Service shall be duly documented and justified in the test report.]

Test method descriptions for the respective trigger methods are found in Annex 9K – Appendices 1 to 4.

6.15.3.3. Step 3: Selection of test level

[Either vehicle based test or component based test shall be performed.

In case the component based test is performed, thermal propagation test shall be complemented by:

(a) Additional test(s) to demonstrate the protection of vehicle occupants against smoke as described in Annex 9K, paragraph7. [In case of smoke resulting from thermal propagation coming out of the intended venting system during the component based test, protection of vehicle occupants against smoke shall be demonstrated by the smoke ingress test according to the Annex 9K, paragraph7. In case the REESS casing does not feature any intended venting system and smoke occurs during the test, the vehicle based test shall be performed]; and

(b) Evidence to demonstrate that the component based test is representative of a vehicle-level behaviour. [Phenomena such as deformation of the casing of the REESS during the thermal propagation test shall be considered as evidence demonstrating that component based test is not representative of a vehicle-level behaviour. In this case, the thermal propagation test shall be performed at the vehicle level or shall at least include the parts of the vehicle relevant for the test.]

][]6.15.3.4. Pass/fail criteria for physical thermal propagation test

During the 5 minutes after the activation of the warning indication, there shall be no evidence of the following hazardous situations:

(a) Fire

(b) Explosion

(c) Smoke inside the passenger compartment

The warning indication may occur when the triggered cell enters thermal runaway or when the REESS has reliably identified a thermal propagation event, provided that the safety objectives listed above are satisfied.

For vehicle based test, the evidence of hazardous condition, i.e. fire, explosion and smoke inside the passenger compartment, shall be verified by visual inspection without disassembling any part of the Tested-Device

For component based test, the evidence of hazardous condition, i.e. fire and explosion, shall be verified by visual inspection without disassembling any part of the Tested-Device.

[6.15.3.4.1. In case that no thermal propagation is observed during 2 h after thermal runaway was triggered in the initiation cell, the requirements of paragraph 6.15.3.4. are deemed to be satisfied.

6.15.3.4.2. In case that no thermal runaway can be triggered during the test with the chosen triggering method, and this is confirmed by repeating the same test procedure (i..e. the same trigger method and the same test level) or by conducting a cell level test, the requirements of paragraph 6.15.3.4. are deemed to be satisfied.]

6.15.4. Risk management analysis method

The manufacturer shall perform and document a risk assessment and risk reduction analysis for considering occupant protection in normal in-use operational modes (e.g. active driving possible, [parking] and external charging modes). The risk analysis shall be holistic and follow a systematic work process including both hardware and software aspects, (see for example ISO 6469-1:2019/AMD 2022 and ISO 26262 or equivalent standards for additional guidance). The work product shall be comprehensive and transparent documentation explaining the safety performance of the vehicle systems in conditions caused by thermal propagation which is triggered by an internal short circuit leading to a single cell thermal runaway.

The manufacturer shall make available a high-level report including essential data and a summary of important information considering occupant protection in the case of a single cell thermal runaway and thermal propagation from the risk assessment and the risk reduction activities to the Type Approval Authority and Technical Service in charge of that approval. The report structure shall comprise a four-part structure with the elements described in paragraphs 6.15.4.1., 6.15.4.2., 6.15.4.3. and 6.15.4.4. below.

6.15.4.1. System analysis

The system analysis includes:

(a) A system diagram of all relevant physical systems and components;

(b) Description of systems/components relevant to single-cell thermal runaway and thermal propagation due to internal short circuit and their interoperability. Relevant systems and components are those which contribute to protection of vehicle occupants from hazardous effects caused by thermal propagation triggered by a single cell thermal runaway include but are not limited to REESS, sensors, thermal management system, battery management system, etc.;

(c) Description of warning indication and operating logic; and

(d) Functional analyses identifying the conditions leading to single cell thermal runaway, i.e. internal short circuit of the cell, and allocating them to the corresponding components or functional units or subsystems;

6.15.4.2. Risk identification and mitigation

A risk reduction analysis using appropriate industry standard methodology (for guidance, see for example, IEC 61508, MIL-STD 882E, ISO 26262, AIAG & VDA FMEA Handbook, fault analysis as in SAE J2929, or similar), which documents the hazards to vehicle occupants caused by thermal propagation triggered by an internal short circuit leading to a single cell thermal runaway and documents the reduction of risk resulting from implementation of the identified risk mitigation functions or characteristics. The severity of the thermal event and the risk of propagation to adjacent cells in the battery pack shall be determined.

The risk identification and mitigation analysis shall include:

(a) Risk mitigation by design;

(b) Risk mitigation by manufacturing control; and

(c) Risk mitigation by other means;

The risk analysis shall also include information about and justify any assumptions made on system performance characteristics and properties, model behaviour or relative relevance and likelihood of specified risk scenarios.

The risk assessment is limited to occupant protection for the relevant operational design domain of the REESS and the vehicle.

6.15.4.3. Risk mitigation effectiveness – validation & verification

The effectiveness of each of the risk reduction measure shall be analysed and evaluated. Effectiveness may be analysed by testing, analysis, simulation, models, reference to scientific papers, field data and/or other appropriate methods, either singly or in combination. Effectiveness assessments shall fulfil the requirements of paragraphs 6.15.4.1. and 6.15.4.2., as appropriate.

6.15.4.3.1. Test and verification methods

Test and verification methods used for unit testing, implementation testing and validation shall be documented, clearly identifying which safety functionalities are addressed with the respective methods. Recognized industry standard tests, for example ISO, IEC, SAE or equivalent, should be used when available and appropriate for the testing purposes. In the absence of appropriate industry standard methods and tests, the manufacturer shall design test methods and verification techniques that are feasible to verify component and/or system performance as required to verify and validate the effectiveness of the risk mitigation strategy. Any such methods used shall be explicitly documented, including an explanation of what property, capability or attribute that is tested and the suitability of the method to generate the data required, as well as the rationale for why the method is appropriate.

6.15.4.3.2. Data sources and quality requirements

The data set shall evaluate performance of the components and functional units that have been identified in the allocation process. The relevance and appropriateness of the data shall be described and justified. Major uncertainty factors shall be identified and quantified as far as possible.

Data can comprise of technical specifications and verifying test reports from suppliers and/or manufacturers, mathematical simulations from theoretical or empirical system models, scientific reports and publications, as well as field data.

All relevant results available shall be gathered to create a full consistent reports. The sources of externally derived data shall be identified.

A completeness check shall be conducted so as to ensure that all relevant information and data needed for the interpretation are available and complete.

A sensitivity check shall be conducted to evaluate the reliability of the final results and the conclusions by determining how they are affected by uncertainties in the data, allocation methods or assumptions made about the REESS.

6.15.4.4. Conclusions

(a) The concluding part of the report shall comprise a brief summary of the major results of the risk reduction analysis and a statement that the requirements in paragraphs 6.15.1. and 6.15.2. are satisfied, including: The methods used are scientifically and technically valid for the scope of the risk reduction analysis;

(b) The data used are appropriate and reasonable in relation to the intention of the risk reduction analysis;

(c) The interpretations are relevant and reflect the assumptions made and the limitations identified for the study;

This part may be in the form of an internal or external critical review report, if the manufacturer has such a process in place.

Annex 9

REESS test procedures

Annex 9 - Appendix 1

Procedure for conducting a standard cycle

A standard cycle shall start with a standard discharge followed by a standard charge. The standard cycle shall be conducted at an ambient temperature of 20 ± 10 °C.

Standard discharge:

Discharge rate:	The discharge procedure including termination criteria shall be defined by the manufacturer. If not specified, then it shall be a discharge with 1C current for a complete REESS and REESS subsystems.
Discharge limit (end voltage):	Specified by the manufacturer

For a complete vehicle, discharge procedure using a dynamometer shall be defined by the manufacturer. Discharge termination will be according to vehicle controls.

Rest period after discharge:	Minimum 15 min

Standard charge:

The charge procedure shall be defined by the manufacturer. If not specified, then it shall be a charge with C/3 current. Charging is continued until normally terminated. Charge termination shall be according to paragraph 2. of Annex 9, Appendix 2 for REESS or REESS subsystem.

For a complete vehicle that can be charged by an external source, charge procedure using an external electric power supply shall be defined by the manufacturer. For a complete vehicle that can be charged by on-board energy sources, a charge procedure using a dynamometer shall be defined by the manufacturer. Charge termination will be according to vehicle controls.

Annex 9 – Appendix 2

Procedure for SOC adjustment

1. The adjustment of SOC shall be conducted at an ambient temperature of 20 ± 10 °C for vehicle-based tests and 22 ± 5 °C for component-based tests.

2. The SOC of the Tested-Device shall be adjusted according to one of the following procedures as applicable. Where different charging procedures are possible, the REESS shall be charged using the procedure which yields the highest SOC:

   (a) For a vehicle with a REESS designed to be externally charged, the REESS shall be charged to the highest SOC in accordance with the procedure specified by the manufacturer for normal operation until the charging process is normally terminated;

   (b) For a vehicle with a REESS designed to be charged only by an energy source on the vehicle, the REESS shall be charged to the highest SOC which is achievable with normal operation of the vehicle. The manufacturer shall advise on the vehicle operation mode to achieve this SOC;

   (c) In case that the REESS or REESS subsystem is used as the Tested-Device, the Tested-Device shall be charged to the highest SOC in accordance with the procedure specified by the manufacturer for normal use operation until the charging process is normally terminated. Procedures specified by the manufacturer for manufacturing, service or maintenance may be considered as appropriate if they achieve an equivalent SOC as for that under normal operating conditions. In case the Tested-Device does not control SOC by itself, the SOC shall be charged to not less than 95 per cent of the maximum normal operating SOC defined by the manufacturer for the specific configuration of the Tested-Device.

3. When the vehicle or REESS subsystem is tested, the SOC shall be no less than 95 per cent of the SOC according to paragraphs 1. and 2. above for REESS designed to be externally charged and shall be no less than 90 per cent of SOC according to paragraphs 1. and 2. above for REESS designed to be charged only by an energy source on the vehicle. The SOC will be confirmed by a method provided by the manufacturer.

Annex 9K

Thermal propagation test

1. Purpose

The purpose of the thermal propagation test is to ensure the occupant safety in a vehicle by assessing the phenomena of REESS or vehicle when a forced thermal runway of a cell in the REESS is caused. The phenomena of forced thermal runaway simulate a severe thermal event caused by an internal short circuit.

2. Installations

[This test shall be conducted wither with a complete vehicle or using the complete REESS or REESS subsystem(s) at the discretion of the manufacturer in agreement with Technical Service. If the manufacturer chooses to test with REESS subsystem(s), the manufacturer shall demonstrate that the test result [can reasonably represent] the performance of the complete REESS with respect to its safety performance under the same conditions.

[For test using REESS or REESS subsystem, the parts of the vehicle relevant for the test, e.g. to reproduce the equivalent phenomena such as deformation of the casing of the REESS during the thermal propagation test, shall be installed to the Tested-Device.]]

3. General test conditions

The following conditions shall apply to the test

3.1. Environmental conditions

(a) [The test shall be conducted either indoors or outdoors. In case of outdoor testing there shall be no precipitation for the duration of the test. Immediately prior to the test commencing, wind speed shall be measured at a location which is no more than 5 m from the Tested-Device and the average wind speed over 10 min shall be less than 28 km/h. It shall be ensured that the results are not affected by gusts of wind. Gusts shall not exceed 36 km/h when measured over a period of 20 s. Test set up shall consider the impact of features such as shielding screens or walls which may create excessive funneling effects during test execution];

(b) The test shall be carried out at a relative humidity of 10% to 90%.

3.2. Tested-Device

(a) Required modifications shall be kept to a minimum compared to the original un-modified Tested-Device. Any modifications of REESS components, such as mechanical and thermal barriers, cooling plates/channels, electrical connections, and cell to cell spacing shall be documented and rationalized as to why such changes do not result in significant change to performance. The original sealing capability of the REESS shall be confirmed not to be compromised through instrumentation and any venting shall be through pre-existing seals. [If the Tested-Device is pre-instrumented, the manufacturer is responsible to verify the sealing capability, otherwise the Technical Service shall ensure this.] All components and features that are required for the functioning of the Tested-Device and safety related features e.g. cell connecting busbars, tab welding, connection and functionality of relevant management system, isolation resistance, etc., shall be maintained and un-compromised;

(b) For vehicle level test, all windows, roof and doors are closed.

(c) At the beginning of the test, the state of charge (SOC) shall be adjusted according to the procedure defined in Annex 9- Appendix 1 to this Regulation;

(d) At the beginning of and, as long as possible, during the test, all necessary functions of the Tested-Device shall be operational. The Tested-Device shall be representative of the REESS when installed in a vehicle that is “on” and set in "parked" mode. The defined thermal management/safety strategy and the battery management system used within the REESS shall be fully operational. The coolant flow could be null or active depending on the management system of the Tested-Device. The native thermal management strategy (if installed), and other relevant management systems of the Tested-Device, which are necessary for the test, shall be operational for as long as possible during the test.

(e) Immediately before turning on the initiation device, the temperature of the cells in the Tested-Device, shall be maintained between 18 °C and maximum operating temperature defined by the manufacturer.

3.3. Initiation cell

In the field, a single cell thermal runaway may occur in any cell location within the REESS. For the test, the initiation cell selection shall consider the number of adjacent cells, cell packaging, and the distance between cells in proximity to the potential initiation cell as well as the practicality of initiation.

The intent is to allow for the selection of any cell in the pack. However, it is understood that there are differing limitations in the ability to access certain cells in any given Tested-Device and that certain cells may pose a higher risk of propagation stemming from a single cell failure. The criteria below will ensure that Tested-Device functionality and safety systems are not compromised by installation of test equipment. It also provides the basis for selecting a cell that is potentially at a higher risk of causing propagation.

Paragraph 3.3.1. below is essential to ensure that the whole system is being tested and any installed safety systems within the Tested-Device are not compromised.

Paragraph 3.3.2. below is subjective to the specific product as well as the test level and the initiation method selected in accordance with paragraph 6.15.3. [Representative case shall] be [determined by the Technical Service] with the help of documentation provided by the manufacturer.

3.3.1. [Installation of test equipment shall not compromise the functionality of the REESS relevant to the safety performance. The installation shall minimize modification to thermal insulators and structure and shall not:

(a) Disable or affect the functionality of the battery management system;

(b) Change pack gas flow direction and permeability, both internal and exit paths.]

3.3.2. [A cell shall be selected that represents severe conditions for generating a potentially hazardous condition in case of a thermal runaway:

(a) A high level of heat transfer to at least one adjacent cell (e.g. thinnest spacers/gaps/barriers or vent direction towards an adjacent cell);

(b) Subject to (a), few heat sinks and non-productive thermal pathways (e.g. edge cell with few adjacent cells and/or with large adjacent air space);

(c) Other criteria known be the manufacturer to reflect a condition/location which may have greater potential to lead to a hazardous condition.]

4. Recorded data and measurements

4.1. The following information shall be recorded during the test and during the observation period. All data measurement systems shall be referenced to the same starting time.

(a) Identification of the test method, including the trigger method, and a description of the test set-up;

(b) Test conditions (e.g. environmental conditions, SOC, and other pre-conditioning parameters);

(c) Temperature of the initiation cell, [ensuring that the trigger device or test instrumentation does not influence the measurement];

(d) Voltage of the initiation cell during the thermal runaway triggering procedure;

(e) Temperature of one adjacent cell;

(f) Video and audio recording, including indication of a time stamp of any observable system state change during the test (e,g, initiation cell thermal runaway/venting, thermal propagation to adjacent cell(s), smoke, fire/flame, explosion, etc);

(g) Condition of the Tested-Device and/or vehicle at the end of the test, supported by video or photographs (before and after test);

(h) If the test is performed on vehicle level, the time stamp of warning indications or alarms to occupants. If the test is performed on REESS or REESS subsystem, the time stamp of the signal to trigger the warning indications;

(i) Type Approval Authorities and/or Technical Services may perform additional optional measurements and record the data, e.g. infrared temperature video, if deemed necessary.

5 Detection criteria of thermal runaway

Thermal runaway can be detected by the following conditions:

(i) The measured voltage of the initiation cell drops, and the drop value exceeds 25% of the initial voltage [for at least 1 second];

(ii) The measured temperature of the initiation cell exceeds the maximum temperature safety limit defined by the manufacturer;

(iii) $dT/dt \geq 1$ °C/s of the measured temperature of the initiation cell for at least 3 consecutive seconds.

(a) Both (i) and (iii) are detected; or

(b) Both (ii) and (iii) are detected.

6. Trigger methods to initiate thermal runaway

[The initiation method shall not affect the adjacent cell(s), e.g. in case localized fast external heating, localized internal heating or laser-based trigger methods are used, the temperature of the adjacent cell(s) shall not exceed the maximum temperature safety limit, defined by the l. Appropriate methods may be used to isolate the adjacent cell(s), provided that the REESS original functionality is not impeded.

]

7. Additional smoke ingress test on vehicle

7.1. Environmental conditions :

(a) The test shall be conducted either indoors or outdoors. In case of outdoor testing there shall be no precipitation for the duration of the test. [If the test is carried out in the open air, sufficient wind protection shall be provided. The air flow velocity for the indoor tests and the wind velocity for outdoor tests, measured at the location of battery venting exit, shall not exceed 2.5 km/h];

(b) The test shall be carried out at a relative humidity of 10% to 90%.

(c) The temperature shall be in the range of the operational temperatures of the smoke machine specifications.

7.2. Smoke machine:

The smoke machine shall be able to generate a flow rate representative of the exhaust of the battery venting exit.

[It shall be able to ensure dense smoke with minimum fluid consumption (approx. 2.3 ml/min in continuous output).]

7.3. Vehicle configuration:

The vehicle shall represent the [future] new and factory built product without previous modifications.

[All windows, roof and doors, as well as air ventilation and air inlets if managed in case of thermal propagation event detection, are closed.]

[Passenger compartment shall be maintained at an under-pressure of at least 2 mbar for the duration of the test.]

7.4. Smoke ingress verification procedure:

The smoke ingress is checked using sufficient numbers of different video camera locations.

[The smoke device exhaust exit shall be positioned at the battery venting exit pointing the same direction as the exhaust from the battery venting.]

7.5. Test steps:

(a) The start time begins with the start of the smoke production by the smoke machine.

In case of the smoke machine needs to warm up before expulsing smoke, first visible smoke from the machine shall be taken as the starting point.

(b) Use the smoke machine during 10 minutes.

(c) Write the time of the first smoke entrance visible on camera if it is the case.

[7.6. Pass/fail criteria for smoke ingress test:

During the 5 minutes after the start moment of the test, determined as described in paragraph 7.5, there shall be no evidence of smoke inside the passenger compartment as verified by visual inspection without disassembling any part of the vehicle.]

Annex 9K – Appendix 1

Thermal runaway initiation method with localized fast external heater

1. Preparation of Tested-Device

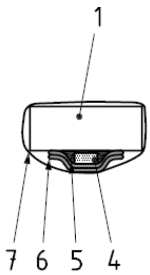
1.1. The feedthrough installation of the chosen heating element should only modify the REESS by permitting electrical and thermocouple connections to the heating element. These connections shall provide greater seal integrity than the other connectors in the REESS.

1.2. The chosen heating element shall be set to avoid direct contact to any surface of the components in the Tested-Device except for the initiation cell. Intimate thermal contact between the heating element and the initiation cell surface is important for the successful application of this method. Thermal contact between the heating element and initiation cell may be improved through various methods (e.g. avoiding air gaps, addition of a heat transfer paste and applying pressure, which should be maintained throughout the test).

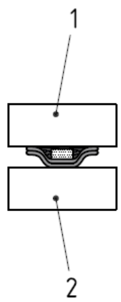
1.3. A sample of potential heater application methods are shown in Figure 1 and the applied method is dependent on the REESS or REESS subsystem design. Maintain a contact pressure for the heating element on the initiation cell during the test to ensure contact and optimal heat transfer, see Figure 1.

Figure 1
Methods to apply pressure on the heating element to maintain heating element contact to initiation cell throughout the test for different cell types.

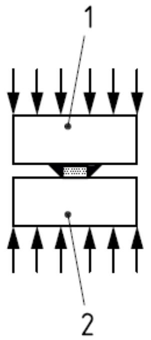
(a) REESS with large spacing between cells



(b) center cell fixed spacing (e.g. prismatic cells



(c) center cell compressed modules (e.g. pouch cells)



1 initiation cell
2 adjacent cell
4 heating element
5 heat transfer paste
6 ceramic paper
7 wire or high-temperature tape

1.5. For implementation in vehicle level tests, the vehicle response shall not be influenced by the insertion of this initiation method into the REESS, [any pass required through the vehicle body shall be minimized].

2. Heater element selection guide

2.1. The trigger method applies a high-powered heat pulse, locally, to the external surface of the initiation cell. The successful implementation of the method requires the application of sufficient power to the chosen heating element but it shall also not apply so much power that there is a premature heating element failure nor a side wall failure of the initiation cell prior to thermal runaway.

2.2. The heating device shall be a resistive heating element, or other suitable heating device/technology capable of delivering the target parameters. Target parameters for the heating element are listed in Table 1.

Table 1
Heater device selection guide: Target parameters

Parameter	*Value*	*Rationale*
Heater device material	Nickel-chrome with an isolating barrier or another suitable resistive heating material	Achieve high temperatures and prevent element failures. Isolating materials may include alumina, ceramic, or fiberglass.
Thickness	<5 mm	Minimize effect of heater on REESS. Some REESS designs may require a thinner heating element.
Area	As small as possible, but no larger than 20 % of the surface area of the targeted face of the initiation cell	Concentrate heat to the smallest feasible area on the cell surface. Largest cell surface should be used, if possible
Heating rate	≥15 °C/s	Similar to heating rates observed within thermal runaway conditions.[a]

Maximum temperature	100 °C larger than the chosen maximum temperature safety limit	Heater shall maintain integrity at the chosen operating temperature and take into account temperature deviations from heater element to thermocouple.[b]
Control method	Thermostatic closed loop	Avoids undesirable test results, such as heating element burnout, elevated heating element temperature, battery cell sidewall ruptures due to high element temperature.[c]
[a]~~-~~The heating rate is measured directly by an external ~~a~~ thermocouple placed on top of the heating element installed in the pack. [b] This temperature may need adjustment for other chemistries and potentially other cell types to avoid cell sidewall ruptures. The manufacturer shall provide the maximum temperature safety limit for the cells in their Tested-Device in the initial submission document. [c] Using a low voltage power source for the heating element will require higher currents (thicker wires), while a higher voltage source will require more resistant isolating material and higher levels of user safety while implementing the test.		

3. Test procedure for vehicle based test

The general conditions in Annex 9K, paragraph 3. shall be satisfied when the method is implemented with the vehicle .

(a) Instrument the REESS as outlined above and connect all thermal management, communication and high voltage lines and reinstall REESS into vehicle.

~~(b) Connect to CAN-bus or other vehicle monitoring system to collect data about battery management system.~~

(c) Install video camera inside vehicle cabin to record video (dashboard/information screen) and audio (warnings) from vehicle during test.

(d) Turn vehicle “on” and set it in the “parked” mode.

(e) Verify there are no warning indications related to REESS or powertrain failure before proceeding.

(f) Begin recording temperature and battery management system data.

(g) Begin sending power to the heating element.

(h) Open relay to heater immediately when thermal runaway is confirmed or after the total energy input to the heater reaches 20 % of initiation cell electric energy.

[(i) The test ends when either condition specified below is met;

(i) The initiation is stopped in accordance with the subparagraph (h) above followed by an observation period of [1 hour], or

(ii) at least 5 minutes elapse after the activation of the warning indication, if thermal propagation is observed; or

(iii) If thermal runaway has occurred in the initiation cell, but no thermal propagation ensued, the observation period of 2 hours after the confirmation of thermal runaway is applied to Tested-Device.]

4. Test procedure for component based test

The general conditions in Annex 9K, paragraph 3. shall be satisfied when the method is implemented on the REESS or REESS subsystem.

(a) Instrument the REESS as outlined above and prepare the REESS such that it represents the situation when it is installed in the vehicle, with the system in the active driving possible mode. Make sure that the thermal management and communication system operate as intended.

(b) Collect the data that are needed to determine if thermal runaway and/or thermal propagation are taking place. Verify that there are no fault codes or failures relevant for the outcome of the test present in the system.

(c) Begin sending power to the heating element.

(d) Switch off the heater immediately when thermal runaway is confirmed or after a total energy input to the heater reaches 20 % of initiation cell electric energy,

(e) The test ends when either condition specified below is met;

(i) The initiation is stopped in accordance with the subparagraph d) above followed by an observation period of 1 hour, or

(ii) at least 5 minutes elapse after the activation of the warning indication, if thermal propagation is observed; or

(iii) If thermal runaway has occurred in the initiation cell, but no thermal propagation ensued, the observation period of 2 hours after the confirmation of thermal runaway is applied to the Tested-Device.

Annex 9K – Appendix 2

Thermal runaway initiation method with internal heater

This test method is similar with the external heating method except it relies on an internal, localized short circuit inside the cell created by a local heater. The purpose of this test is to create a thermal runaway through the creation of a hole in the separator of the triggered cell. The hole comes from the local melting of the separator induced by the local heater.

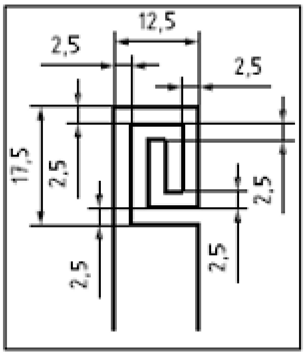
The initiation method applies a high-powered heat pulse, locally, to the Jelly Roll surface of one initiation cell within the REESS via an internal heater with minimal increase in temperature of the adjacent battery cell(s) prior to thermal runaway within the initiation cell. The increase of temperature of adjacent cell(s), prior to thermal runaway in the initiation cell, shall remain below the maximum operating or storage temperature (whichever is higher) for the REESS.

1. Trigger method description

The heating device should be a resistive heating element, or other suitable heating device/technology capable of delivering the target parameters. Target parameters for the heating element are listed in Table1

Parameters to use with this test methodology for typical lithium-ion battery cells for electric vehicles are shown in Table 2 as a guideline. The power of the heater is dependent on cell chemistry, energy density and volume of the initiation cell. The maximum time allowed for the first thermal runaway event shall be agreed between the manufacturer and the Technical Service (see soak time in Table 2)

Figure 1
Example of an internal heater flat spiral of tungsten



(mm)

NOTE: The wire diameter is usually 0.1 mm to 0.3 mm

Table 1
Heating element selection guide – Target Parameters

Parameter	*Value*	*Reasoning*
Heating element material	A suitable resistive heating material with an insulating barrier, e.g. copper or tungsten	Achieve high temperatures and prevent element failures. Isolating material may include polyimide or other heat-resisting material.

Parameter	*Value*	*Reasoning*
Thickness [mm]	<0.5	Due to the heater need to be placed inside of cell, thickness of heater should be controlled in a reasonable value.
Area[mm2]	50*50~15*15	Concentrate heat to the smallest feasible area on the cell surface.
Power of heater[W]	250~700	Provide enough heat to enable initiation of cell thermal runaway.

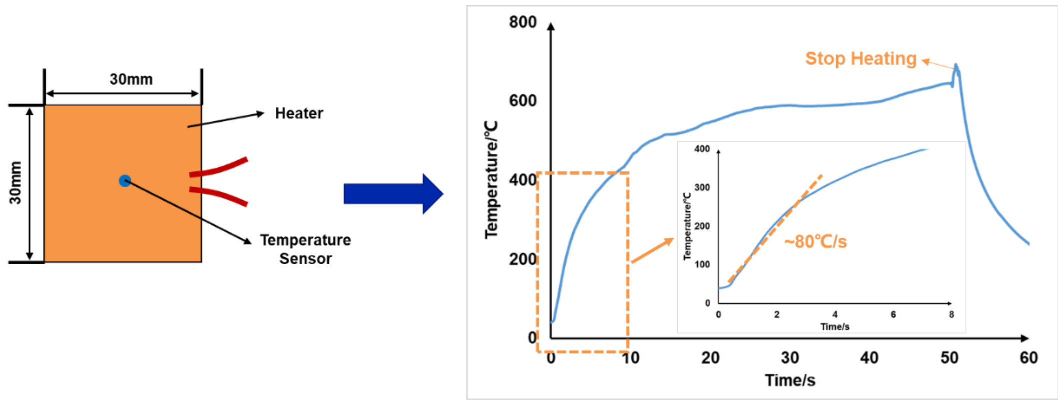
Table 2
Typical heater parameters for implementation of internal heater methodology

Parameter Category	*VED<450Wh/L (eg.: LFP Cell)*	*VED≥450Wh/L (eg.: NCM Cell)*	*Remarks*
Power of heater[W]	400~700	250~700	These values are based on: Cell chemistry/energy density/ volume of the initiation cell
Soak time phase and power off condition	Heating until thermal runaway is achieved or until heater is burnout		Heating until thermal runaway is achieved within 5 min. In any active REESS safety system is inoperable, prior to conducting the test, it is not necessary to agree upon a maximum time limit.

Heater Characteristic (For example):

The dimension of heater is 30mm*30mm, and heating power is 250W. When the internal heater is used to trigger the initiation cell to thermal runaway, the temperature of heater surface will rapidly increase beyond 300 °C with an rate of ~80 °C/s, and the maximum temperature will reach ~700 °C (as shown in Figure 1). For normal design, the separator will rapidly melt down at the temperatures filed, and lead to cell thermal runaway by an internal short circuit

Figure 2
Thermal behaviour of internal heater



[2. Test application and necessary modifications - Subsystem level testing

The use of this test method relies on quickly and effectively heating up a single cell into thermal runaway within a REESS and REESS subsystem. To ensure the test is conducted efficiently, a preliminary test on a single cell or a small number of cells should be performed using a modified cooling strategy (if desired). This subsystem level test permits the refinement of test parameters (heating rate, target temperature, soak time) for the specific cell used in the chosen REESS design, which vary (from those shown in Table 1 and Table 2) upon change of cell chemistry and cell size/construction. Modifications required for subsystem level testing should mimic those found in the REESS to obtain an accurate test result relative to that obtained at a REESS test level.]

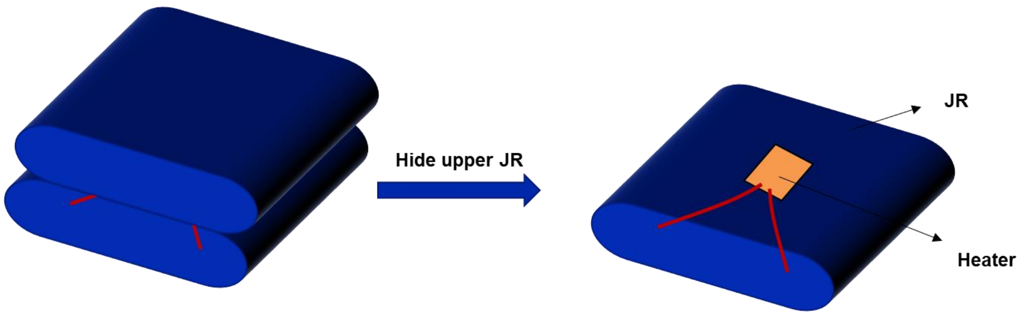
3. <u>Initiation Cell/Cell Block Preparation</u>

The internal heater is assembled in the cell during the production of cell. Here is the example of manufacturing process for this special cell.

3.1. Step 1:

Locate the heater on the surface of the jellyroll. For one-jellyroll-cell, the heater is suggested to be located on the surface of jellyroll. For n-jellyrolls-cell (n≥2), the heater is suggested to be located on the surface of jellyroll and is surround by two jellyrolls, as shown in Figure 3.

Figure 3
Example of location of internal heater in a cell with more than one jellyroll.



3.2. Step 2:

A hole is drilled into the top cover of cell to allow the electrical feedthrough of the heater from the inside to the outside of the cell.

3.3. Step 3:

All wires used in the REESS or REESS subsystem shall be electrically isolated. Furthermore, it should be ensured that no electrolyte or gases can leak out through the space between the wire strand and the wire insulator.

The selection of sealing resin is critical as the strength of seal shall be greater than any installed vent of the cell. Furthermore, it should be ensured that no electrolyte or gases can leak out through the space between the wire strand and the wire insulator.

Next, assemble the cell according to the standard manufacturing process (Figure 4). After it is completely dry, carry out a helium test to check the sealing before filling the cell with electrolyte.

When the helium test is successful, the cell is ready to be filled and formed. After the helium test, verification of the characteristic parameters (voltage, ACR, dimension, *etc*) should be performedand the tolerance range should be provided.

According to requirement of experiment, the prepared cell can be assembled inside the battery module or REESS or REESS subsystem. The CCS component need to be drilled a hole to make sure the electrical feedthrough of the heater can come out of cell block (Figure 5).

Figure 4
Example of cell assembly

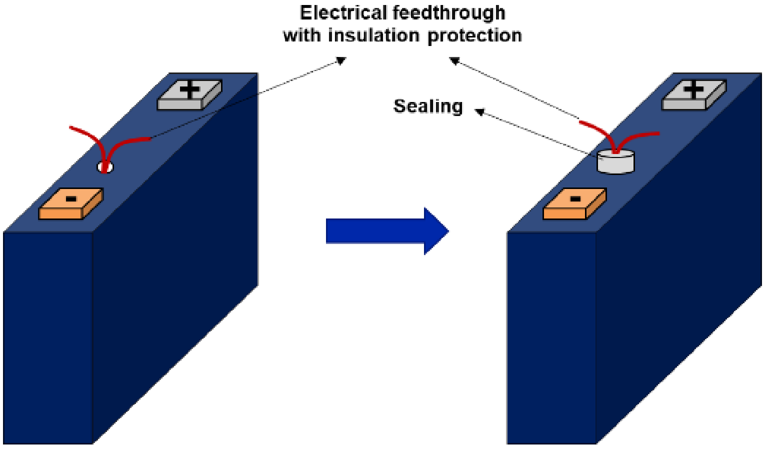
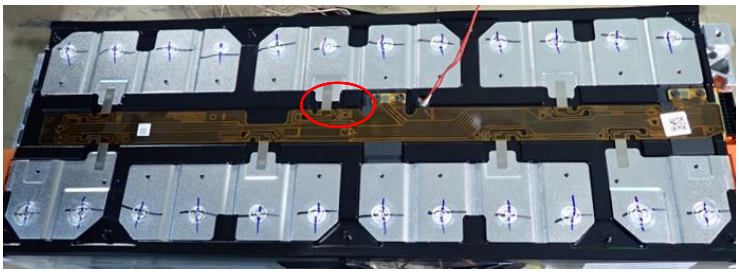


Figure 5
Example of module assembly



3.4. Step 4:

Connect wires of the heater to the outside of the REESS or REESS subsystem though the sealing pad between pack top cover and pack casing and seal the position with sealant. (Figure 5). The wires can also come out of the pack though a hole in the REESS casing, which is then sealed with heat-resistant resin.

Figure 6
Example of battery pack assembly

Annex 9K – Appendix 3

Thermal runaway initiation method with nail penetration

1. Preparation of Tested-Device

If the REESS is enclosed in a housing, a penetrating hole on the housing may be needed to enable the nail to be inserted into a target position of an initiation cell. The device such as gas tight sleeve for the nail that prevents venting gas from leaking out from the nailhole should be applied, if necessary.

The nail penetrating position and direction are selected from the position and direction of the nail where causing a thermal runaway in an initiation cell is possible (e.g. in vertical direction to electrode layer.

[If thermal runaway occurs, the test conditions don’t limit to the following paragraph 2 .]

2. Nail selection guide

The nail type can be chosen from the following parameters.

(i) Material: Steel

(ii) Diameter: 3mm to 8mm

(iii) Shape of tip: Circular cone, Angle: 20-60°

(ⅳ) Penetrating speed: 0.1-1mm/s

3. Test procedure for vehicle based test

The general conditions in Annex 9K, paragraph 3. shall be satisfied when the method is implemented with the vehicle.

(a) Instrument the REESS as outlined above and connect all cooling/communication and high voltage lines and reinstall REESS into vehicle;

(b) Connect to CAN-bus or other vehicle monitoring system to collect data about battery management system;

(c) Install video camera inside vehicle cabin to record video (dashboard/information screen) and audio (warnings) from vehicle during test if applicable;

(d) Install multi-gas measurement to perform according to “Recorded data and measurements” paragraph if applicable;

(e) Turn vehicle “on” and set it in the “parked” mode;

(f) Verify there are no warning indications related to REESS or powertrain failure before proceeding;

(g) Begin recording temperature and battery management system data;

(h) Select the nail shape and diameter and set the appropriate penetrating speed according to the guidance in paragraph 2.(ⅳ);

(i) Tune on the power to the nail operating device;

(j) Stop the nail and let it remain inside the initiation cell stay put when the thermal runaway occurs or the nail has penetrated both the front and back side of the cell;

[(k) The test ends when either condition specified below is met;

(i) The initiation is stopped in accordance with the subparagraph (j) above; or

(ii) 5 minutes after the activation of the warning indication.]

4. Test procedure for component based test

The general conditions in Annex 9K, paragraph 3. shall be satisfied when the method is implemented on the REESS or REESS subsystem.

(a) If the REESS has a cooling system, it may be tested with the cooling system in place;

(b) Connect to CAN-bus or other vehicle monitoring system to collect data about battery management system;

(c) A video camera should be installed to record data on the hazardous-related situations during the test and warning indications;

(d) Install multi-gas measurement to perform according to “Recorded data and measurements” paragraph if applicable;

(e) Turn on the system for the test including REESS to simulate the situation where vehicle is turned "on" and set in "parked" mode;

(f) Verify there are no warning indications related to REESS or powertrain failure before proceeding;

(g) Begin recording temperature and battery management system data;

(h) Select the nail shape and diameter and set the appropriate penetrating speed according to the guidance in paragraph 2.(ⅳ);

(i) Tune on the power to the nail operating device;

(j) Stop the nail and let it remain inside the initiation cell when the thermal runaway occurs or the nail has penetrated both the front and back side of the cell;

[(k) The test ends when either condition specified below is met;

(i) The initiation is stopped in accordance with the subparagraph (j) above, or

(ii) 5 minutes after the activation of the warning indication.]

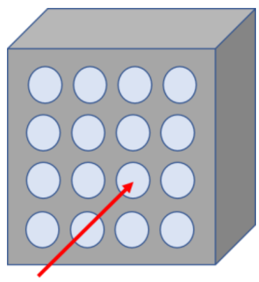
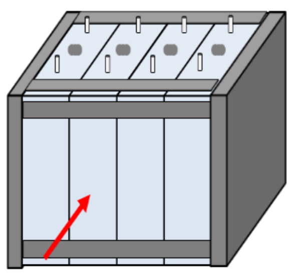
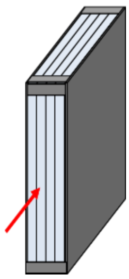
Annex 9K – Appendix 4

Thermal runaway initiation method with laser-based trigger

1. Preparation of Tested-Device

Before conducting the test, the laser beam path shall be secured so that the laser beam reaches a predetermined position on the initiation cell surface. Figure 1 shows examples of laser irradiation to on-board battery modules consisting of different types of battery cells.

Figure 1
Examples of laser irradiation to on-board battery modules consisting of different types of battery cells

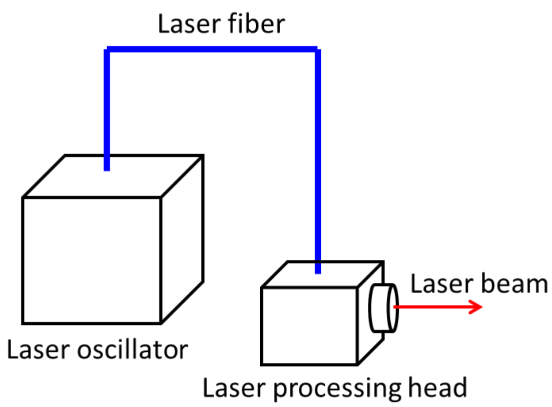
(a) Cylindrical cell module	*(b) Square cell module*	*(c) Pouch cell module*
		

2. Laser selection guide

The laser type can be chosen from material process lasers such as used for cutting, welding or hardening, e.g. $CO2$ laser, YAG laser, semiconductor laser, disk laser, fiber laser, and so on.

An example of a laser irradiation system is shown in Figure 2.

Figure 2
Example of a laser irradiation system



3. Test procedure for vehicle based test

The general conditions in Annex 9K, paragraph 3. shall be satisfied when the method is implemented with the vehicle .

(a) Instrument the REESS as outlined above and connect all cooling/communication and high voltage lines and reinstall REESS into vehicle;

(b) Connect to CAN-bus or other vehicle monitoring system to collect data about battery management system;

(c) Install video camera inside vehicle cabin to record video (dashboard/information screen) and audio (warnings) from vehicle during test if applicable;

(d) Install multi-gas measurement to perform according to “Recorded data and measurements” paragraph if applicable;

(e) Turn vehicle “on” and set it in the “parked” mode;

(f) Verify there are no warning indications related to REESS or powertrain failure before proceeding;

(g) Begin recording temperature and battery management system data;

(h) The battery system is fully charged according to the manufacturer specified conditions;

(i) Place the thermocouples onto the cells to measure the surface temperature. It is recommended to use multiple thermocouples for redundant data acquisition;

(j) Before starting the test, secure the laser beam path so that the laser beam reaches the initiation cell surface of the on-board battery system; (k) The laser irradiation program should be set and confirmed. It is recommended to prepare covers to prevent damage to the laser systems when the initiation cell enters into thermal runaway and vents;

(l) Prepare and set the measurement equipment for cell temperature measurement, etc.;

(m) The temperature controller such as an air conditioning system should have the ability to maintain the ambient temperature until the initiation cell temperature reaches the maximum temperature;

(n) Irradiate the initiation cell with the laser at the determined point. Measure the cell's temperature continuously from irradiation start to observation end;

(o) When the initiation cell surface temperature exceeds 100°C, stop laser irradiation;

(p) Observe until 5 minutes have passed after the warning of the on-board battery system is indicated.

4. Test procedure for component based test

The general conditions in Annex 9K, paragraph 3. shall be satisfied when the method is implemented on the REESS or REESS subsystem.

(a) If the REESS has a cooling system, it may be tested with the cooling system in place;

(b) Connect to CAN-bus or other vehicle monitoring system to collect data about battery management system;

(c) A video camera should be installed to record data on the hazardous-related situations during the test and warning indications;

(d) Install multi-gas measurement to perform according to “Recorded data and measurements” paragraph if applicable;

(e) Turn on the system for the test including REESS to simulate the situation where vehicle is turned "on" and set in "parked" mode;

(f) Verify there are no warning indications related to REESS or powertrain failure before proceeding;

(g) Begin recording temperature and battery management system data;

(h) The battery system is fully charged according to the manufacturer specified conditions;

(i) Place the thermocouples onto the cells to measure the surface temperature. It is recommended to use multiple thermocouples for redundant data acquisition;

(j) Before starting the test, secure the laser beam path so that the laser beam reaches the initiation cell surface of the battery system;

(k) The laser irradiation program and its work should be set and confirmed. It is recommended to prepare covers to prevent damage to the laser systems when the initiation cell enters into thermal runaway and vents;

(l) Prepare and set the measurement equipment for cell temperature measurement, etc.;

(m) The temperature controller such as an air conditioning system should have the ability to maintain the ambient temperature until the initiation cell temperature reaches the maximum temperature;

(n) Irradiate the initiation cell with the laser at the determined point. Measure the cell's temperature continuously from irradiation start to observation end;

(o) When the initiation cell surface temperature exceeds 100℃, stop laser irradiation;

(p) Observe until 5 minutes have passed after the warning of the on-board battery system is indicated.