D6200.1 Specification of testing standard for high-voltage components
1. Summary

Within WP 6200, a total of four tasks are scheduled.

<table>
<thead>
<tr>
<th>Objectives</th>
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<tbody>
<tr>
<td>Development of safety standards for hybrid component testing (Hardware, Software, Procedures)</td>
</tr>
<tr>
<td>New methodology and tools for a secure exchange of simulation models on different simulation systems (e.g. supply of xCU-Functions from partner A to partner B)</td>
</tr>
<tr>
<td>Integration and validation of communication protocol on simulators and test beds.</td>
</tr>
<tr>
<td>New methodology and tools for a consistent use of virtual drive cycle for hybrid commercial vehicles in all development stages (Design, Integration and Testing)</td>
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</tbody>
</table>

This report covers the first of these tasks 6210:

**Description of work**

*Task 6210: Development of secure testing standards for high-voltage components*

To enable a secure testing environments also for high-voltage components like batteries and power converters the basic security regulations will be merged with best-practice solutions to create a new and comprehensive safety standard for hybrid component and powertrain test beds. These standards will also help to bring down development costs significantly in the future.

Allocated resources: AVL 6 PM

The assumption has been made that the task has been interpreted as follows, which in turn reflects on the scope and content of the report:

“To enable a safe testing environment for high voltage components like batteries and their on-board associated power electronics, currently available industry standard regulations will be merged with best practice solutions to evolve a comprehensive safety guideline for HCV hybrid and powertrain testbeds.”

Within Task 6210 of WP 6200, AVL List GmbH focused on identifying the historic and recently published testing standards for high-voltage components, such as traction batteries, electric motors and power converter systems. Particularly, ISO/IEC has now produced specific up to date standards for the use of Lithium Ion cells in Electric vehicle applications, and also for the testing of the Battery packs as systems. With feedback from various real life incidents and the experiences of the rapidly developing automotive EV and hybrid industry, the relevant safety-related guidelines and their applicability for testing environments were examined.
This was achieved by performing extensive literature research, numerous expert interviews and workshops as well as technology/safety assessments. It is important to understand the nature of modern battery technology, so an overview of the products being deployed is given, including popular suppliers and cell chemistries from Asia and USA as well as Europe. Sections 3 -6 include general introductory information. The hazards related with these relatively newly developed solutions are also examined, with some case studies. This is vital to relate to the needs for Health & Safety concepts that will embodied in the design and build of tests facilities, and the subsequent disciplines to be instilled in their routine operation.

A current overview on the global standardization activities in the field of electrified propulsion is reviewed in Sections 7-9, thus creating a common understanding on the activities and the interaction of the involved key organizations.

Sections 10-14 cover facilities design guidelines, equipment and operational topics. Guidelines for the Safe operation Procedures are presented for the handling and testing of devices, whether at the cell level which is typically a 20 – 40 Ah pouch cell weighing 1 kg, up to a full battery pack complete with cell balancing electronics, BMS and cooling circuits and possibly weighing up to 1000kg. The related testing environments are examined for different applications and hazard/risk levels.

There are various support information’s offered in the Annexes. Finally, a comprehensive tabular overview on relevant standards is given.

Figure 1-1: PHEV taxi fire, Beijing
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Figure 2-1: Lithium Ion EV Battery Pack
3. Introduction: Electric Vehicle history and Battery Technology

The introduction of electric drive components and into the automotive powertrain assembly is certainly not a new topic. However such are the advancements in Electrical components and the range and energy density of modern cell chemistries for batteries, there is a significant effort to commercialize the solutions and to achieve mass production as an alternative to conventional powered ICE vehicles.

![Figure 3-1: Early days of Hybrid automotive experience](image1.png)

Mr. F. Porsche driving the Lothner-Porsche Mixte on his record drive at the Exeiberg race in Vienna.

The word “Mixte” was used where we today use “Hybrid”, the combination of an combustion engine with an electrical motor.

Tagblatt:

"...wobei die Geschwindigkeiten der Automobile mittlerweile so groß geworden sind, dass man mit einem Entgegenkommenden gar nicht mehr sprechen könnte!"

"... the speeds of the cars have become now so fast, that one can not talk with the oncoming one!"

For over a century, prototype vehicles tried without sustained success to adopt flooded lead acid batteries, and occasionally short production runs resulted, or niche markets such as milk floats transpired. More recently Nickel Metal Hydride with Potassium Hydroxide electrolytes was introduced into a hybrid vehicle format and this has enjoyed significant growth and market penetration in the form of the Toyota Prius.

![Figure 3-2: Ni MH pack from Toyota Prius](image2.png)

Toyota sold more than 140,000 units of the Prius in the U.S. in 2010, and more than 315,000 in Japan and this has helped to raise public awareness of the future potential of hybrid and also full battery electric vehicles.
The main drivers to successfully introduce hybridization/electrification into the area of heavy duty vehicles are performance, endurance, safety and cost of the integrated powertrains and powertrain components. Exhaustive Lithium Ion research and development continues to optimize and improve the electro-chemical systems accordingly. Over the past decade, the 18650 cell was introduced at just over 1 Ah and now is approaching 4 Ah in mass produced (millions per month) quantities.

Figure 3-3: Performance development of 18650 cells

It can be clearly seen that the energy density, power and performance of the cell is continually being enhanced. It is important to remember that the routine production of Modules and Packs will need to keep pace with the evolutionary cell process, as the knock on effects to BMS algorithms could prove to be a significant task. Co-ordination of the prototype development of packs, and ensuring continuity of cell supply through reasonable periods of production, and then further ongoing aftermarket support both in the maintenance area and long term availability of spare parts is necessary.

New materials and the building of significant production facilities, particularly thanks to USA quantitative easing are forecast to bring large volumes of supply and hopefully significant cost reductions at the cell level.

Figure 3-4: Forecasts for reduced costs and improved performance
Lithium Ion cell technologies have developed over the last decade and from small 1-3 Ah cylindrical and prismatic units for laptops and cellphones to Large Format pouch cells with increased capacities; typically these 20-40AH cells are now being connected in series parallel arrangements to form High Voltage, High energy battery packs. "Lithium Ion" is a generic term, and within this scope are electro-chemical couples such as Lithium Ion Phosphate, Lithium Cobalt, Lithium Manganese and endless further variations, all with their own benefits and disadvantages.

Whilst packs are still complex and relatively expensive, there is a trend to further electrify the range of vehicles on the road in today's society. In the automotive industry, huge investment has been dedicated to the expansion of R&D and cell production facilities, and new vehicles such as the hybrid GM Volt and the Nissan Leaf BEV are now being made.

Further driven by a decline in fossil fuel resources, and environmentally friendly initiatives, there is an optimistic outlook for the future of electrification, and a race to develop even more efficient devices.

We are used to dealing with fuels such as petrol, diesel and others, but now large concentrations of often toxic, explosive and dangerous substances (batteries) are introduced to the supply chain. We will examine storage and handling, shipping, performance and development as well as abuse and importantly the considerations necessary for dealing with unplanned events.

These challenges are nothing new to an industry used to creating and controlling combustion from flammable gases, but they are different.
4. Concerns and Hazards

There have been a number of incidents highlighted by the press over the last couple of years concerning Lithium Ion and other products in the EV industry. This ranges from the loss of at least 2 Boeing 747 cargo planes attributable to cells being air freighted, or to individual vehicle fires and events in manufacturing facilities. The picture below is a Beijing bus as used in the Olympics.

By examining the failure mechanisms of battery related incidents, it is possible to build up a wealth of knowledge, and then to put together standards, guidelines and procedures for dealing with the everyday operations in development, testing and production. Sometimes there are electrochemical events that lead to fires and explosions, and sometimes there are electrical faults that lead to shocks. Often it is down to human error.

As early as 1999, the SAE J 2464 Electric Vehicle Battery abuse Testing standard was published and much time has been spent to quantify the risks and to analyze the events. This information has been used to specify necessary precautionary measure later referred in the design and use of facilities.
Potential hazards of batteries

The hazards of lithium-ion batteries can be broken down as follows:

- Risk of electric voltage or electric current.
- Danger of leaking components
- Risk of fire and/or explosion

Risk of electric shock

Automotive battery packs have now rated voltages from about 100V to 800V to. This DC voltage can cause a fatal electric shock. Therefore, safety measures, such as shock protection and compliance with an insulation resistance are required

Voltage class A
classification of an electric component or circuit with a maximum working voltage of $\leq 30$ V a.c. or $\leq 60$ V d.c.,

Voltage class B
Classification of an electric component or circuit with a maximum working voltage of $(> 30$ and $\leq 1000)$ V a.c. or $(> 60$ and $\leq 1500)$ V d.c.,

NOTE For more details, see ISO 6469-3.

Dangerous DC Voltages above 60V must be respected and work on the electrical circuit is allowed only by trained personnel. This document does not concentrate on fundamental ac or routine dc electrical principles, which are well understood, especially in Europe. The threat by the electric current consists of a hand by arcing (line break) and the other by overload or short circuit. All error cases can quickly lead to local overheating and fire. At a current of 200A a contact resistance of 1 m$\Omega$ leads to a power dissipation of 40W.

Such power may lead at least to an accelerated aging of the device under test, but can also lead to overheating and thermal runaway of the device under test. Another commonly occurring problem in the test area is short-circuiting during handling batteries.

Danger due to escaping substances

Lithium-ion cells are sealed gas-tight, so that during normal operation no ingredients can escape. If the housing is damaged mechanically ingredients can escape in gaseous or liquid form. Damage to the housing can be a production error, by mechanical damage (crash, improper treatment) or by pressure in the cell.

Overpressure usually arises due to overheating of the cell, which may be the result of an overload, short circuit or overload. In liquid form the electrolyte can exit.

This consists of a mixture of linear (DMC) and cyclic (EC, PC) carbonates and the conductive salt LiPF$_6$. The solvents are flammable and highly irritating. In particular, DMC is highly volatile and may form explosive mixtures with air. If the supporting electrolyte comes into contact with moisture, it may form hydrofluoric acid. This is highly toxic and irritating to the respiratory tract.

Gasses occur mainly of vaporized electrolyte (explosive) and decomposition products of electrolytes such as methane, ethane, propane and butane, and aldehydes.
Risk of fire and / or explosion

The materials used in lithium-ion batteries are highly flammable and combustible. A Li-ion battery stores more than ten times of thermal energy as electrical energy. In addition, some of the used cathode materials decompose spontaneously at high temperatures and thereby release heat and oxygen. Since this reaction is exothermic and also releases oxygen, which contributes then to accelerate the other reaction processes, there may be a very fast thermal runaway of the cell. Below is an example of particulate deposits captured from an abuse tests.

![Figure 4-3: Before and after filters from abuse test](image)

Human error

Test systems are now fully programmable, i.e. allowing any testing procedures within the limits of test equipment. This is therefore the possibility to enter test parameters that lead to the runaway of the connected cell. There are indeed limits for currents and voltages, but they are also adjustable. These errors can be summarized as a programming error. Another source of error is when you connect the device under test. The danger here is that connecting cables of different test channels are mixed up.

Cell and module fault

Technical defects in the test system and human error can cognize with devices still largely, but cell errors are mostly non-detectable by external measurements in advance. If a cell fails, e.g. a short circuit, then a runaway of the cell and a fire most likely no longer be avoided. Pictures below show a cell venting and then exploding under short circuit conditions. Overdischarging, low temperature operation and all manner of fault conditions from the BMS are concerns.

![Figure 4-5: Soft short event – venting](image) ![Figure 4-4: Hard short event – explosion](image)
Figure 4-6: Clean Filter

Figure 4-7: Contaminated Filter
Metals and particulates

Figure 4-8: Particulate analysis of contaminated filter.

<table>
<thead>
<tr>
<th>ELEMENT</th>
<th>CONC'N</th>
<th>ELEMENT</th>
<th>CONC'N</th>
<th>ELEMENT</th>
<th>CONC'N</th>
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<td>&lt;0.01</td>
<td>Au</td>
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<td>Ce</td>
<td>&lt;0.01</td>
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<td>Th</td>
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<td>Nd</td>
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<td>U</td>
<td>&lt;0.01</td>
</tr>
</tbody>
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Figure 4-9: Elemental particle analysis of contaminated filter.
# Gas and vapours

![Graph showing gas abundance over time](image)

**Figure 4-10**: Analysis of gas and vapors from collection tube

<table>
<thead>
<tr>
<th>Peak</th>
<th>Elution time</th>
<th>Assignment</th>
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<tbody>
<tr>
<td>A</td>
<td>0.70 min</td>
<td>Air</td>
</tr>
<tr>
<td>B</td>
<td>0.86 min</td>
<td>Carbon dioxide</td>
</tr>
<tr>
<td>C</td>
<td>1.00 min</td>
<td>Propane</td>
</tr>
<tr>
<td>1</td>
<td>1.30 min</td>
<td>1,3-butadiene</td>
</tr>
<tr>
<td>2</td>
<td>1.31 min</td>
<td>Propane</td>
</tr>
<tr>
<td>Y</td>
<td>1.35 min</td>
<td>Acetaldehyde</td>
</tr>
<tr>
<td>D</td>
<td>1.36 min</td>
<td>Methanol</td>
</tr>
<tr>
<td>3</td>
<td>1.91 min</td>
<td>C5-hydrocarbons</td>
</tr>
<tr>
<td>4</td>
<td>2.15 min</td>
<td>Acrolein</td>
</tr>
<tr>
<td>5</td>
<td>2.22 min</td>
<td>Acetone</td>
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<tr>
<td>6</td>
<td>2.26 min</td>
<td>Furfural</td>
</tr>
<tr>
<td>E</td>
<td>4.70 min</td>
<td>Dimethyl carbonate</td>
</tr>
<tr>
<td>7</td>
<td>4.92 min</td>
<td>Acetic acid</td>
</tr>
<tr>
<td>F</td>
<td>6.70 min</td>
<td>Benzene</td>
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<tr>
<td>G</td>
<td>6.73 min</td>
<td>Ethyl methyl carbonate</td>
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<tr>
<td>H</td>
<td>7.43 min</td>
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<tr>
<td>S</td>
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<td>Diethyl carbonate</td>
</tr>
<tr>
<td>K</td>
<td>8.62 min</td>
<td>Hexamethylcyclotrisilane present in blank run</td>
</tr>
<tr>
<td>L</td>
<td>9.64 min</td>
<td>C8-naphthrene</td>
</tr>
<tr>
<td>9</td>
<td>9.75 min</td>
<td>Furfural</td>
</tr>
<tr>
<td>10</td>
<td>10.09 min</td>
<td>Chlorobenzene</td>
</tr>
<tr>
<td>11</td>
<td>10.31 min</td>
<td>Ethyl benzene</td>
</tr>
<tr>
<td>12</td>
<td>10.55 min</td>
<td>p-Xylene</td>
</tr>
</tbody>
</table>

| 13   | 10.70 min   | Phenyl acetylene                    |
| 14   | 11.02 min   | Styrene                             |
| M    | 11.81 min   | Octamethylcyclotrisilane present in blank run |
| 15   | 12.67 min   | Benzaldehyde and phenol             |
| N    | 12.71 min   | Ethylene carbonate                  |
| P    | 13.12 min   | Propylene                           |
| 16   | 13.13 min   | Triblock [3.1:3.0(2.4)] n=3-ene-3-carboxitrile, possibly |
| 17   | 13.30 min   | Benzoilurane                        |
| 25   | 14.34 min   | Indene                              |
| Q    | 14.64 min   | C11 alkane                          |
| 18   | 14.69 min   | Acetophenone                        |
| 19   | 16.11 min   | Benzaldehyde                        |
| R    | 16.40 min   | C12 alkane                          |
| 20   | 17.11 min   | Nonanal or isomer                   |
| 21   | 17.45 min   | 1,3,5 Trichlorobenzene              |
| Z    | 18.3 min    | Capronitram                         |
| S    | 18.55 min   | C16 alkane                          |
| 22   | 18.86 min   | 2-methyl napthalene or isomer       |
| T    | 19.15 min   | Cyclohexyl benzene                  |
| 23   | 19.25 min   | Phenylacetic acid                   |
| U    | 20.18 min   | Biphenyl                            |
| V    | 20.86 min   | Dimethyl phthalate present in blank run |
| 24   | 21.56 min   | Biphenylene                         |
| W    | 22.73 min   | Diethyl phthalate present in blank run |

**Figure 4-11**: Chemical analysis of vapors from collection tube
5. Thermal stability of Lithium Ion Cells and Packs

It should be noted that once a cell goes into a thermal event, the thermal runaway reaction may take place in just a few seconds. Below is the response of a cylindrical cell being cycled where a small particle was inserted during winding, which would result in an internal short circuit.

![Graph showing fast reaction of cell going in to thermal runaway whilst cycling](image1)

Figure 5-1: Graph showing fast reaction of cell going in to thermal runaway whilst cycling

Also, it should be noted that cells can go into thermal runaway as low as 90 degrees C, as shown by the work below on 2 different chemistries that underwent the same wait and seek calorimetric test.

![Graph showing onset temperature of thermal runaway of Lithium Ion Phosphate cell (blue) vs Lithium Cobalt cell (red)](image2)

Figure 5-2: Graph showing onset temperature of thermal runaway of Lithium Ion Phosphate cell (blue) vs Lithium Cobalt cell (red)

All cells will be supported by a Material Data Safety sheet (MSDS). This will give a good introduction to the types of hazards, effects and wastes and there are some typical examples of popular suppliers’ information in Appendix 1. This document should be fully reviewed and understood whenever considering the use of energy storage devices.
6. Identification of Hazards using EUCAR Severity Level Score

The following table is generally adapted to classify and define failures of cells under test. The coding is used on MSDS from cell manufacturers to signify the tolerance and reaction of their designs.

![Assign Hazard Severity Level Score using descriptions adapted from EUCAR and SAND2005-3123](image)

<table>
<thead>
<tr>
<th>Hazard Level</th>
<th>Description</th>
<th>Classification Criteria, Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No effect</td>
<td>No effect, no loss of functionality.</td>
</tr>
<tr>
<td>1</td>
<td>Passive Protection activated</td>
<td>No defect, no leakage, no venting, no fire or flame, no rupture, no explosion, no exothermic reaction or thermal runaway. Cell reversibly damaged. Repair of protection device needed.</td>
</tr>
<tr>
<td>2</td>
<td>Defect / Damage</td>
<td>No leakage, no venting, no fire or flame, no rupture, no explosion, no exothermic reaction or thermal runaway. Cell irreversibly damaged, repair needed</td>
</tr>
<tr>
<td>3</td>
<td>Leakage Delta m &lt; 50%</td>
<td>No venting, no fire or flame**, no rupture, no explosion, Weight loss &lt; 50% of electrolyte weight. (electrolyte = solvent + salt)</td>
</tr>
<tr>
<td>4</td>
<td>Venting Delta m ≥ 50%</td>
<td>No fire or flame**, no rupture, no explosion, Weight loss ≥ 50% of electrolyte weight.</td>
</tr>
<tr>
<td>5</td>
<td>Fire or Flame</td>
<td>No rupture, no explosion, i.e., no flying parts.</td>
</tr>
<tr>
<td>6</td>
<td>Rupture</td>
<td>No explosion, but flying parts, ejection of parts of the active mass.</td>
</tr>
<tr>
<td>7</td>
<td>Explosion</td>
<td>Explosion, i.e., disintegration of the cell.</td>
</tr>
</tbody>
</table>

Figure 6-1: EUCAR rating table

Proposing safety concepts for high voltage component test beds requires a global understanding on the typical validation topics.

To elaborate a sound information basis AVL List GmbH performed extensive literature research & expert interviews to identify relevant testing standards for high-voltage components thus extracting application related risks and hazards.

“When it comes to component standardization, the automotive industry is mainly focusing on the quality, the performance, the classification and – if necessary – on the interfaces to other components and systems. Despite the fact that for hybrid powertrains new standards are developed, already existing regulations need to be adapted and expended. This is true for e.g. norms/standards for performance of energy wires or fuses but also for directives for validating components under automotive environmental conditions.” [QUELLE: “e-mobility. Ein Überblick, 9.Juli 2010]
7. Organizations and standardization activities in the field of electrified propulsion

According to the ISO/IEC guide 2:2004 standardization is the activity of establishing, with regard to actual or potential problems, provisions for common and repeated use, aimed at the achievement of the optimum degree of order in a given context.

In particular, the activity consists of the processes of formulating, issuing and implementing standards. Important benefits of standardization are improvement of the suitability of products, processes and services for their intended purpose, prevention of barriers to trade and facilitation of technological co-operation.

Accordingly, a standard is a document, established by consensus and approved by a recognized body that provides, for common and repeated use, rules, guidelines or characteristics for activities or their results, aimed at the achievement of the optimum degree of order in a given context. Standards should be based on the consolidated result of science, technology and experience, and aimed at the promotion of optimum community benefits.

Within Figure 7-1, the interaction of the standardization and regulation organizations is shown. The International Organization for Standardization (ISO), the International Electro-technical Commission (IEC) and the telecommunication standardizations sector of the International Telecommunication Union (ITU-T) and their regional/national branches are the recognized organizations.

![Diagram of standardization and regulation organizations]

As an example, the Society of Automotive Engineers (SAE) is an organization in the latter meaning of the term “standardization and is mainly active within US. In terms of access to the North American automotive market OEMs and suppliers, the compliance with these SAE standards is frequently mandatory.

The American National Standards Institute (ANSI) is the US-member of e.g. ISO and IEC. However, the ANSI does not develop standards on its own, but falls back on accredited
organizations, e.g. the Underwriters Laboratories for this purpose.

The UL is an independent enterprise for certification and validation of product safety that elaborates standards focusing on safety. For the purpose of elaborating national US standards, the UL is accredited by the ANSI.

There are a several types of Standards to provide specific target ranges, including:

- Performance standards
- Testing standards
- Interface standard / compatibility standards
- Terminology standard
- Product standards

Standardization within the field of electrified propulsion is to some extent different to other areas. At present, national and international standardization concepts compete with one another.

However, since road vehicle markets are international, efforts must aim towards developing international standards right from the start. In order to promote innovations, standardization intentionally is more function-oriented than solution-oriented so from its character performance based rather than descriptive. [Fritsche]

The European Union is especially concerned about not letting national standardization hinder an international consolidation, as several topics from research and development to regulatory requirements need to be considered on a global basis.

Key factors contributing to the break-through of electrified propulsion are

- Infrastructure
- Technology and technique improvement (e.g. energy storage system)
- Customer satisfaction (e.g. acceptable cost)
- Standardization of interface

As there are several industries involved, coordinating these whilst aiming at a common goal is challenging. Over decades, standardization in the areas of electro-technology/energy technology and the automotive industry focused on the specific domains. So electrified propulsion, especially driven by electro-mobility requires interdisciplinary systems thinking and a clear allocation of responsibilities within the involved organizations.

Following standardization on an international level (ISO, IEC) is favorable over national/regional standards deriving from ISO or IEC standards.

The standards by intention are limited in number and focus on the necessary area thus being a technology enabler. At present, standardization aims are

- Defining an acceptable safety level
- Ensuring interoperability by defining communication and software interfaces
- Enabling high quality and reliability by defining tests
- Enabling a reasonable cost level by defining necessary hardware

In any case, standardization obeys the FRAND-principle („fair, reasonable and non-discriminatory“).
Both, the ISO and the IEC are worldwide acting organizations, based upon national memberships.

With the IEC being responsible for electro-technical standardization and the ISO leading all other areas – traditionally including the standardization for the automotive industry and also the E/E systems/components in vehicles – these two organizations join their activities in standardizing interfaces, especially with respect to plug-in hybrid technology. An overview on the structure of both, ISO and IEC is given hereafter.

**Figure 7-2: IEC and ISO structure**

Overview on the structure of the International Organization for Standardization (ISO) and the International Electro-technical Commission (IEC)

Within ISO, the expertise concerning safety relevant topics is clustered in the technical committee 22 ("Road Vehicles"), and segmented as follows:

- TC 22/SC 1: Ignition equipment
- TC 22/SC 2: Braking systems and equipment
- TC 22/SC 3: Electrical and electronic equipment
- TC 22/SC 4: Caravans and light trailers
- TC 22/SC 5: Engine tests
- TC 22/SC 7: Injection equipment and filters for use on road vehicles
- TC 22/SC 8: Lighting and light-signaling
- TC 22/SC 9: Vehicle dynamics and road-holding ability
- TC 22/SC 10: Impact test procedures
- TC 22/SC 11: Safety glazing materials
- TC 22/SC 12: Passive safety crash protection systems
- TC 22/SC 13: Ergonomics applicable to road vehicles
- TC 22/SC 15: Interchangeability of components of commercial vehicles and buses
- TC 22/SC 17: Visibility
- TC 22/SC 19: Wheels
- TC 22/SC 21: Electrically propelled road vehicles
- TC 22/SC 22: Motorcycles
- TC 22/SC 23: Mopeds
- TC 22/SC 25: Vehicles using gaseous fuels

The collaboration between the ISO and the IEC concerning the work on the electro-technical field of road vehicles was based upon the ISO/IEC agreement concerning the work of ISO/TC22 but was replaced by an ISO/IEC memorandum of understanding (MoU) early 2011, as shown below.
Within IEC, especially the technical committee 69 focuses on the preparation of international standards for road vehicles, totally or partly electrically propelled from self-contained power sources, and for electric industrial trucks. The functional safety of road vehicles is scope of the ISO 26262. It applies to safety-related systems that include one or more E/E systems installed onboard of road vehicles.

With respect to battery systems, ISO 12405 and IEC 62660 are particularly relevant for Lithium Ion cells and packs for electrically propelled road vehicles.

The standardization of single cell dimensions is currently under investigation.
Additionally, electric components (e.g. connectors) utilized inside the traction batteries are to be standardized. To highlight the high activity within that field, an overview on typical projects is given below. (2011)
The third relevant international organization involved in the electrification topic, but rather regulating then standardizing, is the United Nations Economic Commission for Europe (UN ECE) dealing with main basic safety requirements for vehicles within the world forum for harmonization of vehicle regulations (Working Party 29), as highlighted in below:

<table>
<thead>
<tr>
<th>Vehicle-related</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISO 6469: Electrically propelled road vehicles; scheduled publication; 11/2011</td>
</tr>
<tr>
<td>ISO TR 8713: Electric road vehicles – Vocabulary; ; scheduled publication; 11/2011</td>
</tr>
<tr>
<td>ISO 26262: Road vehicles – Functional Safety Part 1-10; scheduled publication; 06/2011</td>
</tr>
<tr>
<td>ISO 7637: Electrical disturbances from conducting and coupling; scheduled publication: 12/2011</td>
</tr>
<tr>
<td>ISO 11451: Test methods for el. disturbances from narrowband radiated el.-magn. energy; published</td>
</tr>
<tr>
<td>ISO/IEC 15118: Communication protoccol between electric vehicle and grid Part 1-2; scheduled publication: 12/2012</td>
</tr>
<tr>
<td>ISO 23274: Hybrid-electric road vehicles – Exhaust emissions and fuel consumption measurementsscheduled publication: 11/2012</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Components</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISO 12405: Test specification for lithium ion traction battery systems Part 1-2; scheduled publication: 03/2012</td>
</tr>
<tr>
<td>ISO 14572: Round, unscreened 60V and 600V multicore sheated cables; scheduled publication: 12/2012</td>
</tr>
<tr>
<td>ISO 11452: Component methods for el. disturbances from narrowband radiated el.-magnetic energy; scheduled publication: 04/2012</td>
</tr>
<tr>
<td>ISO 6722: Road vehicles – 60 V and 600 V single.core cables; scheduled publication; 12/2012</td>
</tr>
<tr>
<td>ISO/IEC Design requirments for battery system – dimensions for Li-Ion battery cells; scheduled publication: 12/2012</td>
</tr>
</tbody>
</table>

Figure 7-5: Status of the main standardization projects for (hybrid) electric vehicles
It should be remembered that the Battery pack assembly is complex and involves not only the cells, but many other components such as cell balancing circuits, BMS control, protective circuits and fuses, and cabling possibly cooling and chassis structural housing to name a few.
Typical areas of interest affected by the standardization efforts are:

- Energy storage systems (battery, fuel cell, capacitors with respect to performance)
- Communication (interfaces, protocols, data security)
- Vehicle technology (power electronics, auxiliary components, drive train)
- Product and operating safety (electrical & functional safety, abuse, crash)
- Electromagnetic compatibility (EMC)
- Transport
- Disposal and recycling

The key European based active bodies as we saw in section 4 are:

IEC TC69: “Electric road vehicles and electric industrial trucks”
ISO TC22: “Road vehicles”
ISO TC22/SC21: “Electrically propelled road vehicles”

These committees meet 2-3 times per year and draw attendees from a global cross section of Auto-manufacturers, cells manufacturers, public and government bodies.

Usually, the provision of accepted standards actually does not happen until some years after the products are developed, and they are often in the market and available before the voluntary or mandatory actions defined can be put in place.

This document will focus particularly on current battery related standards, and identify the key factors that will then go on to influence the site safety implications and operation of test and manufacturing facilities.

As long ago UL 1642 for Lithium Ion cells became a world renowned document and early applications in cell phones and laptops embraced this globally.

The SAE J2464 standard identified safety and abuse tests and in 2005 the Sandia National Laboratories introduced the Freedom car drive cycle for endurance benchmarking.
Other standards that are relevant include not just the vehicle components, but also subjects such as safe connection to the electrical grids for charging.

**Battery Standards Evolution**

For the roadmap below, only lithium-ion batteries are considered.

Other technologies such as are not explicitly considered, because according to the experts their use in the coming 10 years plays a minor role. Lithium-ion batteries are currently in terms of storage density and handling the best technical solution.
1999 Issued SAE J2464 Electric Vehicle Battery Abuse Testing


2005 Issued UL 1642 Standard for Lithium Batteries

2009 Revised SAE J2464 Electric and Hybrid Rechargeable Energy Storage System (RESS)

2010 Issued IEC 62660-1 Lithium Ion Cells for the propulsion of electric road vehicles – Performance testing.

2010 Issued IEC 62660-2 Lithium Ion Cells for the propulsion of electric road vehicles – Reliability and Abuse testing.

2011 Issued SAE 2929 Electric and Hybrid Vehicle Propulsion Battery System Standards – Lithium Based Rechargeable cells. Referrals to J2464 etc.

2012 Issued ISO 12405-1 Electrically Propelled Vehicles (ESS) Test Specification for Lithium Ion traction battery systems High Power Applications

2012 Issued ISO 12405-2 Electrically Propelled Vehicles (ESS) Specification for Lithium Ion traction battery systems High Energy Applications

2012 Draft ISO 12405-3 Electrically Propelled Vehicles (ESS) Test Specification for Lithium Ion traction battery systems Safety Performance Requirements
Pack Testing

- ISO 12405-1 “Electrically propelled road vehicle – Test specification for lithium ion traction battery systems Part 1: High power applications”
- ISO 12045-2: “Electrically propelled road vehicle – Test specification for lithium ion traction battery systems Part 2: High energy applications”

Here procedures for lithium-ion battery packs and systems for use in electrically propelled road vehicles are specified. The test procedures enable the determination of the essential characteristics of performance, reliability and abuse of lithium-ion battery packs and systems. They assist the user to compare the test results achieved for different battery packs or systems.

It enables the setting up of a dedicated test plan for an individual battery pack or system subject to agreement between the customer and supplier.

(This standard is associated with IEC 62660 for Lithium Ion cells for Electric Vehicles.)

The battery is now treated as a system rather than a component, and real life testing with cooling, BMS control, cell balancing are all identified, with clear methods for data recording and result analysis.

Battery system with integrated battery control unit (BCU)

ISO 12405 describes performance, reliability and abuse test sequences and the related test objectives (battery system or battery pack).
- For performance issued, energy & capacity tests, power & internal resistance tests, validation of SOC losses, cranking power evaluation at low and high temperatures, energy efficiency determination and cycle life tests are mentioned.
- Reliability tests include dewing tests, thermal shock cycling, vibration tests and mechanical shock.

Figure 8-4: Battery Pack schematic
- Safety relevant tests include short circuit and overcharge as well as overdischarge protection validation.

The vibration test sequences in ISO 12405 are divided in two parts, one dealing with the battery system and the other one with electronic components.

The battery is stressed with stochastically distributed vibration patterns according to IEC 60068-2-64. The test profiles for electronic components are also based upon IEC 60068-2-64, but utilizing randomized patterns.

With respect to the high voltages occurring in battery systems for HEV and BEV, both ISO 12405 norms point to ISO 6469-1 and ISO 6469-3, demanding the fulfillment of the requirements given therein.

Below is a GM Volt battery on a Vibration slip table at the GM test facility in USA.

![Figure 8-5: GM Volt pack on slip table awaiting vibration tests](image)
Cell Testing

The first part of IEC 62660 (formerly IEC 61982-4) specifies performance and life testing of secondary lithium-ion cells used for propulsion of electric vehicles including battery electric vehicles (BEV) and hybrid electric vehicles (HEV). This standard is well written to include experiences from the previous decades and the learning from past attempts at electrification using other Energy storage sources.

The objective of IEC62660-1 is to specify various test procedures and conditions to obtain the essential characteristics of lithium-ion cells for vehicle propulsion applications regarding capacity, power density, energy density, storage life and cycle life. This allows the obtaining of essential data on cells for various designs of battery systems and battery packs.

IEC 62660-2 (formerly IEC 61982-5) specifies test procedures to observe the reliability and abuse behavior of secondary lithium-ion cells used for propulsion of electric vehicles including battery electric vehicles (BEV) and hybrid electric vehicles (HEV). The tests are indispensable for obtaining essential data on reliability and abuse behavior of lithium-ion cells for use in various designs of battery systems and battery packs.

This standard provides standard classification of description of test results to be used for the design of battery systems or battery packs.

The IEC 62660 specifies tests for vehicles including battery electric vehicles (BEV) and hybrid electric vehicles (HEV). In addition to that the values of the various parameters such as voltage, current, power and temperature to be used in the testing of battery cells used for the propulsion of electric road vehicles are given.

The standard also defines specific test conditions and procedures, such as

- Dimensions measurement
- Weight measurements
- Electrical measurement (Capacity, power density and regenerative power density test, energy density test
- Storage test (charge retention test, storage life)
- Cycle life test (Battery electric vehicle test cycle test, hybrid electric vehicle cycle test)
- Energy efficiency test
- Capacity test
- Reliability and abuse test (mechanical test – vibration & shock & crush; thermal test – high temperature endurance & temperature cycling; electrical test: external short circuit & overcharge & forced discharge)

Methods of pre-conditioning and after test evaluation are included. Accurate and repeatable cell testing is extremely important. Assessing the consistency of delivered cells, being on the lookout for cell and batch variations, and an overall achievement of consistency is essential.

All systems should be calibrated and routinely checked to be within defined parameters. Particular attention to cell voltage and current will be necessary to be sure that the capacities integrated and reported are truly reflective, and these will allow benchmarks for further monitoring to be set.
Tolerance for range and accuracy of measured data.

ISO 12405 Specifications

The accuracy of external measurement equipment shall be at least within the following tolerances:
- voltage ± 0,5 %
- current ± 0,5 %
- temperature ± 1 K

The overall accuracy of externally controlled or measured values, relative to the specified or actual values, shall be at least within the following tolerances:
- voltage ± 1 %
- current ± 1 %
- temperature ± 2 K
- time ± 0,1 %
- mass ± 0,1 %
- dimensions ± 0,1 %

All values (time, temperature, current and voltage) shall be noted at least every 5 % of the estimated discharge and charge time, except if it is noted otherwise in the individual test procedure.

IEC 61962-4: Tolerances

- U: +/-1%
- I: +/-1%
- T: +/-2K
- t: +/-0,1%
- m: +/-0,1%
- Dimensions: +/-0,1%

DIN VDE V 0510-11: Tolerances:

- U: +/-1%
- I: +/-1%
- T: +/-2K
- t: +/-0,1%
- capacities +/-2%
- resistance: +/-5%

It should be noted that Lithium Ion cells are particularly sensitive to accurate voltage and current control. In the factory, the correctly applied formation procedures will have a long term effect on life cycle expectancy, and the first cycles during usage will possibly add to this pre-conditioning effect. Initially a constant current with maximum voltage limit is applied in a standard charge, but once the terminal voltage reaches this limit.

Accurate taper current control is needed, reducing accordingly to the cut-off point and achieving fully charged status within manufacturer’s specific data.

4 wire measurement is always required, and between calibration periods should be regularly checked against control output data to avoid overcharging and over discharging.
Below is a typical discharge plot of a C/3 discharge on a 20Ah Lithium Ion Phosphor pouch cell.

![Typical discharge plot](image_url)

**Figure 8-6: Typical Lithium Ion cell discharge curve**

*Speed and accuracy of control, data collection and finite integration of capacity are prerequisites of a good, safe test system.*

*Claims of performance on test equipment data sheets should not necessarily be taken for granted. The use of an oscilloscope to evaluate or commission any particular system is highly recommended. Special attention should be paid to switching transient times, and for instance constant power or constant resistance response.*

*There is a trend in Automotive industry to deploy DC load and power supplies that do not have safety and robustness communication between the hardware and software. Although this often results in lower initial costs for test-beds, this should be avoided if the long term safety and risk analysis requirement re to be achieved.*
Traction Battery related active standards organizations.

Regulation – Type approval:
Guideline 2007/46/EC: “framework for the approval of motor vehicles and their trailers, and of systems, components and separate technical units intended for such vehicles”
UNECE Working party 29
- Reg10: “Approval of vehicles with regard to electromagnetic stability”
- Reg 94: “Protection of occupants”
- Reg 100: “Battery electric vehicles with regard to specific requirements for construction and functional safety”

Propulsion systems:
IEC TC2: “Rotary machinery”
ISO TC22/SC21/WG1: “Vehicle operation conditions, vehicle safety and energy storage installation”
ISO TC22/SC21/WG2: “Definitions and methods of measurement of vehicle performance and of energy consumption”

Power electronics:
ISO TC22/SC3: “Electrical and electronic equipment”
IEC TC22: “Power electronic systems and equipment”
IEC SC22G: “Adjustable speed electric drive systems on cooperating semiconductor power converters”
IEC TC40: “Capacitors and resistors for electronic equipment”
IEC TC69 WG2 “Motors and motor control systems”

Cables, electric conduction, connectors:
IEC TC23/SC23H: “Industrial plugs and socket outlets”
IEC TC20: “Electric cables”
IEC TC46: “Cables, Wires”
IEC TC86: “Fiber optics”
ISO TC22/SC3: “Electrical and electronic equipment”

Energy Storage Systems:
IEC TC21: “Secondary cells and batteries”
IECTC21/SC21A: “Secondary cells and batteries containing alkaline or other non-acid electrolytes”
IEC TC21 PT62485: “Safety requirements for secondary batteries and battery installations”
IEC TC21/JWG69 Li: “Lithium for automobile/automotive applications”
ISO TC22/SC21: “Electrically propelled road vehicles”
IEC TC105: “Fuel cell technologies”
IEC TC105/WG6: “Fuel cell system for propulsion and auxiliary power units”
IEC TC105/AHG1: “Identification of the market needs for standardization work on fuel cell systems for propulsion and auxiliary power units”
Joint working group IEC TC69 and ISO TC22/SC3: “Vehicle to grid communication interface2
IEC TC57: “Power systems management and distributed information exchange”
IEC SC65C & 65E: “Industrial-process measurement and control”
IEC TC69/WG4: “Power supplies and chargers”
ISO TC22/SC3/WG1: “Serial data communication”
ISO TC204: “Intelligent transport systems” Infrastructure:
IEC TC8: “System aspects for electrical energy supply”
IEC TC57: “Power systems management and associated information exchange”
IEC TC64: “Electrical installations and protection against electric shock”
IEC TC69/WG4: “Power supplies and chargers”

Electromagnetic compatibility:
IEC CIS/D: “Electromagnetic disturbances related to electric/electronic equipment on vehicles and internal combustion engine powered devices”
IEC TC77: “Electromagnetic compatibility”
IEC SC 77A: “Low frequency phenomena”
IEC TC106: “Methods for the assessment of electric, magnetic and electromagnetic fields associated with human exposure”
IEC SC47A WG9: “Test procedures and measurement methods for EMC in integrated circuits”
ISO TC22/SC3: “Electrical and electronic equipment”

Safety:
IEC TC64: “Electrical installations and protection against electric shock”
ISO TC22/SC21: “Electrically propelled road vehicles”
ISO TC22/SC21/WG1: “Vehicle operation conditions, vehicle safety and energy storage installation”
IEC TC21 PT62485: “Safety requirements for secondary batteries and battery installations”
9. UN38.3 Transportation

The tests being the prerequisite for transportation of lithium ion cells and batteries are summarized in the “UN Manual of Tests and Criteria”, which is attached in Appendix 2.

The Manual of Tests and Criteria contains criteria, test methods and procedures to be used for classification of dangerous goods according to the provisions of Parts 2 and 3 of the United Nations Recommendations on the Transport of Dangerous Goods.

Model Regulations, as well as of chemicals presenting physical hazards according to the Globally Harmonized System of Classification and Labeling of Chemicals (GHS). As a consequence, it supplements also national or international regulations which are derived from the United Nations Recommendations on the Transport of Dangerous Goods or the GHS.

Originally developed by the Economic and Social Council’s Committee of Experts on the Transport of Dangerous Goods which adopted a first version in 1984, it has been regularly updated and amended every two years. Presently, the updating is done under the auspices of the Committee of Experts on the Transport of Dangerous Goods and on the Globally Harmonized System of Classification and Labeling of Chemicals, which replaces the original committee since 2001.

The classification procedures, test methods and criteria contained in the Manual of Tests and Criteria are divided into three parts, as follows:

Part I: those relating to assignment of explosives to Class 1

Part II: those relating to assignment of self-reactive substances to Division 4.1 and of organic peroxides to Division 5.2

Part III: those relating to assignment of substances or articles to Class 2, Class 3, Class 4, Division 5.1, Class 8 or Class 9.

In December 2004, the Committee of Experts on the Transport of Dangerous Goods and on the Globally Harmonized System of Classification and Labeling of Chemicals decided to add a new part IV relating to test methods concerning transport equipment.

The fifth revised edition includes all the amendments to the fourth revised edition adopted by the Committee at its second and third sessions in 2004 and 2006 (published under the symbols ST/SG/AC.10/11/Rev.4/Amend.1 and ST/SG/AC.10/11/Rev.4/Amend.2) and those adopted at its fourth session in 2008 (ST/SG/AC.10/36/Add.2 and -/Corr.1).

Among the new amendments are revised provisions for the testing and classification of lithium metal and lithium ion batteries (Sub-section 38.3), new test methods for transport equipment (Part IV), an additional test for assigning classification code 1.4S to certain articles (Section 16, unconfined package test), a new test for determining whether pyrotechnic substances are to be considered as flash compositions for the purpose of classification (Appendix 7), as well as various other revised provisions.

With respect to batteries, the manual focuses on environmental tests and misuse test sequences that are can be clustered in two main groups, namely

- Environmental tests: altitude simulation, thermal test, vibration, shock
- Misuse tests: external short circuit, impact (cell level), overcharge, forced discharge (cell level)

**T1-T5 (Same Samples, Tested in Order, All Types)**
- T1: Altitude Simulation
- T2: Thermal Test
- T3: Vibration
- T4: Shock
- T5: External Short Circuit

**T6: Impact (Primary and Secondary Cells Only)**
**T7: Overcharge (Rechargeable Batteries Only)**
**T8: Forced Discharge (Primary and Rechargeable Cells Only)**

Figure 9-1: Tests from UN 38.3.

**Shipping Names**
- UN3090: Lithium (Lithium Metal) Batteries
- UN3091: Lithium Batteries contained in equipment
- UN3480: Lithium-Ion Batteries
- UN3481: Lithium-Ion Batteries contained in equipment

It should be noted that the declaration of conformity and shipping of goods by airfreight is based on self-declaration. There has been much confusion about what, how and even if to test and a new version of the document is due to be released 1 Jan 2013 to try and clear up the confusion. One EV maker read the existing regulation, and concluded that as long as he had used a cell that was tested, then he did not need to do any further tests to air freight a finished vehicle from Germany to China for an exhibition!

Figure 9-2: Some notes from proposed changes to UN38.3
10. Battery testing facilities and environments

As referred to in section 5, European Council for Automotive R&D (EUCAR) published a hazard level classification that is widely accepted when it comes to discussions about risks arising from the unit under test itself (UUT).

<table>
<thead>
<tr>
<th>Hazard Level</th>
<th>Description</th>
<th>Classification Criteria, Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No effect</td>
<td>No effect, no loss of functionality.</td>
</tr>
<tr>
<td>1</td>
<td>Passive Protection</td>
<td>No defect, no leakage, no venting, no fire or flame, no rupture, no explosion, no exothermic reaction or thermal runaway. Cell reversibly damaged. Repair of protection device needed.</td>
</tr>
<tr>
<td>2</td>
<td>Defect / Damage</td>
<td>No leakage, no venting, no fire or flame, no rupture, no explosion, no exothermic reaction or thermal runaway. Cell irreversibly damaged, repair needed.</td>
</tr>
<tr>
<td>3</td>
<td>Leakage ∆m &lt; 50%</td>
<td>No venting, no fire or flame**, no rupture, no explosion, Weight loss &lt; 50% of electrolyte weight. (electrolyte = solvent + salt)</td>
</tr>
<tr>
<td>4</td>
<td>Vventing ∆m ≥ 50%</td>
<td>No fire or flame**, no rupture, no explosion, Weight loss ≥ 50% of electrolyte weight.</td>
</tr>
<tr>
<td>5</td>
<td>Fire or Flame</td>
<td>No rupture, no explosion, i.e., no flying parts.</td>
</tr>
<tr>
<td>6</td>
<td>Rupture</td>
<td>No explosion, but flying parts, ejection of parts of the active mass.</td>
</tr>
<tr>
<td>7</td>
<td>Explosion</td>
<td>Explosion, i.e., disintegration of the cell.</td>
</tr>
</tbody>
</table>

Figure 10-1: EUCAR table often referred to in hazard or risk assessment

EUCAR assigns the hazard levels shown in the table to a given UUT technology based on that technology’s response to abuse conditions or unplanned events. These references are now often referred to in specifying the hazard level to which a building or equipment is to be designed.

Figure 10-2: Typical existing pack cycling test facility shop floor view
**Location, neighborhood and proximity to public**

Testing facilities are often small laboratories located in larger multi-purpose premises. In automotive applications, often battery test equipment is added to existing areas where mechanical testing has previously been conducted. Even though abuse testing may not be planned, an unplanned event can create a major hazard, so levels of spatial separation and dealing with the consequences will need to be introduced.

For production facilities, there will be goods inwards areas, stores, assembly lines and EOL test-beds and all of these will concentrate large amounts of product, with major risk and requiring substantial planning and implementation to local regulations.

Airflow patterns should be identified so that in the layout of labs and enclosed areas, any input air-conditioning will preferentially create a positive pressure between user occupied rooms and the location of the UUT during test.

Ultimately, the final extraction point should be located to cause minimum inconvenience to the surrounding area. Gasses escaping in an event can be significant and dangerous, and a suitably designed scrubber should seriously be considered to capture as much as possible of the toxic pollutants. These can then be disposed accordingly.

The escape of gases into neighboring properties is a serious implication, especially if there are domestic properties nearby.

Similarly, location of Office and White collar staff in relation to test beds should be considered, for instance to make sure large numbers of staff are not housed in offices above battery facilities. Indeed, even the internal air conditioning and ductwork needs to be clearly routed to avoid exposure to large groups of office employees. Regional variations are considerable, but need to be accounted.

**Services and Utilities**

Electrical Input utilizes for the battery can be considerable. It is not unknown to have 3-400 60kW cyclers in one location, so a worst case usage of power is substantial. Grid suitability, cable sizing, distribution will need to be quantified and provided.

UPS backup will be desirable at least on control circuits and computer lines. Additionally, pack cooling may require the presence of cooling, and then the environmental heat load will be taken into account depending on locations as Siberia at values of -30C in winter, to other more moderate climates but as storage temperatures are typically 20 C +/- 5 then this should not be overlooked.

**Goods Receiving and Goods Inwards**

Large amounts of cells and packs will present new challenges. In an ideal world, the storage area should be away from the main facility. There could be separation between batches and redundancy in the number of locations.

A full ATEX investigation will identify risks and measures to be deployed. It will be necessary to consult with H&S, Fire service providers and probably Environmental Health to be sure all bodies are informed and continuous management policies are agreed and audited.
Goods should have identified acceptance procedures, and these should be routinely updated. It should not be taken for granted that a palate of cells or container of packs is safe after arrival from a remote destination by road, sea or air.

Local fire evacuation and assembly points will need to be clearly detailed, to take into account any possible effects of gas escape and wind migration patterns. Site transportation procedures will need to cover the presence of heavy masses, high voltages and all the other issues previously noted. Storage areas will normally be temperature controlled, typically 25 degrees C +-5 C.

**Labeling of high voltage batteries - Packaging**

Traditional signage is well understood, but for Lithium battery packs, the proper shipping name and classification is as follows:

<table>
<thead>
<tr>
<th>Shipping Name:</th>
<th>Lithium Ion Batteries</th>
</tr>
</thead>
<tbody>
<tr>
<td>UN dangerous goods category:</td>
<td>UN 3480</td>
</tr>
<tr>
<td>Dangerous goods class:</td>
<td>9</td>
</tr>
</tbody>
</table>

In Europe, the following regulations apply:

- ADR for road transportation
- IATA for International Air Transport
- IMDG for International maritime transportation.

(Code of Federal Regulation 49CFR parts 100-185 apply in USA)

**Storage**

Storage and disposal of undamaged batteries

- Undamaged batteries are batteries that are mechanically intact and were certainly never operated outside the specifications.
- Storage is in a state in which they cannot be damaged or shorted. These batteries are secured mechanically and electrically isolated store (typically in plastic containers or in transport packaging).
- Is the design of the battery so that live parts are exposed, they have to be protected by suitable covers, insulation, tape, ice caps or the like and secured so that no short circuits occur through contact with conductive parts (tools, shelves made of conductive material or similar).
- They are stored in a designated area.

Storage and disposal of leaking batteries

- Batteries that are either damaged mechanically, in which fluid is withdrawn or smoke or have been operated outside of its specifications represent a higher risk potential.
- Damaged batteries must be labeled as such.
- Damaged battery cells and modules are insulated with fabric tape on the contacts and wrapped with foil. In this package, the cells or modules in which are provided for optionally disposable box and embedded in sand.
- Damaged battery packs or systems to be lifted into the disposal box and covered with sand or paraffin oil.
The evaluation of the risk potential of damaged batteries is to define by the respective project manager.

The way of disposal of damaged batteries with potential hazards must be defined by the project manager in consultation with the safety experts and the fire department.

**Teardown zone**

A safely constructed teardown and disassembly zone will need to be provided. Either as part of the post-test observations in some of the performance tests, or in the event that some fault conditions have been established or signaled, then the facility needs to be designed and integrated to the site.

**Safe disposal**

Procedures for the storage and disposal will need to be in place.

**WEEE directive Environmental Requirements**

**Definitions for the purposes of European Directive 2006/66/EC:**

- Battery or accumulator: Any source of electrical energy generated by direct conversion of chemical energy and consisting of one or more primary battery cells (non-rechargeable) or consisting of one or more secondary battery cells (rechargeable).

- Battery pack: Any set of batteries or accumulators that are connected together and/or encapsulated within an outer casing so as to form a complete unit that the end-user is not intended to split up or open.

**At the European level:**

Li-ion batteries are covered by Directive 2006/66/EC for batteries and accumulators, and waste batteries and accumulators. This Directive prohibits the placing on the market of batteries and accumulators containing certain specified levels of mercury or cadmium, and sets rules for the collection, recycling, processing and disposal of batteries and accumulators.

Li-ion batteries are also covered by acts relating to the application of Decision 2009/603/EC, establishing requirements for registration of producers of batteries and accumulators in accordance with Directive 2006/66/EC as well as Decision 2008/763/EC establishing, pursuant to Directive 2006/66/EC, a common methodology for the calculation of annual sales of portable batteries and accumulators to end-users.

- **Disposal**: pass the battery data (MSDS) to the waste management company.

![Figure 10-3: 20 Ah Lithium Ion pouch cell](image-url)
11. Battery Testing Area Design

The intent of this section is to suggest safety guidelines for design, construction, maintenance, and operation of facilities used for both destructive as well as non-destructive testing of both primary and secondary lithium batteries. It is intended that this procedure be used primarily for developing facilities for the testing of secondary lithium ion batteries.

![Figure 11-1: proposed laboratory layout](image)

All testing of both primary and secondary lithium battery packs and cells capable of over pressurization, exploding, and/or release of toxic chemicals must be performed inside a properly designed test environment or chamber, e.g., room, bunker, enclosure, etc. capable of:

1. Maintaining flammable vapors within the test chamber at or below 20% of the lower flammable limit (LFL);
2. Be mechanical designed to withstand over pressurization by deflagration/detonation; and/or

![Figure 11-2: Cycling facility with central control station](image)
**Containment zones guidelines.**

There are no specific off the shelf rules or regulations, but here are some thoughts from those within the industry who already have experience of working with the products covered by this document. Each project will have to evaluate its own risk and determine solutions on a case by case basis.

**Construction of Indoor Facilities for Non-Fire Related Tests**

Appendix 4 carries excellent design guide information from a well-known Environmental supplier. There are commonly software interfaces to over 20 leading suppliers where tests can be sequenced from a single PC coordinating and commanding cyclers, chambers, vibration tables and other I/O sources.

Along with a comprehensive explanation of ATEX assessment and then a breakdown of options and extras for each layer of safety device, the lowest cost most basic solution is often not going to be acceptable, and again each project will determine its own solution.

The GUS interface which is emerging in Europe for enhanced communication and operation is already taking route in products, and this allows greater control of sequencing and handling of out of tolerance conditions in regard to safety. Some info on this interface can be found in Appendix 8. It is useful for Cyclers, Chamber, Vibration and shock equipment integration.

![Figure 11-3:Pack Cycling facility with secondary barrier (container) for local containment](image)

Access for mounting the UUT in the tests area as well as eventual removal should be considered at an early stage of planning. Intermediate safe storage areas, may need to be identified, and consideration given to estimated volumes of product going through the facility.
Figure 11-4: Typical walk in Environmental Chamber

Figure 11-5: Typical containerized solution which may be externally located and transportable
Typical Construction of bunkers for Abuse Tests

1. Test chambers must be 8-12” (20-30 cm) concrete or cement block walls with rebar, poured concrete floor, steel trussed roof, and concrete slab roof capable of at least 2-3 psi over pressurization. Chambers can also be a pre-fabricated concrete unit having metal hinged (right angle) latched walls-to-floor and ceiling.

2. Free standing, remote test bunkers designed for larger scale battery testing (Auto or >10AH) will require additional re-enforcement and/or construction of stronger material with additional explosion venting.

3. All doors must be metal, must open outward or slide into the wall, and must not be capable of internal self-locking, e.g., panic type internal opening is acceptable. The design should allow for seals around cabling through the chamber walls.

4. Chambers utilized for fire testing where batteries will self-ignite and explode as a result of the flame application must have at least one explosion vent (panel) to dissipate the shock wave. Optimal design provides a pathway for the explosion vent to the exterior of the building. The explosion vent panel must not vent into any employee occupied areas, parking lots or shipping docks.

5. In USA Design and construction should be in accordance with Standard on Explosion Protection by Deflagration Venting, ANSI/NPFA 68-2007.

6. In Europe see Vötsch spec and ATEX see Appendix 4.

7. Optimal design for Battery fire testing is on an outside wall of the building or an exterior chamber

Figure 11-6: External bunker for abuse tests
Local Exhaust Ventilation (LEV) Guidelines

This applies to all areas where events may occur:


2. Ventilation design must include both floor level (6” or 15 cm above floor level) and ceiling height take-off. Air flow through the chamber must be designed to be evenly balanced and not create any short-circuiting between exhaust and make-up air flow where contaminants may concentrate.

3. Provision must be made to ensure adequate make-up air enters the test chamber. The test chamber must be maintained at 25 Pa (0.1 in water) negative pressure.

4. Exhaust ventilation must be directly attached to each test chamber.

5. Multiple chambers can be manifold to a common fan so long as the ventilation rate provided in item (1) above is maintained.

6. Exhaust air must not be directly emitted to the outside environment. All exhaust air must enter a properly designed scrubber or other air pollution control device.

7. Fan motor and housing must be explosion proof.

8. Fan motor, housing, and exhaust ventilation must be corrosion resistant.

9. LEV controls must be located outside the chamber.

10. Facilities that install internal chambers e.g., within the test laboratories, must have dedicated general ventilation systems installed in the test laboratories themselves that can be activated in an emergency. Should a battery release its contents into the general environment, the emergency system can be activated to control chemical and smoke generated. The emergency activation control should be located next to an emergency exit.

Electrical

1. Means for electrical isolation of all chamber system controls must be provided outside the chamber itself and must be capable of being locked and tagged out.

2. Electrical control cutoffs must be maintained between the power source to the control/measurement equipment, and between the control/measurement equipment and the Battery under test. The cutoffs shall be clearly marked and accessible from the exterior of the test chamber.

3. All test chambers must be electrically grounded following NEC or IEC rules.
4. Chamber control systems, e.g. ventilation, temperature, humidity, electrical, etc., must have fail safe devices that activate when a system failure occurs, e.g., power failure, circuit trip, motor burn-out, etc.

The technical requirements for persons, who perform electrical work, be defined in various regulations and VDE requirements, particularly in:

- Accident Prevention Regulation "Electrical Systems and Equipment" (BGV / GUV-V A3)
- DIN VDE 0105-100 "Operation of electrical installations"
- DIN VDE 1000-10 "requirements in the field of electrical engineering working people"

The company has to ensure the health and safety of the workforce under the Occupational Safety Act, and if necessary to improve. An important step is to risk assessment.

Risk assessment is a process for identifying hazards and to assess the risks involved. The assessment of hazards is a prerequisite for taking effective and operational health and safety measures.

Risk assessment consists of:

- a systematic identification and evaluation of relevant risks
- the identification of suitable measures.

A risk of injury may be partly attributable to an inadequate qualification and training of employees. The health and safety measures must comply in any case to the general principles of to the Labour Protection Act. It is the so called "principle of risk minimization" principle.

Due to higher electrical system voltages and increased electrical energy by the HV system exists for the vehicle range a previously nonexistent level of electrical hazards. There is a risk of irreversible damage to the body through body currents and arcs. Through appropriate measures, the spatial and temporal coincidence is to prevent the risks with the people.

Measures are divided into

- technical, such as insulation, solid covers
- organizational, such as compliance with prescribed waiting times to reduce the voltage
- personal, such as personal protective equipment (insulating gloves, helmet with visor), instruction

A combination of these measures is possible. Technical measures are the priority over personal or organizational measures.

**Unattended Tests**

1. In addition to maintaining compliance with SOP for Unattended Testing, the facility shall maintain video equipment capable of monitoring and recording the test chamber during the unattended test.

**Mechanical**

1. Opening in the test chambers should be minimized to only those needed for cabling, thermocouples, video access, etc.
2. Chambers should be evenly spaced with at least 3 feet (1m) spacing between chambers. However, chambers should be spaced at least 25 feet (8m) from unrelated test facilities and/or by a fire wall with a fire resistance rating of not less than 2-hours.

3. Chambers should not be erected in the center of test facilities. Preferably, chambers should be erected along exterior walls without adjacent exposure, e.g., public ways, occupied buildings, etc.

4. Chambers must not discharge battery contents, fire water, and/or wash down water into public waterways, public sewers, or adjoining property. All chambers for large scale testing must have an internal drain that is capable of collecting all wash down, fire water, and battery contents.

5. Free standing fire test bunkers must have an adjacent control room for employee and equipment protection and placement.

6. Remote means of burner ignition must be provided.

**Safety and PPE**

1. A plumbed safety shower and eye wash facilities must be immediately available in the battery test area.

2. A fire suppression system must be installed within the test chamber or above it within the building.

3. Drainage from the chamber must be capable of collecting and holding all wash down, fire water, and battery contents.

4. The facility must maintain a supply of neutralizing agents able to act upon the type of Battery under test.

5. The test chambers must maintain a uniform location for the required Battery Test signage.

6. The facility must maintain a supply of the appropriate personal protective equipment, including gloves and face shields, for use by its employees when engaging handling monitoring Battery tests.

7. All test chambers shall maintain a ventilation failure alarm that remains in operation when a Battery is placed inside the chamber.

**Lexan (Plastic) Test Chamber—Small Battery Test**

Testing within these Lexan enclosures must be conducted within the facility test chambers described above unless experience has proven that the battery system being tested does NOT present destructive energy and that the plastic enclosure provides sufficient protection to contain the energy release.

If the Lexan enclosure is utilized outside the test chamber, local exhaust ventilation must be directly attached to the enclosure to control release of toxic chemicals.
Measures to limit damage

Spatial separation

This is often easier said than done and is highly dependent on local conditions. Is it possible to allow for instance 20m, so that the buildings are independent. Putting the test stands its own small building (container, prefabricated garage) with sufficient distance up to neighboring buildings or the tests will be necessary carried out in a high rise facility or in the middle of town?

Encapsulation of the device under test

This may be vary due to size / energy content
  - Small box (for example, cash box)
  - Air chamber
  - Container
  - Fire-proof room

It goes without saying that the specimen should be placed in a non-flammable environment on a non-conductive surface.

Over-pressurization space.

This energy released from the test object and volume of gas is taken into account. The volume of gas can expand rapidly through temperature effects. This gas flow combined with explosion of a cell (= bursting of housing) should be taken into account. Examples:

<table>
<thead>
<tr>
<th>Device under test</th>
<th>energy</th>
<th>Heat energy in case of fire</th>
<th>total gas</th>
</tr>
</thead>
<tbody>
<tr>
<td>18650 cell 2,2 Ah</td>
<td>8,7 Wh</td>
<td>100 Wh</td>
<td>111</td>
</tr>
<tr>
<td></td>
<td></td>
<td>360 kJ</td>
<td></td>
</tr>
<tr>
<td>Powertool-Pack 20 pc 18650</td>
<td>174 Wh</td>
<td>1740 Wh</td>
<td>2201</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6264 kJ</td>
<td></td>
</tr>
<tr>
<td>Coffee Bag cell 40 Ah</td>
<td>160 Wh</td>
<td>1600 Wh</td>
<td>2001</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5760 kJ</td>
<td></td>
</tr>
<tr>
<td>Hybrid battery 1 kWh</td>
<td>1 kWh</td>
<td>10 kWh</td>
<td>12501</td>
</tr>
<tr>
<td></td>
<td></td>
<td>36 MJ</td>
<td></td>
</tr>
<tr>
<td>Vehicle battery 20 kWh</td>
<td>20 kWh</td>
<td>200 kWh</td>
<td>12500</td>
</tr>
<tr>
<td></td>
<td></td>
<td>720 MJ</td>
<td></td>
</tr>
</tbody>
</table>

Typical melt Energy content of different device under test

<table>
<thead>
<tr>
<th>Device under test</th>
<th>Iron</th>
</tr>
</thead>
<tbody>
<tr>
<td>18650 cell 2,2 Ah</td>
<td>380 g</td>
</tr>
<tr>
<td>Powertool-Pack 20 pc 18650</td>
<td>6,6 kg</td>
</tr>
<tr>
<td>Coffee Bag cell 40 Ah</td>
<td>6 kg</td>
</tr>
<tr>
<td>Hybrid battery 1 kWh</td>
<td>3,8 kg</td>
</tr>
<tr>
<td>Vehicle battery 20 kWh</td>
<td>76 kg</td>
</tr>
</tbody>
</table>
Melt energy content of different device under test calculation:

40AH cell @ 4V nom = 160 Wh 10x energy = 1600 Wh = 5800 kJ
C=0.452 kJ/kg K Iron, melting point = 1500°C
Q= (1500 x 1) / 0.452 = 3300 kJ
Melting Energy = 268 kJ/kg = 1.6 kg

The enclosure must be able to absorb this energy.

You can clearly see that a thin sheet metal, as it is usually used for the production of climatic chambers, has not the ability to bear up a small 18650 cell in this situation. Since the housing not should melt away, is suitable to have at least the double quantities. With the use of sand (a sand bed or extinguishing sand) it should not be used in conjunction with aluminum, because it (similar to iron 1535°C, steel, quartz sand 1860°C) with its low melting temperature of only 660 ° melt would prematurely.

It is suitable either a solid base plate made of steel (but with the problem of conductivity) or a "solid" sand bed like ceramic or stone.

Is used as a climate chamber enclosure, this is not normally able to withstand too high internal pressure; greater than about 20 mbar may not be exceeded (which already corresponds to a force of 50kg to a 50cm * 50cm large area!). This pressure is achieved when 2% added to the volume of the chamber. These are 3,6 l with a 180 I Chamber. That's not even enough for a single 18650 cell. Therefore pressure compensation must be designed in any case, incl. to enable secure disposal of the resulting gases.

There are the following options:

- Installation of a rupture disc
  Vötsch for example offers Chambers in reinforced version (up to 80mBar) in conjunction with a thermally isolated rupture disk on which breaks when pressure increase and the gases escape can be from the Chamber. The "small" Vötsch Chambers (180 and 340 litres) are specified up to 1400l gas flow per second so that this is enough even for a hybrid battery. Outside the Chamber a suction socket is then to provide. Between this suction nozzle and the disposal of the Chamber, no direct connections shall be made as the suction not in the position will be to absorb the flow of gas for a short time resulting from an explosion

- Installation of a pressure valve
  The principle is the same as in the case of the rupture disc that only a reversible door swings open when the pressure builds up in the chamber.

- Exhaust pipe
  As above, but with a much smaller cross section (eg NW80) and without closure. With max. 200l / s for a 18650-cell or a pack of those still sufficient, at least for Hazard Level 0-6.

- Relief on the chamber door
  The chamber locking is performed such that it opens when builds up in the chamber too high a pressure. In any case, a catcher to take to prevent that the door can open completely Not recommended, a person standing in front of the chamber may be injured..
12. Overview Test Equipment and safe operating procedures

Performance & Safety Tests in Battery Development

![Performance Tests](image1)

![Safety Tests](image2)

Figure 12-1: Types of battery tests - mechanical, performance and abuse

**Structure of a battery test bed**

A battery test bed contains usually of the following components:

1. Device under test so the battery or cell

2. The test room is the room in which the device under test is stored during the measurement. They range from "on the table", simple containers (boxes, buckets), climate / temperature chambers (in the following both are referred to as a climate chamber) to specific combinations of environmental chambers, containers and specially equipped rooms. The test chamber can also undertake the task of cooling the device under test.

3. The battery test system has the task to charge electric, automated work through the test program and to collect the required measurement data. Often the control center (usually a PC) is operated separately from the actual test system. To protect the system test this can be set up in a separate room as the test specimen. A great physical distance has a negative effect on performance.

4. Cabling between the device under test and test system

5. Optionally, additional safety features:
a. Redundant monitoring devices  
i. as a separate entity  
ii. As part of the test system  
iii. As part of the climate chamber  
b. Safety control system, e.g. for access control, door latch, activation of the extinguishing means, monitoring functions  
i. as a separate entity  
ii. As part of the test system  
iii. As part of the climate chamber

Figure 12-2: Cell fixture examples

Figure 12-3: 4-wire cell connection in Environmental Chamber
Test bed with safety technology

The following figure shows the block diagram of a battery test stand is shown with safety equipment:

Figure 12-4: Schematic for Environmental Chamber showing some safety concepts
General rules of conduct

- All work on the test bed and the equipment should be performed only by qualified and trained professionals.
- A visual inspection of the device under test and the wiring after the initial construction and modifications to be carried out.
- Access to the test bed while running is only permitted for competent personnel. (Exceptions are the work of managers, project managers and responsible officers.)
- Escape routes and fire department driveway areas shall be kept clear at all times. This applies also for fire alarms, fire extinguishers, gas detectors and electrical systems. Emergency exit doors must not be altered and not obstructed.
- The location of the fire extinguisher can be seen on the escape route plans, which are located at each exit.
- Safety indicated by signs and the rules and prohibitions must be observed.
- The control room is not designed as a permanent workplace.
- Identified defects are reported immediately to the responsible person.
- Operation at set inoperable safety equipment is prohibited.
- Trip hazards must be avoided. Lying around tool, unneeded parts, cables and pipes laid on the floor, etc. are potential sources of stumbling, and must therefore be avoided or appropriately secured and labeled.
- Slipping hazards are eliminated immediately (e.g. coolants, oil stains ...).
- Open fires and smoking within the test bed is prohibited.
- Eating and drinking in the test bed and workshop area is not allowed.
- Generally, to ensure the test bed and workshop area for cleanliness and order.

Access control

This refers to two areas:

1. Unauthorized persons are not allowed in the danger zone.
   This can be done for example by smart card or key systems. Only designated and authorized persons or persons accompanied designated or authorized persons in the danger zone. It should be noted that this must relate to the control station (if separate).

2. The danger zone is sealed off while a test run
   This includes:
   a. The door of the enclosure (e.g. climate control) cannot be opened while running a test.
   b. It cannot be started until the inspection door is closed.
   c.

Both criteria can be ensured, for example, by combining a battery test system with a climate chamber (with the appropriate options).

Depending on the size of the device under test, this course must also refer to the container or room door.
Figure 12-5: Typical Vibration system showing actuator, slip table and amplifier
Guidelines for the operation

Working on a battery test bed

- It is the responsibility of the labor leaders to discuss the proposed work with all stakeholders and to vote and to refer expressly to the dangers.
- Before using a battery test bed is basically to observe the manual of the test bed.
- A short-circuit the battery terminals must be prevented by appropriate measures, e.g. by fitting insulating caps.
- The used tool must be specified in general as a "power tool" (1000 V). Before and after using the tool and the electric protection gloves is carried out to check for undamaged and awareness.
- When working with batteries (build, connect, etc.) are to wear protective eyewear. No metal parts, such as for example jewelry, piercings may be worn, etc.
- Works may be carried out only in zero potential state (except in the low voltage range, <120 V DC or 50 V AC).
- The terminals can also be under voltage at open main switch and pressed emergency stop buttons, when a battery is connected!
- The opening of the chamber temperature is only after the matching (heating or cooling) of the battery and allows all components connected to the ambient temperature. (Danger of short circuit in the test sample by condensation of water.)

Specifics for the work on cell and module test stands (<120 V DC)

- Electrical hazard that arises from cells and modules is not the voltage, but the high short-circuit current and the associated arc.
- The poles of the cells and modules must be insulated and protected against short circuit.

Special features of the work of packaging & system test beds (> 120 V DC)

- The essential requirements for preparing and ensuring the voltage-free state in the work shall be covered by the 5 safety rules. Responsible for implementation and the release is in charge of the work. These 5 Safety Rules must be complied with in the following order:

1. **Unlock**
   - Turn main switch of the battery tester off.
   - Battery packs and systems have usually contactors and HV-service switch with which they can be switched off completely.

2. **Secure against reclosing**

3. **Determine voltage free status**
   - by measuring, as close as possible to the work site.
   - The meter is to be checked for proper functioning.

4. **Earthing and shortcircuiting**
   - from earthing and shortcircuiting can be waived, if there is no risk that a replacement supply (e.g. emergency circuit, independent switching of the battery by battery-own control) the lines re-energized.

5. **Provide protection by cover or barriers for any neighboring live parts.**
   - e.g. by insulating mats
**Test programs**

- The required test runs for the test bed must be prepared with due care and checked in a review (e.g. project manager).
- The limits (voltage, current, temperature) for the batteries are properly taken into account in the software in such a way so that they never exceeded in the test.
- If the limits are exceeded by a defect in the hardware or software, an additional software algorithm or a dedicated hardware monitor circuit have to switch off the battery tester to avoid over-or deep discharge of the battery.

![Figure 12-6: Typical test sequence program](image_url)
Display and alarms messages

To the test bed, traffic light lamps, flashlights, and acoustic detectors are attached to report operational and error conditions on the test bed. The test beds are to mark by the plant manager, that the fire department can recognize in case of an alarm before entering the plant what batteries it is.

Cell test beds, valid indicators and alarms – Typical procedures

<table>
<thead>
<tr>
<th>Indicator / Alarms</th>
<th>Reason</th>
<th>Prescribed behavior</th>
<th>Message goes to:</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ZTL1 / Control room:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>green traffic light</td>
<td>Test bed is ready to use. No test run.</td>
<td>Entering the test bed and opening of the climate chamber is allowed.</td>
<td>---</td>
</tr>
<tr>
<td>yellow traffic light</td>
<td>Test bed is active, test run is running.</td>
<td>Entering the test bed and opening of the climate chamber is allowed only to authorized personnel.</td>
<td>---</td>
</tr>
<tr>
<td>red traffic light</td>
<td>There exists an error or alarm.</td>
<td>Entering the test bed and opening of the climate chamber is allowed only to authorized personnel and permitted in accordance with the gas/fire alarms.</td>
<td>Central control center doormen</td>
</tr>
<tr>
<td>yellow flash light &quot;gas alarm&quot;</td>
<td>Gas alarm</td>
<td>The test bed shall not be entered or to leave. Entry is permitted only by the fire department or after release by security specialist. The doorman is to communicate and to arrive the security specialist or the fire brigade is to wait</td>
<td>Central control center doormen</td>
</tr>
<tr>
<td>red flash light &quot;fire alarm&quot;</td>
<td>Fire alarm. The extinguishing system can be active.</td>
<td></td>
<td>Central control center doormen fire department</td>
</tr>
</tbody>
</table>
Figure 12-7: Typical safety matrix

**Battery: Risks assessment typical signage**

According to [P. Gollob], the main hazards related to traction battery validation at the test bed can be clustered as follows:

**Mechanical hazard:** Weight up to several hundreds of kg

**Electrical hazards**
DC voltage up to 1000V – hazard for operators from 60 VDC onwards
Short circuit currents up to 5000A
Electric arc

**Thermal hazards**
Critical temperature exposure of traction battery
„Thermal Runaway“

**Fire and explosion hazards**
Ignitable gases
Ignition source (spark)
Secondary fire

**Hazardous substances**
Decomposition products
Electrolyte vapor
Smoke

**Human error**
Untrained employees
13. Fire Fighting

Behavior at incidents and case of fire

- Any incident with batteries is the fire department about to alert the emergency number or a manual call points. The plant manager, the work supervisor, as well as a battery expert from the field of DSB are in addition to communicate.

- Hazard and safety information concerning the type of battery to be tested must be strictly observed and followed. The work supervisor is responsible to read the safety data sheet of the respective battery manufacturer before the start of the construction, and he makes sure that it is in the control room.

- Basically consists in improper handling of the battery (mechanical damage, thermal or electrical overload), especially with already damaged batteries fire risk. Be sure to keep away sources of ignition.

- Inhalation of leaked gases or vapors must be avoided at all costs. For fresh air after possibly inhalation of gases or vapors is to ensure. In any case, a doctor must be consulted.

- After eye or skin contact with the electrolyte and electrode materials should be washed exposed areas with plenty of water. There is also an eye shower available in the control room. In any case, a doctor must be consulted.

- After possible ingestion of electrolyte fluid, a doctor must be consulted in any case.

- The plant manager is responsible for ensuring that there are the appropriate fire extinguishers on the test bed.

- "Lithium battery - safety incident" will be recorded and investigated.

Initial response to a developing fire:

- For a developing fire in a lithium battery, the test bed or in the operating room firefighting can be made by an employee with the means of the first fire support (fire extinguisher, fire hydrant wall).

- Paying attention to self-protection measures:
  - Do not inhale escaping vapors and flue gases
  - Keep a safe distance to live parts:
    - Fire extinguisher: 1 m
    - Wall Hydrant - nozzle: 5 m
  - All other measures are to be set by the fire department.

- In order to combat incipient fires and extinguishing agents approved fire extinguishers:
  - CO2
  - Foam, if type-tested for low-voltage systems.
  - Water
Measures in the fire of batteries (except for developing fire)

- Manually deactivation, if that has not already happened automatically.
- Use extinguishing measures that are carried out by the fire department.
- Climatic chambers, burn in which batteries may only be opened by the fire department.

Permanent inerting of the test room

This can be done with nitrogen or with noble gases, also here is the lock with an additional O₂ sensor guaranteed when combined with addition Vötsch (no test without inerting / test is terminated when inerting is no longer guaranteed).

By inerting the device under test is removed from oxygen, so that the maximum energy transfer in case of failure on the reaction of lithium, possibly also the pos. electrode, can be limited. The electrolyte and the negative electrode cannot burn without oxygen.

As a result, the energy output is limited to about 3 times the electrical energy. In addition, the probability of an explosion and the resulting combustion gas is reduced.

Figure 13-1: Schematic for facility fire suppression using inert gas or water fog
Extinguishing or Surpression system

1. with gas (N2 or CO2)
   In a typical flush volume of 90m3 / h and adopted 100°C temperature increase can dissipate about 200kJ per minute - about half the energy content of a 18650 cell. Such a device is therefore more suitable for flushing the chamber as a real fire-extinguishing device.

2. with water
   Due to its high energy content (4.2kJ/kg K), the energy content of a 18650-cell would be absorbed (at 80 ° temperature rise) by one liter of water, taking into account the heat of vaporization (2256kJ/kg) is about 8 times of the amount.
   However, water is not uncritical:
   a. through its conductivity makes it a problem with the electrical safety
   b. may arise in connection with lithium, oxyhydrogen gas can occur which leads to explosion in connection with the conducting salt its produces highly toxic hydrofluoric acid
   Therefore, water is generally not recommended.

3. with sand
   This can be done by a reservoir above the DUT, which is emptied in the event of fire on the DUT. Since the sand is relatively inert and has a high heat capacity in the best extinguishing effect is achieved.

Appendix X includes some details from an FAA investigation into fire hazards aboard aircraft. It is generally accepted that the use of Halon as an extinguishing medium is no longer accepted, the document is included purely for further reference material.
14. Conclusions

Within Task 6.210 the availability and the development of secure testing standards for high voltage components was investigated.

To enable secure testing environments for high-voltage (battery) components, we have identified some key standards, equipment and regulations which are referred to in this document and are the basis for understanding the hazards and risks associated with today's EV projects. This information of appropriate safety concepts can be integrated locally into best-practice solutions to create a new and satisfactory safety standard for hybrid components and powertrain test beds.

Standardization can also help to bring down development costs significantly in the future, but the industry is in the early phases and neither equipment nor materials are at the levels of maturity to achieve this. Safe facilities are extremely capital intensive and short cutting of safety requirements may well be perilous rather than effective.

As part of this research project, AVL List GmbH focused on:

- Standards with regard to batteries that are developed and issued.
- Standards for the tests to be issued in the near future.
- Safe operating procedures, the test facilities and their technical features, (dependent on know-how and best practice experience)

In determining the security measures the device under test (energy content, design, prototype or production version with protection circuit) as well as the local spatial and human factors are relevant.

The security measures for any facility shall be designed so that injuries can be avoided in any case. The safe working of local staff, and the impact on surroundings and locations needs to be fully understood, and often local regulations may indeed vary.

Since, in principle cannot be avoided that a battery event may occur, local responsible staff must be fully trained, and consultation with local authorities must be effective depending on the expected size and implications of the event.

In addition the acknowledged rules of technology (such as clear labeling, proper tools and components ...) each project will be on a case by case basis, research into material contents and then solutions to specific needs are necessary. It is recommended that each development group should always perform a safety analysis and their results stored for future reference.

Even in case of outsourcing of tasks should keep track of those responsible.
15. Appendix 1 MSDS for Lithium Ion Cells

Kokam

MATERIAL SAFETY DATA SHEET

<table>
<thead>
<tr>
<th>Section 1. Chemical Product And Company Identification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product Name : Superior Lithium Polymer Battery(SLPB)</td>
</tr>
<tr>
<td>Battery Type : Rechargeable Battery</td>
</tr>
<tr>
<td>Description : Lithium Cobalt Dioxide Chemistry or</td>
</tr>
<tr>
<td>Lithium Cobalt Manganese Nickel Oxide</td>
</tr>
<tr>
<td>Model : SLPB Series</td>
</tr>
<tr>
<td>Electrochemical System</td>
</tr>
<tr>
<td>Negative Electrode : Carbon</td>
</tr>
<tr>
<td>Positive Electrode : Lithium Cobalt Dioxide (LiCoO₂)</td>
</tr>
<tr>
<td>Lithium Cobalt Manganese Nickel Oxide (LiMnNiCoO₄)</td>
</tr>
<tr>
<td>Electrolyte : Solution of lithium hexafluorophosphate</td>
</tr>
<tr>
<td>(LiPF₆) in a mixture of organic solvent</td>
</tr>
<tr>
<td>Ethylene Carbonate(EC) +</td>
</tr>
<tr>
<td>Ethylmethyl Carbonate(EMC)</td>
</tr>
<tr>
<td>Nominal Voltage : 3.7V</td>
</tr>
<tr>
<td>Overall Chemical Reaction :</td>
</tr>
<tr>
<td>Li₄C + Li₁₄₂ ↔ C + LiCoO₂</td>
</tr>
<tr>
<td>Li₄C + Li₁₄₂ ↔ C + LiMnNiCoO₂</td>
</tr>
</tbody>
</table>

Manufactured by : Kokam Co., Ltd.

Address : Head office : 1261-3 Jungwang-dong, Siheung-Si, Kyunggi-Do, Korea 429-849 (Sihwa-Kongdan 2Na 304)
Factory : 483-42, Yachon-Ri, Gayakok-Myun, Nonsan-Si, Chungnam, Korea 320-844

Emergency Telephone Number :
International : 1-703-527-3887
U.S.A : 1-800-424-9300
Technical Contact Telephone Number : 82-31-362-0100 or 82-41-742-9221

Date Prepared : August 21, 2006
Date Reviewed : December 12, 2008
Revision No : 4.0
Revision Date : April 8, 2009

Kokam Co., Ltd.
Section 2. Composition/Information on Ingredients

<table>
<thead>
<tr>
<th>Chemical Name</th>
<th>CAS #</th>
<th>ACGIH TLV</th>
<th>Percent of Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lithium Cobalt Dioxide(LiCoO₂)</td>
<td>473894-38-1</td>
<td>0.02mg/m³ as Co</td>
<td>20-50</td>
</tr>
<tr>
<td>Lithium Cobalt Manganese</td>
<td>182442-95-1</td>
<td>0.2mg/m³ as Mn</td>
<td></td>
</tr>
<tr>
<td>Nickel Oxide(LiMnNiCoO₂)</td>
<td></td>
<td>0.2mg/m³ as Ni</td>
<td></td>
</tr>
<tr>
<td>Carbon(Graphite, Proprietary)</td>
<td>7782-42-5</td>
<td>2mg/m³ (R)</td>
<td>15-35</td>
</tr>
<tr>
<td>PVDF(Polyvinylidene Fluoride)</td>
<td>24937-79-9</td>
<td>&lt;8</td>
<td></td>
</tr>
<tr>
<td>Aluminum Foil</td>
<td>7429-90-5</td>
<td>3-12</td>
<td></td>
</tr>
<tr>
<td>Copper Foil</td>
<td>7440-50-8</td>
<td>3-12</td>
<td></td>
</tr>
<tr>
<td>Electrolyte</td>
<td></td>
<td></td>
<td>10-20</td>
</tr>
<tr>
<td>Al Film Cover</td>
<td>N/A</td>
<td></td>
<td>&lt;5</td>
</tr>
</tbody>
</table>

*The balance of the battery is inert materials*

ACGIH: American Council of Government Industrial Hygienists
TLV: Threshold Limit Value are personal exposure limits determined by the ACGIH

Section 3. Hazards Identification

Emergency overview:
- Do not open or disassemble.
- Do not expose to fire or open flame.
- Do not mix with batteries of varying sizes, chemistries or types.
- Do not puncture, deform incinerate or heat above 85°C.

Potential health effects:
- The materials contained in this battery may only represent a hazard if the integrity of the battery is compromised or if the battery is physically or electrically abused.

(1) Physical:
- The Lithium ion polymer rechargeable batteries described in this Material Safety Data Sheet are sealed units which are not hazardous when used according to the recommendations of the Manufacturer.
- Under normal conditions of use, the solid electrode materials and liquid electrolyte they contain are non-reactive provided the battery integrity is maintained and seals remain intact.
- Risk of exposure is only in case of abuse (mechanical, thermal, electrical) leading to the activation of safety valves and/or the rupture of the battery containers. Electrolyte leakage, electrode materials reaction with moisture/water or battery vent/explosion/fire may follow, depending upon the circumstances.

(2) Chemical:

*Classification of dangerous substances contained into the product*

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As per directive 67/548/EEC

<table>
<thead>
<tr>
<th>Substance</th>
<th>CAS No.</th>
<th>Chemical Symbol</th>
<th>Melting Point</th>
<th>Boiling Point</th>
<th>Exposure Limit</th>
<th>Indication of danger</th>
<th>Special risk</th>
<th>Safety advice(2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LiCoO₂</td>
<td>473894-38-1</td>
<td>LiMnNiCoO₂</td>
<td>&gt;1000 °C</td>
<td>N/A</td>
<td>0.1mg/m³ as Co 1.0mg/m³ as Ni</td>
<td>OSHA</td>
<td>R22 R43</td>
<td>S2 S22 S24 S26 S36</td>
</tr>
<tr>
<td>21324-40-3</td>
<td></td>
<td>LiPF₆ (decompose s at 160 °C)</td>
<td>N/A</td>
<td>N/A</td>
<td>None established</td>
<td>OSHA</td>
<td>Implant Corrosive</td>
<td></td>
</tr>
</tbody>
</table>

(1) — Nature of special risks:
R14 Reacts with water
R21 Harmful in contact with skin
R22 Harmful if swallowed
R41 Risk of serious damage to the eye
R42/43 May cause sensitization by inhalation and skin contact
R43 May cause sensitization by skin contact

(2) — Safety advices:
S2 Keep out of reach from children
S8 Keep away from moisture
S22 Do not breathe dust
S24 Avoid contact with skin
S26 In case of contact with eyes, rinse immediately with plenty of water and seek medical Protective clothing
S36 Wear suitable protective clothing
S37 Wear suitable gloves

Section 4. First Aid Measures

In case or battery rupture or explosion, evacuate personnel from contaminated area and provide maximum ventilation to clear out fumes/gases

In all case, seek medical attention

Eye Contacts: Flush with plenty of water/eyes closed) for at 15 minutes.

Skin Contacts: Remove all contaminated clothing and flush affected areas with plenty of water and soap for at least 15 minutes.

Do not apply greases or ointments.

Ingestion: Dilute by giving plenty of water and get immediate medical attention.

Assure that the victim does not aspirate vomited material by se of potential drainage

Assure that mucus does not obstruct the airway.

Do not give anything y mouth to an unconscious person.

Inhalation: Remove to fresh air and ventilate the contaminated area.

Give oxygen or artificial respiration if needed.

Section 5. Fire Fighting Measures

Fire and explosion hazard: The battery can leak and/or spout vaporized or decomposed and

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combustible electrolyte fumes in case of exposure above 70°C resulting from inappropriate use or the environment.
Cells or batteries may flame or leak potentially hazardous organic vapors if exposed to excessive heat or fire. Fire, excessive heat, or over voltage conditions may produce hazardous decomposition products.
Damaged or opened cells or batteries can result in rapid heating and the release of flammable vapors.
Vapors may be heavier than air and may travel along the ground or be moved by ventilation to an ignition source and flash back.
Fire, excessive heat, or over voltage conditions may produce hazardous decomposition products.
Use a positive pressure self-contained breathing apparatus if batteries are involved in a fire. Full protective clothing is necessary. During water application, caution is advised as burning pieces of flammable particles may be ejected from the fire.

**Extinguishing Media** :
- Suitable: \( \text{CO}_2 \)
- Dry chemical or Foam extinguishers
- Not to be used: Type D extinguishers

**Special exposure hazards** :
Following cell overheating due to external source or due to improper use, electrolyte leakage or battery container rupture may occur and release inner component/material in the environment.

- **Eye contact**: The electrolyte solution contained in the battery is irritant to ocular tissues.
- **Skin contact**: The electrolyte solution contained in the battery causes skin irritation.
- **Ingestion**: The ingestion of electrolyte solution causes tissue damage to throat and gastro/respiratory tract.
- **Inhalation**: Contents of a leaking or ruptured battery can cause respiratory tract, mucus, membrane irritation and edema.

**Special Protective equipment** :
- Use self-contained breathing apparatus to avoid breathing irritant fumes.
- Wear protective clothing and body contact with electrolyte solution.

---

**Section 6. Accidental Release Measures**
The material contained within the batteries would only be expelled under abusive conditions.
Using shovel or broom, cover battery or spilled substances with dry sand or vermiculite, place in
approved container (after cooling if necessary) and dispose in accordance with local regulations.

Section 7. Handling and Storage
The batteries should not be opened, destroyed nor incinerated since they may leak or rupture and release in the environment the ingredients they contain.

Handling: Batteries are designed to be recharged. However, improperly charging a cell or battery may cause the cell or battery to flame.
Use only approved chargers and Procedures.
Never disassemble a battery or bypass any safety device.
Do not crush, pierce, short (+) and (-) battery terminals with conductive (i.e. metal) goods.
Do not directly heat or solder.
Do not throw into fire.
Do not mix batteries of different types and brands.
Do not mix new and used batteries.
Keep batteries in non conductive (i.e. plastic) trays.

Storage: Do not store batteries above 60°C or below -20°C.
Store batteries in a cool (below 30°C), dry area that is subject to little temperature change.
Elevated temperatures can result in reduced battery service life.
Battery exposure to temperatures in excess of 130°C will result in the battery venting flammable liquid and gases.
Batteries should be separated from other materials and stored in a noncombustible, well ventilated, sprinkler-protected structure with sufficient clearance between walls and battery stacks.
Do not store batteries in a manner that allows terminals to short circuit.
Extended short-circuiting creates high temperatures in the cell. High temperatures can cause burns in skin or cause the cell to flame.
Avoid reversing battery polarity within the battery assembly. To do so may cause cell to flame or to leak.
Do not place batteries near heating equipment, nor expose to direct sunlight for long periods.
Other: Follow manufacturers recommendations regarding maximum recommended currents and operating temperature range. Applying pressure on deforming the battery may lead to disassembly followed by eye, skin and throat irritation.

Section 8. Exposure Controls / Personal Protection
No engineering controls are required for handling batteries that have not been damaged.

Respiratory protection: Not necessary under normal use.
   In case of battery rupture, use self contained full-face respiratory equipment
Hand Protection: Not necessary under normal use. 
Use gloves of handling a leaking or ruptured battery.

Eye Protection: Not necessary under normal use. 
Wear safety goggles or glasses with side shields if handling a leaking or ruptured battery.

Skin protection: Not necessary under normal use. 
Use rubber protective working in case of handling of a ruptured battery.

Section 9. Physical And Chemical Properties

<table>
<thead>
<tr>
<th>Temperature range</th>
<th>Continuous</th>
<th>Occasional</th>
</tr>
</thead>
<tbody>
<tr>
<td>In storage</td>
<td>+30°C max</td>
<td>-20°C to +60°C</td>
</tr>
<tr>
<td>During discharge</td>
<td>-20°C to +60°C</td>
<td>-20°C to +60°C</td>
</tr>
<tr>
<td>During charge</td>
<td>0°C to +45°C</td>
<td>0°C to +45°C</td>
</tr>
</tbody>
</table>

Section 10. Stability And Reactivity

Conditions to avoid: Heat above 60°C or incinerate. 
Deform, mutilate, crush, pierce, disassemble  
Short circuit  
Prolonged exposure to humid conditions.

Materials to avoid: N/A

Hazardous decomposition products: 
Fire, excessive heat, or over voltage conditions may produce hazardous decomposition products.

Section 11. Toxicological Information

(1) Irritancy: The electrolytes contained in this battery can irritate eyes with any contact. 
Prolonged contact with the skin or mucous membranes may cause irritation.

(2) Sensitization: No information is available at this time.

(3) Carcinogenicity: No information is available at this time.

(4) Reproductive toxicity: No information is available at this time.

(5) Teratogenicity: No information is available at this time.

(6) Mutagenicity: No information is available at this time.

Section 12. Ecological Information

Not applicable to this material / product.

Section 13. Disposal Considerations

Dispose in accordance with applicable regulations which vary from country to country.
(In most countries, the trashing of used batteries is forbidden and the end-users are invited to dispose them properly, eventually through not-for-profit profit organizations, mandated by local government or organized on a voluntary basis by professionals).

Batteries should be completely discharged prior to disposal and / or the terminals taped or capped to prevent short circuit.

When completely discharged it is not considered hazardous.

This product does not contain any materials listed by the United Stated EPA as requiring specific waste disposal requirements.

These are exempted from the hazardous waste disposal standards under Universal Waste Regulations.

Disposal of large quantities of Lithium-Ion batteries or cells may be subject to Federal, State, or Local regulations.

Consult you local, state and provincial regulations regarding disposal of these batteries.

## Section 14. Transport Information

### United Nations :

<table>
<thead>
<tr>
<th>UN No</th>
<th>Classification</th>
<th>Packing Instructions</th>
</tr>
</thead>
<tbody>
<tr>
<td>3480</td>
<td>9</td>
<td>for Air Transport</td>
</tr>
<tr>
<td></td>
<td></td>
<td>IMDG for Sea Transport</td>
</tr>
</tbody>
</table>

### International conventions :

- Air: IATA - Yes
- Sea: IMDG - Yes
- Land: ADR (road) - Yes
- RID (Rail) - Yes

### Other :

- in the USA: Code of Federal Regulations (49 CFR Ch. 1 § 173-185)

### Special packaging information

- Cells and batteries must be packed in inner packaging that completely encloses the cell or battery.
- Cells and batteries must be protected to avoid short circuits.
- Each package must be capable of withstanding a 1.2 m drop test in any orientation without:
  1. Damage to cells or batteries contained within the packaging;
  2. Shifting of the contents allowing battery to battery contact; and

### Special shipping information :

- This battery has been tested to Section 38.3 of ‘UN Manual of Tests and Criteria’. The amount of Lithium contained in these batteries is below the limits set by the DOT in Section 49CFR173 and IATA. These can be shipped with the following label:

---

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Section 15. Regulatory Information

Depending on their lithium equivalent weight content, and ability to pass safety test defined by UN in the “Recommendations on the Transport of Dangerous Goods” Chapter 38.3 Manual of Tests and Criteria Ref. ST/SG/AC/10/11 Third Revised Edition 1999”. The Lithium-ion cells and the battery packs may or may not be assigned to the UN No 3480 Class-9 that is restricted for transport.

Section 16. Other Information
This information has been compiled from sources considered to be dependable and is, to the best of our knowledge and belief, accurate and reliable as of the date compiled. However, no representation, warranty (either expressed or implied) or guarantee is made to the accuracy, reliability or completeness of the information contained herein.

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This information relates to the specific materials designated and may not be valid for such material used in combination with any other materials or in any process. It is the user’s responsibility to safety himself as to the suitability and completeness of this information for his particular use.

Kokam does not accept liability for any loss or damage that may occur, whether direct, indirect, incidental or consequential, from the use of this information. Kokam does not offer warranty against patent infringement. Additional information is available by calling the telephone number above designated purpose.
SAFETY DATA SHEET

Section 1: Identification of the Substance/Preparation and of the Company/Undertaking

Product Name: High Power Lithium Ion Cell, Phosphate-Based
Product Use: Cell and cell packs
Synonyms: High Power Lithium Ion Battery, Phosphate-Based
Manufacturer: 200 West Street
Waltham, MA 02451
Phone Number: (617) 778-5700
Fax: (617) 924-8910
24-hour Emergency: Chemtrec: (800) 424-9300

Section 2: Hazards Identification

<table>
<thead>
<tr>
<th>Protective Clothing</th>
<th>NFPA Rating (USA)</th>
<th>EC Classification</th>
<th>WHMIS (Canada)</th>
<th>Transportation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not required with normal use</td>
<td></td>
<td>Not Classified as Hazardous</td>
<td></td>
<td>See Section 14</td>
</tr>
</tbody>
</table>

Preparation Hazards and Classification: Not classified as dangerous or hazardous with normal use. The cell should not be opened or burned. Exposure to the ingredients contained within or their combustion products could be harmful. European Communities (EC): This product is not classified as hazardous according to Regulation (EC) No. 1272/2008. This product contains dangerous ingredients however, there is no expected release during use of the product and there is a barrier preventing exposure of the user and the environment.

Appearance, Color and Odor: Solid object with no odor.
Primary Route(s) of Exposure: These chemicals are contained in a sealed enclosure. Risk of exposure occurs only if the cell is mechanically, thermally or electrically abused to the point of compromising the enclosure. If this occurs, exposure to the electrolyte solution contained within can occur by Inhalation, Ingestion, Eye contact and Skin contact.

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SAFETY DATA SHEET

Section 2: Hazards Identification, continued

Potential Health Effects: ACUTE (short term): see Section 8 for exposure controls
In the event that this cell has been ruptured, the electrolyte solution contained within
the cell would be corrosive and can cause burns to skin and eyes.
Inhalation: Inhalation of materials from a sealed cell is not an expected route of exposure.
Vapors or mists from a ruptured cell may cause respiratory irritation.
Ingestion: Swallowing of materials from a sealed cell is not an expected route of exposure.
Swallowing the contents of an open cell can cause serious chemical burns of mouth,
esophagus, and gastrointestinal tract.
Skin: Contact between the cell and skin will not cause any harm. Skin contact with contents
of an open cell can cause severe irritation or burns to the skin.
Eye: Contact between the cell and the eye will not cause any harm. Eye contact with
contents of an open cell can cause severe irritation or burns to the eye.

CHRONIC (long term): see Section 11 for additional toxicological data

Medical Conditions Aggravated by Exposure: Not applicable
Interactions With Other Chemicals: Immersion in high conductivity liquids may cause corrosion and breaching of the cell
enclosure.
Potential Environmental Effects: Not available

Section 3: Composition/Information on Ingredients

As a solid, manufactured article, exposure to hazardous ingredients is not expected with normal use.

USA: This cell is an article pursuant to 29 CFR 1910.1200 and, as such, is not subject to the OSHA Hazard Communication
Standard requirement. The information contained in this Material Safety Data Sheet contains valuable information critical to
the safe handling and proper use of the product. This SDS should be retained and available for employees and other users of
this product.

Canada: This is not a controlled product under WHMIS. This product meets the definition of a “manufactured article” and is
not subject to the regulations of the Hazardous Products Act.

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SAFETY DATA SHEET

Section 4: First Aid Measures

Inhalation:  If contents of an opened cell are inhaled, remove source of contamination or move victim to fresh air. Obtain medical advice.

Eye Contact:  Contact with the contents of an opened cell can cause burns. If eye contact with contents of an open cell occurs, immediately flush the contaminated eye(s) with lukewarm, gently flowing water for at least 30 minutes while holding the eyelids open. Neutral saline solution may be used as soon as it is available. If necessary, continue flushing during transport to emergency care facility. Take care not to rinse contaminated water into the unaffected eye or onto face. Quickly transport victim to an emergency care facility.

Skin Contact:  Contact with the contents of an opened cell can cause burns. If skin contact with contents of an open cell occurs, as quickly as possible remove contaminated clothing, shoes and leather goods. Immediately flush with lukewarm, gently flowing water for at least 30 minutes. If irritation or pain persists, seek medical attention. Completely decontaminate clothing, shoes and leather goods before reuse or discard.

Ingestion:  Contact with the contents of an opened cell can cause burns. If ingestion of contents of an open cell occurs, NEVER give anything by mouth if victim is rapidly losing consciousness, or is unconscious or convulsing. Have victim rinse mouth thoroughly with water. DO NOT INDUCE VOMITING. If vomiting occurs naturally, have victim lean forward to reduce risk of aspiration. Have victim rinse mouth with water again. Quickly transport victim to an emergency care facility.

Section 5: Fire Fighting Measures

Flammable Properties:  Lithium ion batteries contain flammable liquid electrolyte that may vent, ignite and produce sparks when subjected to high temperatures (> 150 °C (302 °F)), when damaged or abused (e.g., mechanical damage or electrical overcharge). Burning cells can ignite other batteries in close proximity.

Suitable extinguishing Media:  Small Fires - Dry chemical, CO₂, water spray or regular foam.
Large Fires - Water spray, fog or regular foam. Move containers from fire area if you can do it without risk.

Unsuitable extinguishing Media:  Not Applicable

Explosion Data:
Sensitivity to Mechanical Impact:  Extreme mechanical abuse will result in rupture of the individual battery cells.

Sensitivity to Static Discharge:  Electrostatic discharges imposed directly on the spilled electrolyte may start combustion.

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Section 5: Fire Fighting Measures, continued

Specific Hazards arising from the Chemical:
The interaction of water or water vapor and exposed lithium hexafluorophosphate (LiPF6) may result in the generation of hydrogen and hydrogen fluoride (HF) gas. Contact with battery electrolyte may be irritating to skin, eyes and mucous membranes. Fire will produce irritating, corrosive and/or toxic gases. Fumes may cause dizziness or suffocation.

Protective Equipment and precautions for firefighters:
Wear positive pressure self-contained breathing apparatus (SCBA). Structural firefighters’ protective clothing will only provide limited protection. Fight fire from a safe distance.

NFPA:
<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Health</td>
<td>0</td>
</tr>
<tr>
<td>Flammability</td>
<td>1</td>
</tr>
<tr>
<td>Instability</td>
<td>0</td>
</tr>
</tbody>
</table>

Section 6: Accidental Release Measures

Personal Precautions:
As an immediate precautionary measure, isolate spill or leak area for at least 25 meters (75 feet) in all directions. Keep unauthorized personnel away. Stay upwind. Keep out of low areas.
Ventilate closed areas before entering.
Wear adequate personal protective equipment as indicated in Section 8.

Environmental Precautions:
Prevent material from contaminating soil and from entering sewers or waterways.

Methods for Containment:
Stop the leak if safe to do so. Contain the spilled liquid with dry sand or earth. Clean up spills immediately.

Methods for Clean-up:
Absorb spilled material with an inert absorbent (dry sand or earth). Scoop contaminated absorbent into an acceptable waste container. Collect all contaminated absorbent and dispose of according to directions in Section 13.
Scrub the area with detergent and water; collect all contaminated wash water for proper disposal.

Section 7: Handling and Storage

Handling/Transportation:
Do not open, dissemble, crush or burn cell. Do not expose cell to temperatures outside the range of -40°C to 80°C.

Storage:
Store cell in a dry location. To minimize any adverse affects on battery performance it is recommended that the cells be kept at room temperature (25°C +/- 5°C). Elevated temperatures can result in shortened cell life. Keep out of reach of children.
SAFETY DATA SHEET

Section 8: Exposure Controls/Personal Protection

Exposure Limit Values: Airborne exposures to hazardous substances are not expected when product is used for its intended purpose.

Engineering Controls: Use local exhaust ventilation or other engineering controls to control sources of dust, mist, fume and vapor.

Personal Protection:

Respiratory Protection: Not necessary under normal conditions.

Skin Protection: Not necessary under normal conditions. Wear neoprene or natural rubber gloves if handling an open or leaking cell.

Eye Protection: Not necessary under normal conditions. Wear safety glasses if handling an open or leaking cell.

Other Protective Equipment: Have a safety shower and eye-wash fountain readily available in the immediate work area.

Hygiene Measures: Do not eat, drink or smoke in work areas. Maintain good housekeeping.

Section 9: Physical and Chemical Properties

<table>
<thead>
<tr>
<th>Physical State:</th>
<th>Solid</th>
<th>Vapor Pressure (mm Hg @ 20°C):</th>
<th>Not applicable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appearance:</td>
<td>Cell</td>
<td>Vapor Density:</td>
<td>Not applicable</td>
</tr>
<tr>
<td>pH:</td>
<td>Not applicable</td>
<td>Solubility in Water:</td>
<td>Insoluble</td>
</tr>
<tr>
<td>Relative Density:</td>
<td>Not available</td>
<td>Water / Oil distribution coefficient:</td>
<td>Not applicable</td>
</tr>
<tr>
<td>Boiling Point:</td>
<td>Not applicable</td>
<td>Odor Type:</td>
<td>Odorless</td>
</tr>
<tr>
<td>Melting Point:</td>
<td>Not applicable</td>
<td>Odor Threshold:</td>
<td>Not applicable</td>
</tr>
<tr>
<td>Viscosity:</td>
<td>Not applicable</td>
<td>Evaporation Rate:</td>
<td>Not applicable</td>
</tr>
<tr>
<td>Oxidizing Properties:</td>
<td>Not applicable</td>
<td>Auto Ignition Temperature (°C):</td>
<td>Not applicable</td>
</tr>
<tr>
<td>Flash Point and Method (°C):</td>
<td>Not applicable</td>
<td>Flammability Limits (%):</td>
<td>Not applicable</td>
</tr>
</tbody>
</table>

Section 10: Stability and Reactivity

Stability: Stable

Conditions to Avoid: Avoid exposing the cell to fire or temperatures above 80°C. Do not disassemble, crush, short or install with incorrect polarity. Avoid mechanical or electrical abuse.

Incompatible Materials: Do not immerse in seawater or other high conductivity liquids.

Hazardous Decomposition Products: This material may release toxic fumes if burned or exposed to fire. Breaching of the cell enclosure may lead to generation of hazardous fumes which may include extremely hazardous HF (hydrofluoric acid).

Possibility of Hazardous Reactions: Not available

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Section 11: Toxicological Information

<table>
<thead>
<tr>
<th>Acute Toxicity Data</th>
<th>Acute oral, dermal and inhalation toxicity data are not available for this article.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Other Toxicity Data</td>
<td>Risk of irritation occurs only if the cell is mechanically, thermally or electrically abused to the point of compromising the enclosure. If this occurs, irritation to the skin, eyes and respiratory tract may occur.</td>
</tr>
<tr>
<td>Irritation:</td>
<td>Not applicable</td>
</tr>
<tr>
<td>Corrosivity:</td>
<td>Not applicable</td>
</tr>
<tr>
<td>Sensitization:</td>
<td>Not available</td>
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<tr>
<td>Neurological Effects:</td>
<td>Not applicable</td>
</tr>
<tr>
<td>Genetic Effects:</td>
<td>Not applicable</td>
</tr>
<tr>
<td>Reproductive Effects:</td>
<td>Not applicable</td>
</tr>
<tr>
<td>Developmental Effects:</td>
<td>Not applicable</td>
</tr>
<tr>
<td>Target Organ Effects:</td>
<td>Not applicable</td>
</tr>
<tr>
<td>Carcinogenicity:</td>
<td>Normal safe handling of this product will not result in exposure to substances that are considered human carcinogens by IARC (International Agency for Research on Cancer), ACGIH (American Conference of Governmental Industrial Hygienists, OSHA or NTP (National Toxicology Program).</td>
</tr>
</tbody>
</table>

Section 12: Ecological Information

| Ecotoxicity:        | Not available                                                                   |
| Mobility:           | Not available                                                                   |
| Persistence and degradability: | Not readily biodegradable                                                     |
| Bioaccumulative potential: | Not available                                                                   |
| Other adverse effects: | Solid cells released into the natural environment will slowly degrade and may release harmful or toxic substances. Cells are not intended to be released into water or on land but should be disposed or recycled according to local regulations. |

Section 13: Disposal Considerations

| Waste Disposal Method: | Cell recycling is encouraged. Do NOT dump into any sewers, on the ground or into any body of water. Store material for disposal as indicated in Section 7 Handling and Storage. |
| USA:                  | Dispose of in accordance with local, state and federal laws and regulations. |
| Canada:               | Dispose of in accordance with local, provincial and federal laws and regulations. |
| EC:                   | Waste must be disposed of in accordance with relevant EC Directives and national, regional and local environmental control regulations. For disposal within the EC, the appropriate code according to the European Waste Catalogue (EWC) should be used. |
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Section 14: Transport Information

A123 Systems lithium-ion cells and batteries are designed to comply with all applicable shipping regulations as prescribed by industry and legal standards which includes compliance with the UN Recommendations on the Transport of Dangerous Goods, IATA Dangerous Goods Regulations and applicable U.S. DOT regulations for the safe transport of lithium-ion batteries and the International Maritime Dangerous Goods Code. Each of the listed cells in Section 1 have passed the UN Manual of Tests and Criteria Part III Subsection 38.3, which is required by all of the directives listed above.

In the US, shipments of lithium ion cells and batteries are classified as Class 9, UN3480, Packing Group II, by the U.S. Hazardous Materials Regulations (HMR). Packaging, markings and documentation requirements are defined in Title 49 of the Code of Federal Regulations (CFR), Section 173.185, of the U.S. HMR. Excepted cells and batteries are allowed to be transported within the US without Class 9 packaging and markings, but must conform to other requirements as stipulated in Special Provisions 188 and 189 in the 49 CFR Section 173.185 of the U.S. HMR.

International shipments of lithium ion cells and batteries are generally classified as Class 9, UN3480, Packing Group II, by the International Civil Aviation Organization (ICAO) and the International Maritime Dangerous Goods (IMDG) Code. Packaging, markings and documentation requirements are defined in the International Air Transport Association (IATA) Dangerous Goods Regulations (DGR) Packing Instructions 965 and Packing Instruction P903 of the IMDG Code. Excepted cells and batteries are allowed to be transported internationally without Class 9 packaging and markings, but must conform to other requirements as stipulated in Packing Instructions 965 of the IATA DGR and Special Provision 188 under the IMDG Code.

Section 15: Regulatory Information

USA

<table>
<thead>
<tr>
<th>TSCA Status:</th>
<th>All ingredients in the product are listed on the TSCA inventory.</th>
</tr>
</thead>
<tbody>
<tr>
<td>SARA Title III:</td>
<td>None</td>
</tr>
<tr>
<td>Sec. 302/304:</td>
<td>None</td>
</tr>
<tr>
<td>Sec. 311/312:</td>
<td>None</td>
</tr>
<tr>
<td>Sec. 313:</td>
<td>None</td>
</tr>
<tr>
<td>CERCLA RQ:</td>
<td></td>
</tr>
</tbody>
</table>

California Prop 65:

This product does not contain chemicals known to the State of California to cause cancer or reproductive toxicity.

Canada

This product has been classified in accordance with the hazard criteria of the Controlled Products Regulations and the SDS contains all the information required by the Controlled Products Regulations.

WHMIS Classification: Not Controlled

New Substance:

Lithium hexafluorophosphate is listed on the NDSL. All other ingredients in the product are listed, as required, on Canada’s Domestic Substances List (DSL).

Notification Regulations:

NPRI Substances: This product does not contain any NPRI chemicals.

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Section 15: Regulatory Information, continued

EC Classification for the Substance/Preparation: This product is not classified as hazardous according to Regulation (EC) No. 1272/2008. Keep out of the reach of children.

EINECS Status:

<table>
<thead>
<tr>
<th>Cell component</th>
<th>Chemical Name</th>
<th>CAS No.</th>
<th>EINECS</th>
<th>Concentration range in electrolyte (w/w %)</th>
<th>Mass range in cell (g/g %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrolyte salt</td>
<td>Lithium hexafluorophosphate</td>
<td>21324-40-3</td>
<td>244-334-7</td>
<td>10 - 20</td>
<td>1 - 5</td>
</tr>
<tr>
<td>Electrolyte solvents</td>
<td>Includes one or more of the following:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ethylene Carbonate,</td>
<td>96-49-1</td>
<td>202-510-0</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Propylene Carbonate,</td>
<td>108-32-7</td>
<td>203-572-1</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Diethyl Carbonate,</td>
<td>105-58-8</td>
<td>203-311-1</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dimethyl Carbonate</td>
<td>616-38-6</td>
<td>210-478-4</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ethyl Methyl Carbonate</td>
<td>623-53-0</td>
<td>Not Listed</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Section 16: Other Information

Preparation Information: October 13, 2009
Revision Date:

Revision Summary: October 13, 2009:
- Revised Section 5 Protective Equipment sub part.
- Revised Section 6 Personal Precautions sub part.
- Reformatted parts of SDS.
March 4, 2010:
- Revised Section 14 and removed reference to IATA edition and packing instruction part.
September 23, 2010:
- Added APP72161227-M1-A to cell list.
- Updated A123 SYSTEMS logo.
- Format changes to accommodate web posting.
March 30, 2011 (REV 19):
- Added AMP20M1HD-A to cell list.
- Updated NFPA information.
- Updated temperatures in section 7.
- Updated section 14.
- Updated company address.

Manufacturer Disclaimer: The information and recommendations set forth are made in good faith and believed to be accurate at the date of preparation.
16. Appendix 2 UN38.3 Transportation

Recommendations on the

TRANSPORT
OF
DANGEROUS GOODS

Manual of
Tests and Criteria

Fifth revised edition

Amendment 1

UNITED NATIONS
FOREWORD

The Manual of Tests and Criteria contains criteria, test methods and procedures to be used for classification of dangerous goods according to the provisions of Parts 2 and 3 of the United Nations Recommendations on the Transport of Dangerous Goods, Model Regulations\(^1\), as well as of chemicals presenting physical hazards according to the Globally Harmonized System of Classification and Labelling of Chemicals (GHS)\(^2\).

As a consequence, it supplements also national or international regulations which are derived from the United Nations Recommendations on the Transport of Dangerous Goods or the GHS.

Originally developed by the Economic and Social Council’s Committee of Experts on the Transport of Dangerous Goods which adopted a first version in 1984, it has been regularly updated and amended every two years. Presently, the updating is done under the auspices of the Committee of Experts on the Transport of Dangerous Goods and on the Globally Harmonized System of Classification and Labelling of Chemicals, which replaces the original committee since 2001.

The fifth revised edition, published in 2009, includes all the amendments to the fourth revised edition adopted by the Committee at its second and third sessions in 2004 and 2006 (published under the symbols ST/SG/AC.10/11/Rev.4/Amend.1 and ST/SG/AC.10/11/Rev.4/Amend.2) and those adopted at its fourth session in 2008 (ST/SG/AC.10/36/Add.2 and -/Corr.1).

The amendments listed in this publication were adopted by the Committee at its fifth session (10 December 2010)\(^3\). This publication also include the corrections adopted by the Sub-Committee of Experts on the Transport of Dangerous at its thirty-ninth session (20-24 June 2011)\(^4\).

The amendments listed include:

- Amendments to the procedure for assignment to a Division of Class 1;
- Amendments to test series 7 for the classification as extremely insensitive explosive article;
- A test method for the classification of gases and gas mixtures as chemically unstable (new section 35);
- Amendments to the procedures to be followed for the classification of lithium metal and lithium ion cells and batteries;
- Amendments to the variations permitted for MEGCo design without additional testing;
- A new appendix 8 detailing the response descriptors to be used for the purposes of Test series 7.

\(^{2}\) ST/SG/AC.10/30/Rev.4. United Nations publication, sales No. 11.II.E.6.
\(^{3}\) ST/SG/AC.10/38/Add.2.
\(^{4}\) ST/SG/AC.10/C.3/78, Annex IV.
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<table>
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<tr>
<th>AMENDMENTS TO PART III OF THE MANUAL</th>
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<tbody>
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<td>Section 38</td>
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<table>
<thead>
<tr>
<th>AMENDMENTS TO PART IV OF THE MANUAL</th>
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<tr>
<td>Section 41</td>
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<table>
<thead>
<tr>
<th>NEW APPENDIX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appendix 8</td>
</tr>
</tbody>
</table>
SECTION 38

38.3 Amend to read as follows:

"38.3 Lithium metal and lithium ion batteries

38.3.1 Purpose

This section presents the procedures to be followed for the classification of lithium metal and lithium ion cells and batteries (see UN Nos. 3090, 3091, 3480 and 3481, and the applicable special provisions of Chapter 3.3 of the Model Regulations).

38.3.2 Scope

38.3.2.1 All cell types shall be subjected to tests T.1 to T.6 and T.8. All non-rechargeable battery types, including those composed of previously tested cells, shall be subjected to tests T.1 to T.5. All rechargeable battery types, including those composed of previously tested cells, shall be subjected to tests T.1 to T.5 and T.7. In addition, rechargeable single cell batteries with overcharge protection shall be subjected to test T.7. A component cell that is not transported separately from the battery it is part of needs only to be tested according to tests T.6 and T.8. A component cell that is transported separately from the battery shall be tested as a cell.

38.3.2.2 Lithium metal and lithium ion cells and batteries shall be subjected to the tests, as required by special provisions 188 and 230 of Chapter 3.3 of the Model Regulations prior to the transport of a particular cell or battery type. Cells or batteries which differ from a tested type by:

(a) For primary cells and batteries, a change of more than 0.1 g or 20% by mass, whichever is greater, to the cathode, to the anode, or to the electrolyte;

(b) For rechargeable cells and batteries, a change in nominal energy in Watt-hours of more than 20% or an increase in nominal voltage of more than 20%; or

(c) A change that would lead to failure of any of the tests,

shall be considered a new type and shall be subjected to the required tests.

NOTE: The type of change that might be considered to differ from a tested type, such that it might lead to failure of any of the test results, may include, but is not limited to:

(a) A change in the material of the anode, the cathode, the separator or the electrolyte;

(b) A change of protective devices, including hardware and software;

(c) A change of safety design in cells or batteries, such as a venting valve;

(d) A change in the number of component cells; and

(e) A change in connecting mode of component cells.

In the event that a cell or battery type does not meet one or more of the test requirements, steps shall be taken to correct the deficiency or deficiencies that caused the failure before such cell or battery type is retested.

38.3.2.3 For the purposes of classification, the following definitions apply:

*Aggregate lithium content* means the sum of the grams of lithium content contained by the cells comprising a battery.
**Battery** means two or more cells which are electrically connected together and fitted with devices necessary for use, for example, case, terminals, marking and protective devices. A single cell battery is considered a "cell" and shall be tested according to the testing requirements for "cells" for the purposes of the Model Regulations and this Manual (see also the definition for "cell").

**NOTE:** Units that are commonly referred to as "battery packs", "modules" or "battery assemblies" having the primary function of providing a source of power to another piece of equipment are for the purposes of the Model Regulations and this Manual treated as batteries.

**Button cell or battery** means a round small cell or battery when the overall height is less than the diameter.

**Cell** means a single encased electrochemical unit (one positive and one negative electrode) which exhibits a voltage differential across its two terminals. Under the Model Regulations and this Manual, to the extent the encased electrochemical unit meets the definition of "cell" herein, it is a "cell", not a "battery", regardless of whether the unit is termed a "battery" or a "single cell battery" outside of the Model Regulations and this Manual.

**Component cell** means a cell contained in a battery.

**Cycle** means one sequence of fully charging and fully discharging a rechargeable cell or battery.

**Disassembly** means a vent or rupture where solid matter from any part of a cell or battery penetrates a wire mesh screen (annealed aluminium wire with a diameter of 0.25 mm and grid density of 6 to 7 wires per cm) placed 25 cm away from the cell or battery.

**Effluent** means a liquid or gas released when a cell or battery vents or leaks.

**Fire** means that flames are emitted from the test cell or battery.

**First cycle** means the initial cycle following completion of all manufacturing processes.

**Fully charged** means a rechargeable cell or battery which has been electrically charged to its design rated capacity.

**Fully discharged** means either:

- a primary cell or battery which has been electrically discharged to remove 100% of its rated capacity; or
- a rechargeable cell or battery which has been electrically discharged to its endpoint voltage as specified by the manufacturer.

**Large battery** means a lithium metal battery or lithium ion battery with a gross mass of more than 12 kg.

**Large cell** means a cell with a gross mass of more than 500 g.

**Leakage** means the visible escape of electrolyte or other material from a cell or battery or the loss of material (except battery casing, handling devices or labels) from a cell or battery such that the loss of mass exceeds the values in Table 38.3.1.

**Lithium content** is applied to lithium metal and lithium alloy cells and batteries, and for a cell means the mass of lithium in the anode of a lithium metal or lithium alloy cell, which for a primary cell is measured when the cell is in an undischarged state and for a rechargeable cell is measured when the cell is fully charged. The lithium content of a battery equals the sum of the grams of lithium content contained in the component cells of the battery.
Lithium ion cell or battery means a rechargeable electrochemical cell or battery in which the positive and negative electrodes are both intercalation compounds (intercalated lithium exists in an ionic or quasi-atomic form with the lattice of the electrode material) constructed with no metallic lithium in either electrode. A lithium polymer cell or battery that uses lithium ion chemistries, as described herein, is regulated as a lithium ion cell or battery.

Mass loss means a loss of mass that exceeds the values in Table 38.3.1 below.

### Table 38.3.1: Mass loss limit

<table>
<thead>
<tr>
<th>Mass M of cell or battery</th>
<th>Mass loss limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>M &lt; 1 g</td>
<td>0.5%</td>
</tr>
<tr>
<td>1 g ≤ M ≤ 75 g</td>
<td>0.2%</td>
</tr>
<tr>
<td>M &gt; 75 g</td>
<td>0.1%</td>
</tr>
</tbody>
</table>

**NOTE:** In order to quantify the mass loss, the following procedure is provided:

\[
\text{Mass loss (\%)} = \left(\frac{M_1 - M_2}{M_1}\right) \times 100
\]

where \(M_1\) is the mass before the test and \(M_2\) is the mass after the test. When mass loss does not exceed the values in Table 38.3.1, it shall be considered as "no mass loss".

Nominal energy or Watt-hour rating, expressed in watt-hours, means the energy value of a cell or battery determined under specified conditions and declared by the manufacturer. The nominal energy is calculated by multiplying nominal voltage by rated capacity expressed in ampere-hours.

Nominal voltage means the approximate value of the voltage used to designate or identify a cell or battery.

Open circuit voltage means the voltage across the terminals of a cell or battery when no external current is flowing.

Primary cell or battery means a cell or battery which is not designed to be electrically charged or recharged.

Prismatic cell or battery means a cell or battery whose ends are similar, equal and parallel rectilinear figures, and whose sides are parallelograms.

Protective devices means devices such as fuses, diodes and current limiters which interrupt the current flow, block the current flow in one direction or limit the current flow in an electrical circuit.

Rated capacity means the capacity, in ampere-hours or milliamperes-hours, of a cell or battery as measured by subjecting it to a load, temperature and voltage cut-off point specified by the manufacturer.

**NOTE:** The following IEC standards provide guidance and methodology for determining the rated capacity:

1. IEC 61960 (First Edition 2003-12): Secondary cells and batteries containing alkaline or other non-acid electrolytes – Secondary lithium cells and batteries for portable applications;

2. IEC 62133 (First Edition 2002-10): Secondary cells and batteries containing alkaline or other non-acid electrolytes – Safety requirements for portable sealed secondary cells, and for batteries made from them, for use in portable applications;


Rechargeable cell or battery means a cell or battery which is designed to be electrically recharged.
Rupture means the mechanical failure of a cell container or battery case induced by an internal or external cause, resulting in exposure or spillage but not ejection of solid materials.

Short circuit means a direct connection between positive and negative terminals of a cell or battery that provides a virtual zero resistance path for current flow.

Single cell battery means a single electrochemical unit fitted with devices necessary for use, for example, case, terminals, marking and protective devices.

Small battery means a lithium metal battery or lithium ion battery with a gross mass of not more than 12 kg.

Small cell means a cell with a gross mass of not more than 500 g.

Type means a particular electrochemical system and physical design of cells or batteries.

Undischarged means a primary cell or battery that has not been wholly or partly discharged.

Venting means the release of excessive internal pressure from a cell or battery in a manner intended by design to preclude rupture or disassembly.

Watt-hour rating, see Nominal energy.

38.3.3 When a cell or battery type is to be tested under this sub-section, the number and condition of cells and batteries of each type to be tested are as follows:

(a) When testing primary cells and batteries under tests T.1 to T.5 the following shall be tested in the quantity indicated:

(i) ten cells in undischarged states;
(ii) ten cells in fully discharged states;
(iii) four small batteries in undischarged states;
(iv) four small batteries in fully discharged states;
(v) four large batteries in undischarged states; and
(vi) four large batteries in fully discharged states.

(b) When testing rechargeable cells and batteries under tests T.1 to T.5 the following shall be tested in the quantity indicated:

(i) ten cells at first cycle, in fully charged states;
(ii) four small batteries at first cycle, in fully charged states;
(iii) four small batteries after 50 cycles ending in fully charged states;
(iv) two large batteries at first cycle, in fully charged states; and
(v) two large batteries after 25 cycles ending in fully charged states.

(c) When testing primary and rechargeable cells under test T.6, the following shall be tested in the quantity indicated:

(i) for primary cells, five cells in undischarged states and five cells in fully discharged states;
(ii) for component cells of primary batteries, five cells in undischarged states and five cells in fully discharged states;
(iii) for rechargeable cells, five cells at first cycle at 50% of the design rated capacity; and
(iv) for component cells of rechargeable batteries, five cells at first cycle at 50% of the design rated capacity.

(d) When testing rechargeable batteries or rechargeable single cell batteries under test T.7, the following shall be tested in the quantity indicated:

(i) four small batteries at first cycle, in fully charged states;
(ii) four small batteries after 50 cycles ending in fully charged states;
(iii) two large batteries at first cycle, in fully charged states; and
(iv) two large batteries after 25 cycles ending in fully charged states.

Batteries not equipped with overcharge protection that are designed for use only in a battery assembly, which affords such protection, are not subject to the requirements of this test.

(e) When testing primary and rechargeable cells and component cells under test T.8, the following shall be tested in the quantity indicated:

(i) ten primary cells in fully discharged states;
(ii) ten primary component cells in fully discharged states;
(iii) ten rechargeable cells, at first cycle in fully discharged states;
(iv) ten rechargeable component cells, at first cycle in fully discharged states;
(v) ten rechargeable cells after 50 cycles ending in fully discharged states; and
(vi) ten rechargeable component cells after 50 cycles ending in fully discharged states.

(f) When testing a battery assembly in which the aggregate lithium content of all anodes, when fully charged, is not more than 500 g, or in the case of a lithium ion battery, with a Watt-hour rating of not more than 6 200 Watt-hours, that is assembled from batteries that have passed all applicable tests, one battery assembly in a fully charged state shall be tested under tests T.3, T.4 and T.5, and, in addition, test T.7 in the case of a rechargeable battery assembly. For a rechargeable battery assembly, the assembly shall have been cycled at least 25 cycles.

When batteries that have passed all applicable tests are electrically connected to form a battery assembly in which the aggregate lithium content of all anodes, when fully charged, is more than 500 g, or in the case of a lithium ion battery, with a Watt-hour rating of more than 6 200 Watt-hours, that battery assembly does not need to be tested if it is equipped with a system capable of monitoring the battery assembly and preventing short circuits, or over discharge between the batteries in the assembly and any overheat or overcharge of the battery assembly.

38.3.4 Procedure

Tests T.1 to T.5 shall be conducted in sequence on the same cell or battery. Tests T.6 and T.8 shall be conducted using not otherwise tested cells or batteries. Test T.7 may be conducted using undamaged batteries previously used in tests T.1 to T.5 for purposes of testing on cycled batteries.
38.3.4.1 Test T.1: Altitude simulation

38.3.4.1.1 Purpose
This test simulates air transport under low-pressure conditions.

38.3.4.1.2 Test procedure
Test cells and batteries shall be stored at a pressure of 11.6 kPa or less for at least six hours at ambient temperature (20 ± 5 °C).

38.3.4.1.3 Requirement
Cells and batteries meet this requirement if there is no leakage, no venting, no disassembly, no rupture and no fire and if the open circuit voltage of each test cell or battery after testing is not less than 90% of its voltage immediately prior to this procedure. The requirement relating to voltage is not applicable to test cells and batteries at fully discharged states.

38.3.4.2 Test T.2: Thermal test

38.3.4.2.1 Purpose
This test assesses cell and battery seal integrity and internal electrical connections. The test is conducted using rapid and extreme temperature changes.

38.3.4.2.2 Test procedure
Test cells and batteries are to be stored for at least six hours at a test temperature equal to 72 ± 2 °C, followed by storage for at least six hours at a test temperature equal to - 40 ± 2 °C. The maximum time interval between test temperature extremes is 30 minutes. This procedure is to be repeated until 10 total cycles are complete, after which all test cells and batteries are to be stored for 24 hours at ambient temperature (20 ± 5 °C). For large cells and batteries the duration of exposure to the test temperature extremes should be at least 12 hours.

38.3.4.2.3 Requirement
Cells and batteries meet this requirement if there is no leakage, no venting, no disassembly, no rupture and no fire and if the open circuit voltage of each test cell or battery after testing is not less than 90% of its voltage immediately prior to this procedure. The requirement relating to voltage is not applicable to test cells and batteries at fully discharged states.

38.3.4.3 Test T.3: Vibration

38.3.4.3.1 Purpose
This test simulates vibration during transport.

38.3.4.3.2 Test procedure
Cells and batteries are firmly secured to the platform of the vibration machine without distorting the cells in such a manner as to faithfully transmit the vibration. The vibration shall be a sinusoidal waveform with a logarithmic sweep between 7 Hz and 200 Hz and back to 7 Hz traversed in 15 minutes. This cycle shall be repeated 12 times for a total of 3 hours for each of three mutually perpendicular mounting positions of the cell. One of the directions of vibration must be perpendicular to the terminal face.

The logarithmic frequency sweep shall differ for cells and batteries with a gross mass of not more than 12 kg (cells and small batteries), and for batteries with a gross mass of more than 12 kg (large batteries).
For cells and small batteries: from 7 Hz a peak acceleration of 1 gₑ is maintained until 18 Hz is reached. The amplitude is then maintained at 0.8 mm (1.6 mm total excursion) and the frequency increased until a peak acceleration of 8 gₑ occurs (approximately 50 Hz). A peak acceleration of 8 gₑ is then maintained until the frequency is increased to 200 Hz.

For large batteries: from 7 Hz to a peak acceleration of 1 gₑ is maintained until 18 Hz is reached. The amplitude is then maintained at 0.8 mm (1.6 mm total excursion) and the frequency increased until a peak acceleration of 2 gₑ occurs (approximately 25 Hz). A peak acceleration of 2 gₑ is then maintained until the frequency is increased to 200 Hz.

38.3.4.3.3 Requirement

Cells and batteries meet this requirement if there is no leakage, no venting, no disassembly, no rupture and no fire during the test and after the test and if the open circuit voltage of each test cell or battery directly after testing in its third perpendicular mounting position is not less than 90% of its voltage immediately prior to this procedure. The requirement relating to voltage is not applicable to test cells and batteries at fully discharged states.

38.3.4.4 Test T.4: Shock

38.3.4.4.1 Purpose

This test simulates possible impacts during transport.

38.3.4.4.2 Test procedure

Test cells and batteries shall be secured to the testing machine by means of a rigid mount which will support all mounting surfaces of each test battery. Each cell or battery shall be subjected to a half-sine shock of peak acceleration of 150 gₑ and pulse duration of 6 milliseconds. Each cell or battery shall be subjected to three shocks in the positive direction followed by three shocks in the negative direction of three mutually perpendicular mounting positions of the cell or battery for a total of 18 shocks.

However, large cells and large batteries shall be subjected to a half-sine shock of peak acceleration of 50 gₑ and pulse duration of 11 milliseconds. Each cell or battery is subjected to three shocks in the positive direction followed by three shocks in the negative direction of each of three mutually perpendicular mounting positions of the cell for a total of 18 shocks.

38.3.4.4.3 Requirement

Cells and batteries meet this requirement if there is no leakage, no venting, no disassembly, no rupture and no fire and if the open circuit voltage of each test cell or battery after testing is not less than 90% of its voltage immediately prior to this procedure. The requirement relating to voltage is not applicable to test cells and batteries at fully discharged states.

38.3.4.5 Test T.5: External short circuit

38.3.4.5.1 Purpose

This test simulates an external short circuit.
38.3.4.5.2 Test procedure

The cell or battery to be tested shall be temperature stabilized so that its external case temperature reaches $55 \pm 2 ^\circ C$ and then the cell or battery shall be subjected to a short circuit condition with a total external resistance of less than 0.1 ohm at $55 \pm 2 ^\circ C$. This short circuit condition is continued for at least one hour after the cell or battery external case temperature has returned to $55 \pm 2 ^\circ C$.

38.3.4.5.3 Requirement

Cells and batteries meet this requirement if their external temperature does not exceed 170 $^\circ C$ and there is no disassembly, no rupture and no fire during the test and within six hours after the test.

38.3.4.6 Test T.6: Impact / Crush

38.3.4.6.1 Purpose

These tests simulate mechanical abuse from an impact or crush that may result in an internal short circuit.

38.3.4.6.2 Test procedure – Impact (applicable to cylindrical cells greater than 20 mm in diameter)

The sample cell or component cell is to be placed on a flat smooth surface. A 15.8 mm ± 0.1mm diameter, at least 6 cm long, or the longest dimension of the cell, whichever is greater, Type 316 stainless steel bar is to be placed across the centre of the sample. A 9.1 kg ± 0.1 kg mass is to be dropped from a height of 61 ± 2.5 cm at the intersection of the bar and sample in a controlled manner using a near frictionless, vertical sliding track or channel with minimal drag on the falling mass. The vertical track or channel used to guide the falling mass shall be oriented 90 degrees from the horizontal supporting surface.

The test sample is to be impacted with its longitudinal axis parallel to the flat surface and perpendicular to the longitudinal axis of the 15.8 mm ± 0.1mm diameter curved surface lying across the centre of the test sample. Each sample is to be subjected to only a single impact.

38.3.4.6.3 Test Procedure – Crush (applicable to prismatic, pouch, coin/button cells and cylindrical cells not more than 20 mm in diameter)

A cell or component cell is to be crushed between two flat surfaces. The crushing is to be gradual with a speed of approximately 1.5 cm/s at the first point of contact. The crushing is to be continued until the first of the three options below is reached.

(a) The applied force reaches 13 kN ± 0.78 kN;

   Example: The force shall be applied by a hydraulic ram with a 32 mm diameter piston until a pressure of 17 MPa is reached on the hydraulic ram.

(b) The voltage of the cell drops by at least 100 mV; or

(c) The cell is deformed by 50% or more of its original thickness.

Once the maximum pressure has been obtained, the voltage drops by 100 mV or more, or the cell is deformed by at least 50% of its original thickness, the pressure shall be released.

A prismatic or pouch cell shall be crushed by applying the force to the widest side. A button/coin cell shall be crushed by applying the force on its flat surfaces. For cylindrical cells, the crush force shall be applied perpendicular to the longitudinal axis.
Each test cell or component cell is to be subjected to one crush only. The test sample shall be observed for a further 6 h. The test shall be conducted using test cells or component cells that have not previously been subjected to other tests.

38.3.4.6.4 Requirement

Cells and component cells meet this requirement if their external temperature does not exceed 170 °C and there is no disassembly and no fire during the test and within six hours after this test.

38.3.4.7 Test T.7: Overcharge

38.3.4.7.1 Purpose

This test evaluates the ability of a rechargeable battery to withstand an overcharge condition.

38.3.4.7.2 Test procedure

The charge current shall be twice the manufacturer's recommended maximum continuous charge current. The minimum voltage of the test shall be as follows:

(a) when the manufacturer's recommended charge voltage is not more than 18V, the minimum voltage of the test shall be the lesser of two times the maximum charge voltage of the battery or 22V.

(b) when the manufacturer's recommended charge voltage is more than 18V, the minimum voltage of the test shall be 1.2 times the maximum charge voltage.

Tests are to be conducted at ambient temperature. The duration of the test shall be 24 hours.

38.3.4.7.3 Requirement

Rechargeable batteries meet this requirement if there is no disassembly and no fire during the test and within seven days after the test.

38.3.4.8 Test T.8: Forced discharge

38.3.4.8.1 Purpose

This test evaluates the ability of a primary or a rechargeable cell to withstand a forced discharge condition.

38.3.4.8.2 Test procedure

Each cell shall be forced discharged at ambient temperature by connecting it in series with a 12V D.C. power supply at an initial current equal to the maximum discharge current specified by the manufacturer.

The specified discharge current is to be obtained by connecting a resistive load of the appropriate size and rating in series with the test cell. Each cell shall be forced discharged for a time interval (in hours) equal to its rated capacity divided by the initial test current (in ampere).

38.3.4.8.3 Requirement

Primary or rechargeable cells meet this requirement if there is no disassembly and no fire during the test and within seven days after the test. ".
### Appendix 3 SAND

**PSTG Generic Procedure for Safety and Abuse Testing of Electrochemical Power Sources (U)**

**AUTHOR:** W. BILL AVERILL, 2546  
**OWNER:** THOMAS WUNSCH, 2546

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1.0 PURPOSE, SCOPE, AND OWNERSHIP

The purpose of this Generic Procedure (GP) is to inform laboratory personnel of the general procedures and relevant safety and health practices to be followed for abuse and safety testing of electrochemical power sources including, but not limited to, primary cells and batteries, secondary cells and batteries, ultracapacitors, and fuel cells fabricated by the Power Source Technology Group (PSTG) Energy Components and Metrology Group as well as those procured from outside commercial sources. The information contained in this document is intended to inform operators of the hazards that are encountered with abuse and safety testing of cells and batteries. The goal of this GP is to ensure that the operator knows all of the safe operating procedures.

This GP also outlines the hazard minimization and mitigation actions to be taken above and beyond the general information contained in pertinent sections of the current editions of MN471001, ES&H Manual and ES&H Manual Supplements. Refer to the following link for more details http://www-irn.sandia.gov/corpdata/esh-manuals/mn471001/m001toc.htm.

The review period for the PSTG Generic Procedure Safety and Abuse Testing of Electrochemical Power Sources is three years.

2.0 RESPONSIBILITIES

The individuals conducting the activities described in this GP will be responsible for reading, understanding, and adhering to this GP and the appropriate Operating Procedures (OPs) as acknowledged by their electronic signature on the concurrence lists for those documents.

These same individuals shall also be responsible for reading, understanding, and adhering to the procedures in Section 8.1 References of this GP.

All personnel are responsible for the disposal of any waste materials generated as a result of these activities in accordance with MN471001, ES&H Manual, Section19A - Hazardous Waste Management at SNL/SIM.

3.0 TRAINING AND QUALIFICATIONS

Personnel shall meet all current corporate and department requirements for ES&H training, and the Primary Hazard Screening (PHS) requirements, before any work can take place. A PHS shall be completed for all facility and project activities. The PHS may identify that a Hazard Analysis (HA) needs to be completed as well. The PHS and HA assist in developing implementing procedures and training requirements that personnel need to safely perform their work. Refer to the following link for more details http://phs/, or enter the following information into your Web browser http://www-im.sandia.gov/iss/isms_software/.

To gain access to the PHSs, you will need to do the following:
1. Click PHS Module.
2. Click Start PHS Version 4.X.
3. Enter your Sandia User name and Kerberos Password.
4. The PHS and HARP Main Menu dialog box appears.
5. Under All Documents, click Search.

6. A search dialog box appears. In the Search for documents by, enter information in one of the fields.

7. Click Search.

8. Your search information should be displayed. If there is not any search information displayed, try your search again using different information.

In addition, users of this GP need to complete all assigned corporate required training as well. Refer to the Training and Employee Development System (TEDS), this is the SNL corporate training database that tracks training requirements. Refer to the following links for the particular corporate required training in your organization:

- https://tedsprod.sandia.gov/etds/TEDSEveryOne.jsf

NOTE: There is specific information available for dealing with Lithium Hazards that can be obtained from your ES&H Training Coordinator. In order to electronically sign-off on this GP, you must successfully complete the required training dealing with Lithium Hazards.

Required training for Lab 1105 is as follows:

- ELC106, R&D Electrical Safety (> 50 Volts),
- ELC106R, R&D Electrical Safety Refresher (> 50 Volts),
- ENV112, Hazardous Waste and Environmental Management Training,
- ESH100, ES&H Awareness,
- LAB100, Laboratory Standard Information and Training,
- LAB103, Site-Specific Laboratory Safety Training,
- PRS150, Pressure Safety Orientation, and
- RSP215, Air-Purifying Respiratory Protection (including an annual respirator fit test).

4.0 EMERGENCY PROCESS

Instructions for laboratory personnel response to medical emergencies, fires, and chemical releases are according to the MN471001, ES&H Manual, Attachment 15-1: What to Do During an Emergency.

4.1 Basic Notification

All Events, Issues, Concerns and Near Misses must be reported to line management who will gather the necessary facts and assess the reporting needs.

**BASIC NOTIFICATION, Immediately contact:**

| Your Manager | If unable to contact your immediate Manager, you may contact a peer manager or your next level of management. Direct notification is preferred, voicemail and email must be avoided if the issue is time critical. |

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5.0 HAZARDS

5.1 Abuse Testing

WARNING: Abuse tests are inherently dangerous; failure to practice the following procedures could result in serious injury or even death to laboratory personnel.

All abuse tests should monitor:
- voltage, and
- external cell temperature.

These measurements are used for safety monitoring and to obtain scientific test data.

All abuse testing must be coordinated through the 2546 Department Manager and the Abuse Testing Laboratory Owner.

Dry erase boards for Building 905, Room 1105 Test Bays C through H are attached to the main blast door and information will be written on each dry erase board describing each specific test taking place, refer to Section 5.3.5 Signage of this GP for more details. Personnel SHALL check with the identified point-of-contact (POC) listed on the dry erase board before entering a test bay. If the main blast door is closed, all personnel MUST receive clearance from the Abuse Testing Laboratory Owner before attempting to open the main blast door.

Local exhaust ventilation will be used during all tests. Turn OFF make-up air, and turn main blower to HIGH. Verify scrubber water is flowing before proceeding with test. Proper operation of the ventilation system WILL produce a negative pressure in the Test Bay area relative to the Control Room (1105A) and the Main Laboratory (1105).

NOTE: For test units with a capacity greater than 10 Ampere-hours, CLOSE the main blast door.

NOTE: For all tests, CLOSE the Test Bay door.
5.2 Hazard Identification

5.2.1 General
Safety and abuse testing operations are inherently hazardous. Units under test are intentionally taken to the limits of their design and frequently beyond. This often results in catastrophic failure of the unit thereby producing flames, toxic chemical emissions, and flying debris.

5.2.2 Pressure

5.2.2.1 Venting
Cells frequently incorporate safety vents, which allow the escape of built-up pressure under abusive conditions.

Venting can often result in the ejection of the cell contents including the emission of toxic or irritant gasses and particulates, and the production of flames.

Venting is a normal occurrence during safety and abuse testing.

5.2.3 Chemical

NOTE: Refer to the PSTG-GP-HWWHC-1, Generic Procedure Handling and Working with Hazardous Chemicals, for more details on the procedures for handling hazardous chemicals. Refer to the PSTG Website, under Active Procedures.

5.2.3.1 Flammable Materials
Cell electrolytes are often flammable and can form explosive gas mixtures under certain conditions.

5.2.3.2 Release of Toxic or Irritant Gasses
Cell chemistry determines what toxic or irritant gasses may be released during the course of an abuse test. Some examples include thionyl chloride, hydrogen chloride, hydrogen fluoride, or sulfur dioxide.

5.2.3.3 Release of Toxic or Irritant Particulates
The cell chemistry of the battery also determines what toxic or irritant particulates may be released during the course of an abuse test. Of particular concern is the release of oxides of nickel, which are considered to be suspect carcinogens and must be handled as particularly hazardous substances. Another hazardous substance of concern are lithium oxides, which are formed from a lithium fire. Lithium oxides are corrosive to the eyes, skin, and respiratory tract.

Refer to the MN471001, Section 6E – Laboratory Standard – Chemical Hygiene Plan for information on particularly hazardous substances.

5.2.3.4 Release of Corrosive Material
Cell chemistry, once again, determines if there is a potential for the release of corrosive materials. Corrosive materials can be acidic or basic.
5.2.4 Electrical

5.2.4.1 High Voltage
While most individual cells operate in the low voltage regime (< 50 volts), many batteries or modules can exceed 50 volts and therefore present a high voltage handling hazard. Refer to Section 5.3 Controls for mitigation of this hazard.

5.2.4.2 High Current
Many batteries are capable of generating high currents under short circuit conditions. Short circuit conditions can lead to the production of sparks, hot or molten metal, and if sustained, venting of the unit. Refer to Section 5.3 Controls for mitigation of this hazard.

5.2.5 Thermal

5.2.5.1 Fire
Fire is a normal occurrence during safety and abuse testing. As long as a fire is contained within the test bay, no fire fighting actions are necessary.

Lithium primary cells may ignite if exposed to temperatures above 180 °Celsius (C).

Electrolytes may be flammable and under certain conditions can form explosive mixtures with air.

5.2.5.2 Operation of Thermal Batteries
This type of battery usually only poses a possible hazard to laboratory personnel when activated. The case temperature can be 200 Celsius or above under normal conditions and may reach 1000 Celsius under abnormal conditions.

5.2.5.3 Test Fixtures (Overheat Tests, Test Chambers)
Test operators should be aware that test fixtures such as heat blocks and environmental chambers may pose thermal hazards during all phases of the test (i.e., before, during, and after).

5.2.6 Mechanical

5.2.6.1 Flying Debris
Abuse tests may result in violent venting which may produce flying debris.

5.2.6.2 Use of Hydraulic Equipment
Some abuse tests use hydraulic equipment to crush or puncture cells or batteries. Under normal circumstances, test operators are not likely to be exposed to this mechanical hazard because it is operated remotely.

5.2.7 Other
Post-test units that have not vented (i.e., overcharged units) may be unstable. Provision for their destruction in place must be addressed in the test planning stages.
5.3 Controls

5.3.1 General
Test operators need to be aware of the hazards associated with the electrochemical storage system with which they are working. The electrochemistry of a unit under test, as well as any unusual hazards posed by that system shall be communicated to the test operator prior to testing. This includes Material Safety Data Sheets (MSDSs) from the manufacturer of the test unit.

A primary safety principle for handling cells and batteries is to avoid potential short circuits by working on insulating surfaces, using short and well insulated leads on the test unit, and keeping test unit leads disconnected from other circuitry until just before the test.

Since flames are frequently produced during the course of an abuse test, non-combustible materials should be used in test set-ups whenever possible.

5.3.2 Barriers
Testing shall be conducted in test bays or containment vessels designed for such purposes. A graded approach should be used in the selection of containment vessels. Small tests may be conducted in polycarbonate containers. Large scale tests may require containers constructed of non-flammable materials that can withstand strong mechanical impacts (i.e., concrete, and steel).

Containers that are intended to be pressure tight must have an approved Pressure Safety Data Package and be maintained according to the MN471000, Pressure Safety Manual.

Multiple levels of barriers (secondary containment, test bay door and blast door) are to be used when working with high capacity (> 10 Ampere-hour) systems.

5.3.3 Personnel Protective Equipment (PPE)
Safety glasses shall be worn when handling cells or batteries at room temperature.

Safety glasses, face-shield, and insulating gloves shall be worn when handling cells or batteries taken from an elevated temperature environment or cold storage.

High voltage hazards require electrical PPE. At a minimum, safety glasses and electrically rated gloves are required for live electrical work greater than 50 volts.

Test operators involved in post-test clean-up need to be aware of the hazards posed by the cell chemistry that has been tested, and use the appropriate PPE. The appropriate PPE for clean-up operations will be determined prior to testing by consulting with the Industrial Hygiene Program.

5.3.4 Engineering Controls

5.3.4.1 Local Exhaust Ventilation (LEV)
To mitigate toxic and irritant gas and particulate emissions, Local Exhaust Ventilation (LEV) systems, preferably with scrubbers, will be used.
5.3.4.2 Hold downs, Clamps, Other Securing Devices
Cells and batteries should be secured to the test apparatus or test bench to minimize the effects of flying debris. Securing the test unit also increases the probability of successful continuous video surveillance during and after the test.

5.3.4.3 Temperature Monitoring
Thermocouples are typically used to provide test data, but also serve as a means to determine when the test unit has cooled sufficiently to allow personnel re-entry to the test bay. The temperature-based criterion for re-entry is that the test unit is below 50 °Celsius. Other criteria (e.g., time) may be applied in parallel to control test bay personnel re-entry.

5.3.4.4 Remote Control of Test Instruments
Whenever possible, tests should be initiated by remote control as well as monitored remotely. Remote control can be as simple as an AC power circuit with a switch in a room outside of the test bay, or as complex as complete computer control over the initiation and termination of a test.

5.3.5 Signage
Written notice of abuse tests will be posted on the test bay door or at another nearby control point.

This notice can include the following type of information:
- the type of test,
- the cell chemistry,
- the duration of the test,
- the Point-of-Contact’s (POC) name, and
- the POC’s phone number.

5.3.6 Administrative and Procedural Controls
All testing shall be coordinated through the appropriate Department Manager or their designated Agent. The use of pre-planning checklists is a key part of the safety process and is highly encouraged. Test plans are developed for complex, large-scale test series.

All electrical work will be conducted in accordance with the Sandia Electrical Safety Manual (Corporate Process Requirement No: CPR400.1.1.28). Only properly trained, qualified personnel may perform live electrical work. Approach boundaries for shock protection and arc flash protection boundaries as described in Article 130 of National Fire Prevention Association (NFPA) 70E: Standard for Electrical Safety in the Workplace will be observed.

6.0 DEFINITIONS
Definitions for terms in this GP can be found at Sandia’s Internal Website in the MN47001 ES&EH Manuals Glossary.

7.0 PROCEDURE PROCESS
NOTE: The procedures presented in this Section are representative of the testing that is conducted at the time this GP was issued. Other test procedures may be developed, and documented referencing this GP.
Refer to the SAND99-0497 Electrochemical Storage System Abuse Test Procedure Manual and the specific abuse test sections within this manual for more details:

- Short Circuit Test, see Section 4.1,
- Overcharge Test, see Section 4.3,
- Crush Test, see Section 2.6,
- Over-Temperature Test, see Section 3.2, and
- Water Immersion Test, see Section 2.5.

**NOTE:** Each test unit will have photos taken before and after each test. During the test, video cameras will document changes to the UUT from at least two different angles.

**NOTE:** Safety steps and their hazards have been omitted because test articles (i.e., UUT) behave differently on a test-by-test basis. For particular hazards from a test article, refer to the Test Series Plan for more details.

### 7.1 Short Circuit Test

#### 7.1.1 Conditions

1. The UUT will be at room temperature and at 100% state of charge.
2. When practical, attach the UUT to some kind of solid non-flammable base (e.g., concrete base) for stabilization in the event of violent venting.
3. **BEFORE** conducting the short circuit test, measure the resistance of the relay and its associated circuitry, along with any external load resistor.
4. Place the UUT with the attached solid non-flammable base (e.g., concrete base) into a six-sided transparent plastic box, the use of secondary containment is often recommended to control the spread of particle contamination.
5. Apply the short circuit using a remote-controlled relay.
6. Apply the short circuit for one-hour.

#### 7.1.2 Measurements

**NOTE:** These measurements consist of at least one channel of thermocouple data, total UUT voltage, and the voltage drop across a current viewing resistor (CVR) to determine current.

1. Take electrical measurements at one millisecond intervals for the first 30 seconds of the test.
2. Take electrical measurements at one second intervals for the remainder of the test.
3. Analysis of gases and vapors emitted during the test may be performed depending on customer requirements.

### 7.2 Overcharge Tests

**NOTE:** The end of the overcharge test is often 200% State of Charge (SOC). DO NOT re-enter the test bay until the UUT has been discharged to a safe SOC (<50% SOC) or has been destroyed.
7.2.1 Conditions

1. The UUT will be at room temperature and at 100% state of charge.
2. When practical, attach the UUT to some kind of solid non-flammable base (e.g., concrete base) for stabilization in the event of violent venting.
3. Place the UUT with the attached solid non-flammable base (e.g., concrete base) into a six-sided transparent plastic box; the use of secondary containment is often recommended to control the spread of particle contamination.
4. Over-charge the UUT using a remote control power supply.

NOTE: Typical currents are 32 amperes and 1x the capacity of the UUT (C/1 rate).
5. Operate the power supply in a constant current mode with an upper voltage limit based on the specifications of the UUT.

CAUTION: Once the module is above 100% state of change (SOC), it is unsafe for laboratory personnel to enter the test bay.
6. Terminate the test once the UUT achieves a pre-determined end point (e.g., 200% SOC).

NOTE: Usually the test is terminated at 200% SOC. This can be changed at the discretion of the test owner.
7. To verify that the UUT is safe, appropriate safing measure are determined and set-up during pre-planning. This safing measure may include the following actions:
   - use a resistance load to discharge the UUT,
   - heat the UUT with electric heat tape or blankets until discharge, or
   - mechanically crush or puncture the UUT until discharge or destruction.
8. Use wires and equipment to control discharge of the UUT that DO NOT require re-entry into the test bay.

7.2.2 Measurements

NOTE: These measurements consist of at least one channel of thermocouple data, total UUT voltage, and the voltage drop across a CVR to determine current.
1. Take electrical measurements at one second intervals for the duration of the test.
2. Analysis of gases and vapors emitted during the test may be performed depending on customer requirements.

7.3 Crush Test

NOTE: The Abuse Lab operates three crush fixtures: 1) Big Blue, 2) Orion, and 3) Old Grey. Big Blue is utilized to crush larger objects (e.g., battery packs, and or modules) and operates in the vertical orientation. Orion is the nail test/penetration apparatus for either battery packs or larger single cells, and operates in the horizontal orientation. Old Grey can be used as a nail penetrator device or a regular crush fixture for single cell functions in a vertical direction.
NOTE: A UUT to be crushed or penetrated may need to be rigorously stabilized, and this issue must be addressed on a case-by-case basis. Specific details may be contained in a Test Plan if applicable.

NOTE: Crush fixtures are typically crushed vertically. The direction of applied pressure can be along each of three axes relative to the UUT. To make sure that a UUT does not move during a crush test, a specific fixture may be required. Refer to the Test Series Plan for details.

NOTE: The hydraulics are tested before each crush test to verify transducer signals and to initialize the ram displacement at the zero point.

7.3.1 Conditions

1. The UUT will be at room temperature and at 100% state of charge.
2. Place the UUT on a non-combustible surface.
3. Position the UUT so that one, 75 millimeter (mm) radius platen of the crush fixture will be in its center.
4. Crush the UUT until there is a 15% displacement of the UUT.
5. Hold this force on the UUT for five minutes.
   
   NOTE: The maximum force to be applied to the UUT will be limited to 1,000 times the UUT weight. This can be changed at discretion of the test owner.

6. Crush the UUT until there is a 50% displacement of the UUT, or force equal to a thousand times of the UUT’s weight is reached.
7. Hold this force on the UUT for five minutes.
8. The initial crush testing for the UUT is complete.

   NOTE: Voltage is monitored during the crush test. When the test is completed, the voltage does not always drop to a zero voltage state.

7.3.2 Additional Testing

9. Continue to crush the UUT past the displacement level of the UUT.

   NOTE: The UUT is crushed until it is destroyed or until it catches fire.

   NOTE: If the crush fixture cannot apply any more force to the UUT, this would complete the test for the UUT.

10. The crush testing for the UUT is complete.

7.3.3 Measurements

   NOTE: These measurements consist of at least one channel of thermocouple data, and total UUT voltage.

1. Take electrical measurements at one second intervals for the duration of the test.
2. Take position transducer and load cell voltages to determine displacement and applied force.
7.4 Over-Temperature Test

NOTE: The UUT can fail due to a multitude of causes during an over-temperature test. The general re-entry criteria to the testing bay is that the temperature of the UUT is less than 50° C. Refer to the Test Series Plan for specific re-entry guidelines.

7.4.1 Conditions
1. The UUT will be at room temperature and at 100% state of charge.
2. Place the UUT into a six-sided transparent plastic box to control the spread of particle contamination.

NOTE: A spark source for ignition of vent gases may be used.

NOTE: The over-temperature apparatus may operate in two modes: the Continuous Heat Ramp, or the Step-Wise mode. Refer to the Continuous Heat Ramp Mode Section, or the Step-Wise Mode Section below.

7.4.1.1 Continuous Heat Ramp Mode

NOTE: The heating rate is fixed; a typical heating rate is five degrees Celsius per minute. The maximum temperature of the heating apparatus is 250° Celsius.

3. Place the UUT into the heating apparatus.
4. Heat the UUT in the heating apparatus until the upper temperature limit is reached or until the UUT is destroyed.

7.4.1.2 Step-Wise Mode
3. Place the UUT into the heating apparatus.
4. Heat the UUT to the first temperature step.
5. Set the heating rate to zero and stay at the constant temperature until the UUT has equilibrated.

NOTE: The time that the UUT is held at a constant temperature is based on the mass of the UUT. The UUT must be evenly heated, this can take approximately 30-120 minutes to complete.
6. Set the heating rate to a positive value and heat the UUT to the next temperature step.

NOTE: The temperature steps are usually in ten degree increments.
7. Set the heating rate to zero and stay at the constant temperature until the UUT has equilibrated.
8. Repeat this heat and hold process until the UUT temperature reaches 250° Celsius, or the UUT is destroyed.
7.4.2 Measurements

NOTE: These measurements consist of at least two channels of thermocouple data, and total UUT voltage.

Take electrical measurements at one second intervals for the duration of the test.

7.5 Water Immersion Test

7.5.1 Conditions
1. The UUT will be at room temperature and at 100% state of charge.
2. Place the UUT in a transparent plastic tank to allow complete coverage of the UUT with simulated sea water.
3. Add simulated sea water (i.e., 35.0 g NaCl/1000 g water) to the plastic tank from a remotely actuated valve until the UUT is completely submerged in sea water.
4. Observe the UUT for at least one hour, or the amount of time determined by the test owner.

7.5.2 Measurements

NOTE: These measurements consist of at least one channel of thermocouple data, and total UUT voltage.

Take electrical measurements at one second intervals for the duration of the test.

7.6 Post Procedure

NOTE: A floor cleaning must be performed after every major event and on a quarterly schedule regardless of lab activity level.

7.7 Lab 1105 Cleaning Procedures

7.7.1 Definitions

Deconned: Means to make as clean as possible, but never again to be acceptable as sterile. This can include: the material, the equipment, and the area where the test was conducted.

Sanitize: To make sanitary, as by cleaning, disinfecting, or sterilizing.

State of Health (SOH): Condition of the test unit. This can consist of conditions and parameters used to indicate the health of a battery like: voltage, a visual inspection, temperature, and/or other possible inspections.

Sterile: Free from live bacteria or other microorganisms.

Test Unit (TU): This can be a battery, cell, module, capacitor, energy storage unit, or any other object tested in the Safety/Abuse Lab environment.

Test Bay: Is a particular area within Building 905 that consists of rooms 1105C through 1105H.
7.7.2 Entering Test Bay Criteria
Determine if the test bay is safe for entry and subsequent cleaning:
1. Based on the magnitude of the test, waiting over night is highly recommended before entry into a post-test test bay scenario. Other criteria follow.
   - Unit Under Test (UUT) unit must be less than 100 degrees (°) Celsius (C) before blast door can be opened (if applicable).
   - UUT must be less than 50 °C before test bay door can be opened
   - UUT may need further safeing procedures before entry into the test bay and subsequent cleaning can take place.
     - The ventilation time interval will be at two hours based on air exchanges as posted on door, unless the UUT is actively smoldering, smoking, venting, large electrolyte release or some other hazardous activity; and thereafter on an as needed basis to be determined by qualified personnel.

2. Ascertain UUT state of health (SOH; see Section 7.7.1 Definitions).

   NOTE: Voltage is one proxy condition to indicate the test units SOH.

   NOTE: If UUT voltage is greater than 50 volts, refer to: Power Sources Technology Group (PSTG) Generic Procedure (GP) For Working Over 50 Volts (PSTG-GP-HIVOLT-1).

3. When the entering test bay criteria has been met, go to Section 7.7.3.1 Authorized Workers.

7.7.3.1 Authorized Workers
Authorized Workers are responsible for the following:

1. Conducting laboratory operations in accordance with this GP, OSHA regulations, Sandia requirements, the SNL ES&H Manual, DOE Order 10CFR 851, NFPA 70E, ANSI/NFPA-70, (National Electrical Code), and DOE and SNL directives.

2. Following Working Over 50 Volts (PSTG-GP-HIVOLT-1) when preparing to do energized work over 50V, or at other voltage and current combinations having power or energy at levels associated with electrical shock, burn, or arc flash.

3. If UUT is less than 50 volts, further safeing my not be necessary.

4. If further safeing is deemed necessary, the UUT may be discharged by means of an appropriate resistor bank or by means of an electronic load, refer to Section 7.2.1 Conditions of this GP for further safeing procedures. A mechanical crushing device may be used to further safe/destroy larger test units, refer to Section 7.3 Crush Test of this GP for further instructions regarding crush procedures.

5. Verify voltage is at zero or insignificant.
6. UUT is validated as being placed in a safe condition.

7. Once the Authorized Worker has met the following criteria, they may enter the test bay and proceed with cleaning.

7.7.4 Personal Protection Equipment (PPE) Requirements

Batteries, capacitors, or other such devices containing nickel oxides that are tested in the Abuse Lab Room 1105, which vent or are otherwise destroyed, require the following PPE:

1. Full Face Respirator with a minimum P100 filter,
2. Tyvek coveralls,
3. Nitrile or latex gloves,
4. Booties, and
5. Head covering optional.

NOTE: See the specific PPE called out per each specific event listed below.

7.7.4.1 Clean-Up of Vented 18650 Batteries Containing NiOx

The required PPE is as follows:

1. Full-face respirator with P100 filters,
2. Tyvek coveralls,
3. Double nitrile/latex gloves,
4. Booties, and
5. Voluntary use of head covering.

NOTE: If the event happened in a Plexiglass containment, PPE is not required until the containment is opened.
7.7.4.2 Clean-Up of Vented 18650 Batteries NOT Containing NiOx
The required PPE is as follows:
1. Lab coat,
2. Double nitrile-latex gloves,
3. Booties, and
4. Safety glasses with side-shields.

7.7.4.3 Painting of Containment Rooms
The required PPE is as follows:
1. Tyvek coveralls,
2. Nitrile-latex gloves,
3. Booties, and
4. Safety glasses with side-shields.

The required Engineering Controls are as follows:
1. The ventilation system is on and working and functional during all painting.
2. Low VOC paint is used to paint the contaminated rooms.

7.7.4.4 Pressure Washing Containment Rooms
The required PPE is as follows:
1. Full-face respirator with P100 filters,
2. Tyvek coveralls,
3. Double nitrile-latex gloves,
4. Booties, and
5. Voluntary use of head covering.

7.7.4.5 Portable Hand Tools and Soldering Tools
The required PPE is as follows:
1. Safety glasses with side shields.

7.7.4.6 Apparatus Clean-Up in Fume Hood, Room 1105
The required PPE is as follows:
1. Nitrile or latex gloves, and
2. Safety glasses with side shields.
7.7.5 Cleaning Procedures
1. Refer to Section 7.7.3 Entering Test Bay Criteria and verify that this procedure has been completed before safely entering the Test Bay.
2. Refer to Section 7.7.4 Personal Protection Equipment (PPE) Requirements and verify that all laboratory personal are wearing the proper PPE for the specific cleaning activity before entering any Test Bay.
3. Vacuum the Test Bay and equipment with a HEPA vacuum (when possible).
4. Refer to Section 7.7.4.4 Pressure Washing Containment Rooms and verify that all laboratory personal are wearing the proper PPE for pressure washing before entering any Test Bay.
5. Dispose of waste water from pressure washing down sanitary sewer system as per the Waste Water Discharge Permit located in the specific Laboratory Operations Notebook (LON), or refer to the PSTG Document Control Database and find the Waste Water Discharge Permit for 905/1105, and the Waste Water Discharge Permit for 905/1105B.
6. Wet wiping and wet mopping may be utilized in lieu of, or in addition to pressure washing.
7. Dispose of spent batteries, cells, capacitors, other parts, and all other debris as hazardous waste according to the ES&H Manual, Chapter 19A – Hazardous Waste Management at SNL/NM.
8. Test equipment not destroyed may be further decontaminated for recommissioning by wet wiping with alcohol or deionized water wet-wipes.
9. Test Bays may be painted if deemed necessary, refer to Section 7.7.4.3 Painting of Containment Rooms for the proper Personal Protection Equipment (PPE) Requirements and verify that all laboratory personal are wearing the proper PPE.
10. Respirators may be washed off. The rinsate may be disposed of down the sanitary sewer system per the Waste Water Discharge Permit for 905/1105.

7.7.6 Contaminated Test Equipment
It is acceptable to re-use test equipment that has been contaminated and is sufficiently “decontaminated” with the proper cleaning procedures (as outlined in Section 7.7.5), but the equipment should be stored behind the blast door threshold.

NOTE: For Lab 1105 (in Building 905) the goal is not to sanitize the test bays or lab spaces, but to manage the hazards. For example, exposure to nickel oxide is a hazard that shall be minimized through administrative and engineering controls.

7.7.7 Hazardous Waste
All hazardous waste will be disposed of according to Hazardous Waste and Environmental Management guidelines as discussed in the ES&H Manual, Chapter 19A – Hazardous Waste Management at SNL/NM, or contact the Division ES&H Team for specific questions and details regarding storage and disposal issues.

Dispose of the following separately, because no other solid or liquid lab waste of any kind is to be packaged with battery waste:
• Batteries,
• Battery Packs, and
• Capacitors.

Cover the following items with non-conductive tape (electrical tape is acceptable) in preparation for disposal:
• Battery Terminals, and
• Capacitor Terminals.

NOTE: Some batteries may be eligible for recycling and should be discussed with the Division ES&H Team on a case-by-case basis.

8.0 ES&H REPORTING AND DOCUMENTATION

8.1 References
Article 130 of NFPA 70E: Standard for Electrical Safety in the Workplace.


PSTG- GP-HWWHC-1, Generic Handling and Working with Hazardous Chemicals.

PHS 9712737426-012 905/1105 Lithium Ambient Cell/Battery Test Lab, refer to the following link Section3 Training and Qualifications for instructions to gain access to the PHS system.

Required Reading for Building 905 Residents (see the ETG 2550 Webpage):
• ECF Emergency Preparedness and Management: Plan and Procedure (ETG-GP-EPMPP; see the 2550 ES&H Webpage, under ES&H Information),
• Explosives Technologies Group (ETG) Global Procedure (GP) for Facility Operations (ETG-GP-FACOPS; see the 2550 ES&H Webpage, under 2550 Technical Work Documents (TWDs),
• Building 905 Safety Video (see the 2550 ES&H Webpage, under Training),
• Work Planning and Control Process for Explosives Technologies Group (2550); see the 2550 ES&H Webpage under 2550 Technical Work Documents (TWDs), and
• Explosives Technologies Group (ETG) Global Procedure (GP) for Handling and Working with Hazardous Chemicals (ETG-GP-HWWHC).
8.2 Records
There are no records at this time.

8.3 Required Readings
Minimum Operational Performance Standard for Lithium Batteries; Radio Technical Commission for
Aeronautics (RTCA) Document DO-227, June 23, 1995. Refer to the following link for more details
http://www.rtea.org/downloads/DEC%202004%20-%202005-01-06.htm#_Toc92863951

Society of Automotive Engineers (SAE) Surface Vehicle Recommended Practice, Document J2464
MAR1999. Refer to the following link for more details http://www.sae.org/servlets/index, in the Search
SAE field; enter J2464 to retrieve this document.

Smallwood, February 1999, refer to the following link for more detail http://www.prod.sandia.gov/cgi-
bin/techlib/access-control.pl/1999/990497.pdf

9.0 WASTE MANAGEMENT
PSTG personnel should take measures to minimize the generation of hazardous waste from work with
hazardous chemicals.

PSTG personnel shall:
- Dispose of hazardous waste in accordance with MN471001, ES&H Manual, Section 19A -
  Hazardous Waste Management at SNL/NM.
- Contact the Environmental Protection and Waste Management Representatives on the Division
  2000 ES&H Team for additional guidance.

For more information, contact the Division 2000 ES&H Environmental Protection Representative.

9.1 Common Waste Steams
Refer to Management of Common Waste Steams for more information regarding waste steams.

9.1.1 Batteries
Refer to the Management of Common Waste Steams, and scroll to the Batteries section for more details.

9.1.2 Solder for Recycling
Refer to the Management of Common Waste Steams, and scroll to the Solder section for more details.

NOTE: Do not put the entire wipe or cotton swab in the Soldering for Recycling container. Only
place the piece that has solder or flux attached to it in the container.

9.2 Corporate and Center Waste Profiles
For the Corporate and Center Waste Profiles, refer to the following links for more details:
- Site Wide Waste Profiles, and
- Waste Profile Approval Notice.
9.2.1 Epoxies and/or Adhesives
Members of the Workforce may use the above waste profile only if the following is true:
- The epoxy is cured.
- The epoxy is used for its intended purpose(s), taking care not to allow them to become contaminated with other materials which may be RCRA regulated.
- Ingredients in the epoxy shall not contain any RCRA-regulated metals: Arsenic, Barium, Cadmium, Chromium, Lead, Mercury, Selenium, or Silver.
- Place all contaminated items in a clear plastic bag.
- Seal the bag and write the waste profile number on the bag.
- Deposit the bag in the regular trash.

Conductive epoxies are hazardous waste since they contain metals, such as silver. Use the Site Wide Waste Profiles and Waste Profile Approval Notice URLs, for additional information and requirements.

NOTE: Approval of this Waste Profile does not negate your responsibility of complying with other applicable Chapters/Sections of the ES&H Manual.

9.2.2 Oils and/or Greases
Members of the Workforce may use the above waste profile only if the following is true:
- The rags, wipes, gloves, PPE & containers, that have become contaminated with commercial lubricants (cutting fluids, lubrication oils or grease), have no free liquids.
- The rags, wipes, gloves, PPE & containers that have become contaminated with commercial lubricants were used for its intended purpose (lubrication), taking care not to allow them to become contaminated with other materials which may be RCRA regulated. This profile does not apply if these products are used as ingredients.
- Ingredients in the commercial lubricants shall not contain any RCRA-regulated metals: Arsenic, Barium, Cadmium, Chromium, Lead, Mercury, Selenium, or Silver.
- Place all contaminated items in a clear plastic bag.
- Seal the bag and write the waste profile number on the bag.
- Deposit the bag in the regular trash.

Use the Site Wide Waste Profiles and Waste Profile Approval Notice URLs, for additional information and requirements.

NOTE: Approval of this Waste Profile does not negate your responsibility of complying with other applicable Chapters/Sections of the ES&H Manual.

9.2.3 Solvents
Wipes or rags contaminated with solvents and used until dry may not be hazardous waste and, therefore, can be thrown in the regular trash.

NOTE: Contact the Division ES&H Team environmental protection representative to make this determination.
9.3 Flammable Hazardous Waste
Flammable hazardous waste shall be stored in a flammable cabinet or appropriate waste container.

NOTE: Cabinet and/or container should be marked “Contains Hazardous Waste.”
Saturated flammable solvent contaminated wipes shall be placed in a sealed bag and have a hazardous waste label on it with the solvent information. This bag shall be stored in a hazardous waste cabinet or container.

Flammable liquid solvent shall be in the original chemical container or appropriate waste container, with a hazardous waste label on it with the solvent information.

9.4 Non-Flammable Hazardous Waste
Non-flammable hazardous waste should be stored in a chemical cabinet or appropriate waste container. Cabinet and/or container should be marked “contains hazardous waste.”

Non-flammable contaminated wipes shall be placed in a sealed bag and have a hazardous waste label on it with the waste information.

Non-flammable liquid waste shall be in the original chemical container or appropriate waste container, with a hazardous waste label on it with the waste information.

9.5 Recycling at Sandia
Refer to Recycling at Sandia for more information.

9.6 Sharps
Refer to the Safe Disposal of Nonchemical Wastes section, and scroll to the Glass or Sharp Objects section.

9.7 Solder
Refer to the Management of Common Waste Streams, and scroll to the Solder section for more details.

9.8 Waste Description and Disposal Request (WDDR)
Refer to the WDDR for more details. This electronic form is currently the only method available to request hazardous waste pick-up.

9.9 Waste Water Permit
Refer to the Waste Water Permit for more details for any liquid discharges, such as water rinse, or liquid from a sonic cleaner, must have a permit.

10.0 GENERAL INFORMATION OR OFF-NORMAL PROCEDURES
- Carbon dioxide fire extinguishers are available for equipment fires.
- Specialized “Lith-X” fire extinguishers are available for lithium metal fires. Lith-X fire extinguishers are not to be used on any other type of fire.
- Eye wash and safety shower facilities are available in the event of chemical exposure.
18. Appendix 4 ATEX

Hawker

Instructions for use

ATEX CELLS

EnerSys Power/Full Solutions
Instructions for use Hawker® ATEX CELLS

EC Declaration of Compliance
Ex cells for vehicle drive batteries

EnerSys® hereby confirms that these cells (see below description with serial number and number of the EC type examination certificate, SIRA certification service, notified body number 0518) comply with the provisions of Directive 94 / 9 / EC Devices and Protection Systems for Intended Use in Areas at the Risk of Explosion. The fundamental health and safety requirements are fulfilled by the compliance with the norms: IEC 60079-0, IEC 60079-7, IEC 61241-0 and IEC 61241-1.

Signed ____________________ (ATEX/IECEx authorised manager)

Serial No.: ______________________

Ex cell type: ______________________

EC type examination certificate: SIRA 01 ATEX 30 ___ U
IECEx Certificate of conformity: IECEx SIR 07.006 ___ U

This declaration certifies compliance with the above directives, but does not contain an assurance of properties within the legal meaning. The safety notes of the product documentation supplied must be observed.

Instructions for use

1. Introduction
2. Safety notes
3. Identification and area of use
4. Mounting
5. Commissioning
6. Operation and charging
7. Maintenance and repairs
8. Normative notes to be observed

1. Introduction
These instructions for use contain notes for the mounting and the safe operation of the Ex cells in vehicle batteries. The Ex cells are components within the meaning of the Directive 94/9/EC (ATEX/IECEx). For the production and circulation as a battery, further requirements of the Directive must be fulfilled, which are not covered by the component certification of the cells and are not the content of these instructions for use.

2. Safety notes
The use of various cell models inside one battery is not permissible. This also applies for design sizes of the same type, executions and or capacities. The Ex cells fulfil the safety requirements in the event of intended use.

The Special Terms and Conditions for Safe Application in accordance with EC Type Examination Certificate Number: SIRA 01ATEX3016U, SIRA 01ATEX3019U, SIRA 01ATEX3087U, SIRA 01ATEX3090U and IECEx Certificate of Conformity IECEx SIR07.0061U, IECEx SIR07.0062U, IECEx SIR07.0063U, IECEx SIR07.0064U must be fulfilled.

If the cells are built together as batteries, as a minimum the conditions set out in EN 60079-7:2007 must be observed:
5.7.1 General information
5.7.1.2 Battery container
5.7.1.3 Cells
5.7.1.4 Connector
5.7.4 Charging of cells
5.7.5 Discharging of cells
5.7.6 Inclusion of other ignition protection types
5.7.7 Switching off and transport
6.6.1 Insulation resistance
6.6.3 Shock test
6.6.4 Ventilation
3. Labelling and area of application

These instructions for use applies for cells in accordance with EC Type Examination Certificate and IECEx Certificate of Conformity Number:

**IECEx SIRO7.0061U - SIRA 01ATEX016U Type B Lead Acid Motive Power cells (PzB, PzMB)**

**IECEx SIRO7.0062U - SIRA 01ATEX019U Type D Lead Acid Motive Power cells (PzB, PzM)**

**IECEx SIRO7.0063U - SIRA 01ATEX087U Type B Lead Acid Motive Power cells (PzV)**

**IECEx SIRO7.0064U - SIRA 01ATEX090U Type D Lead Acid Motive Power cells (PzV)**

The U character behind the certificate number indicates that this certificate must not be mistaken for a certificate intended for a device or protective system. This component certificate may only be used as the basis for the certification of a device or protective system. The certificates indicated therefore only refer to the conception and type testing of the specified component cells in compliance with Directive 94/9/EC. To produce and circulate the cells, the manufacturer must fulfill other requirements of the Directive, which are not covered by these certificates. This gives rise to the necessity that a final installation of operation must have fulfilled the requirements of an ATEX and/or IECEx-certified business and able persons.

**II 2G Ex d I I II 2D Ex TD A21 IP65**

**I M2 Ex e I I**

**Ex e I**

**Ex TD A21 T80°C IP65**

**Ex e I**

These Ex cells may be used in the following areas only:

- **Group I category M2**
- **Group II category 2 – zone 1 and 21**
- **Group II category 3 – zone 2 and 22**

Manufacturers in accordance with the Directive:

EnerSys® SARL, ZI Est, rue A.Fleming, 62033 Arras, France

4. Mounting

When mounting, the cells must always be lifted by the two posts simultaneously with insulated hanging equipment.

Ex cells may only be connected in a row. During mounting, the correct polarity must be observed. For the electrical wiring, only components authorised by EnerSys may be used. Optional aquatic system and electrolyte circulation must be wired in accordance with EnerSys requirements, e.g., “comply with the electrical wiring”. Request corresponding information, if required.

**Note:** The connection technology, aquatic system and electrolyte circulation are part of the cell component test and approval and must therefore not be modified.

All components should be obtained from EnerSys.

End connections and intermediate take-offs may also be carried out with approved components. New, unused screws M 10 x 20 with the prescribed screw lock must be used. Torque 26 ± 2 Nm! It is absolutely mandatory to ensure correct contacting and thread engagement.

The connections must be tightened to the lid. To ensure the IP protection, a lid without any hole must be used.

When using connector caps with a hole (only on the negative pole for voltage measurement), the connector chamber must be filled with grease Berutox M 21 KN. Battery or cell periphery with electronic components cannot be used with an ATEX/IECEx battery.

No level indicator must be mounted on PzB-type Ex cells (no Ex approval as a component) and no Easy Control must be mounted on PzV-type Ex cells (also no Ex approval as component).

Only Ex cells of the same type, size and capacity may be wired together.

The Ex cells must be installed firmly in the battery container. Possible clearances must be filled with stable acidproof filling material. The use of foam-like filling material is not permissible.

5. Commissioning

For the commissioning of the ex cells, the instruction for use of Hawker® perfect plus, Hawker Water Less® and Hawker evolution must be observed (see www.enersys-hawker.com). In addition, the instruction for use of the device or protective system, in which these Ex cells are integrated, applies. Lead-acid cells, in particular flooded cells, can only be stored to a limited extent without regular recharging. New cells are fully charged on delivery. Hawker perfect plus and Water Less cells must be recharged every 6 weeks at the latest. Hawker evolution cells at the latest within 3 months. When reconstraining batteries, only cells of the same charge and same charging conditions should be wired together. The open-circuit voltage of the cells should be at least 2.13 V / cell in fully charged condition.

6. Operation and charging

For charging and operation, the instruction for use of the normal battery design can be used (see www.enersys-hawker.com). In addition, the instruction for use of the device or protective system, in which these Ex cells are integrated, applies.

**Identification values of the Ex cells**

- **Maximum permissible nominal voltage in battery system:** 500 V
- **Ambient temperature range:** -20 to 40 °C
- **Maximum permissible temperature of the battery cells:** 55 °C
- **Rated current:** 6.2 $C_p$

<table>
<thead>
<tr>
<th>Nominal capacity $C_p$</th>
<th>Connection cross-section</th>
<th>Rated current</th>
</tr>
</thead>
<tbody>
<tr>
<td>up to 200 Ah</td>
<td>16 mm²</td>
<td>40 A</td>
</tr>
<tr>
<td>up to 320 Ah</td>
<td>25 mm²</td>
<td>64 A</td>
</tr>
<tr>
<td>up to 480 Ah</td>
<td>35 mm²</td>
<td>96 A</td>
</tr>
<tr>
<td>up to 640 Ah</td>
<td>50 mm²</td>
<td>128 A</td>
</tr>
<tr>
<td>up to 900 Ah</td>
<td>70 mm²</td>
<td>180 A</td>
</tr>
<tr>
<td>up to 1550 Ah</td>
<td>95 mm²</td>
<td>310 A</td>
</tr>
</tbody>
</table>

Only approved charging devices and charging characteristics may be used. When integrating charging devices in the vehicle and when charging the batteries in areas at risk of explosion, it is mandatory that the charging system is integrated in the compliance assessment (see EN 60079-7, Item 5.7.4). Batteries that have reached a higher temperature than 40°C by the end of charging must be cooled down to 40°C before use in areas at risk of explosion.

7. Maintenance and repairs

Only approved EnerSys original spare parts and components may be used. Only Ex cells of a manufacturer with the same type, size and capacity may be used as a replacement.

In addition, the instruction for use of the device or protective system, in which these Ex cells are integrated, applies. To conduct this work, the rules of EN 60079-19 must be observed. The work carried out must be documented and the device or protective system must be identified with a corresponding R label.
## 8. Normative notes to be observed (extract)

<table>
<thead>
<tr>
<th>Directive</th>
<th>Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Directive</td>
<td>94/9/EC</td>
</tr>
<tr>
<td>DIN EN 1127-1</td>
<td>Explosive atmospheres - Explosion prevention and protection - Part 1: Basic concepts and methodology</td>
</tr>
<tr>
<td>DIN EN 1175-1</td>
<td>Safety of industrial trucks – Electrical requirements Part 1: General requirements for battery powered trucks</td>
</tr>
<tr>
<td>DIN EN 60079-0</td>
<td>Explosive atmospheres – Part 0: Equipment - General requirements.</td>
</tr>
<tr>
<td>DIN EN 60079-7</td>
<td>Explosive atmospheres – Part 7: Equipment protection by increased safety “e”</td>
</tr>
<tr>
<td>DIN EN 60079-19</td>
<td>Explosive atmospheres – Part 18: Equipment repair, overhaul and reclamation</td>
</tr>
<tr>
<td>DIN EN 60079-19</td>
<td>Correction 1</td>
</tr>
<tr>
<td>DIN EN 61241-0</td>
<td>Electrical apparatus for use in the presence of combustible dust – Part 0: General requirements</td>
</tr>
<tr>
<td>DIN EN 61241-1</td>
<td>Electrical apparatus for use in the presence of combustible dust – Part 1: Type of protection “tD”</td>
</tr>
<tr>
<td>DIN EN 50272-3</td>
<td>Safety requirements for secondary batteries and battery installations - Part 3: Traction batteries</td>
</tr>
</tbody>
</table>
Wherever you do business, EnerSys® can support you with motive power energy. The Husk® branded battery range, matched chargers and systems provide trouble free performance under the most demanding service conditions. Our strategically located manufacturing plants are efficient and responsive with a culture of continuous improvement and added value for our business partners.

EnerSys has an enviable position in technology leadership and with significant investment in research and development we intend to stay at the leading edge in product innovation. The recently developed energy solutions: Water Less® 20™ and Hawker® XFC™ batteries, Lifetech and Lifespeed IQ™ HF chargers. have defined new benefits for our customers: faster discharge, more machine availability, lower operating and investment costs, reduced carbon footprint. Our team of development engineers is driven by the desire to build the best energy solutions and works closely with our customers and suppliers to identify development opportunities. Our bias for rapid innovation means we get new products to market fast.

EnerSys’s integrated sales and service network is dedicated to providing our customers with the best solutions and after sales support for their business. Whether you require 1 battery or a complete fleet of batteries, chargers, a battery handling system and a state of the art fleet management system, you can count on us. EnerSys is the world’s largest industrial battery manufacturer and we are dedicated to being the best.

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Implementation of ATEX Guidelines

Temperature and Climatic Test Chambers
for Usage under Conditions Carrying a Risk of Fire and Explosion
What are ATEX guidelines?

Introduction

ATEX (French abbreviation for ‘Atmosphere Explosive’) is a European guideline ensuring the safe operation of industrial systems in explosion sensitive environments or under conditions carrying a risk of explosion.

Two EU guidelines were released to execute these tasks - 99/92/EG and 94/9/EG. Since July 1st, 2003 these guidelines are binding. The installation of explosion-proved systems not complying with these guidelines will no longer be permitted.

The guideline 99/92/EG describes the duties of the system user whereas the 94/9/EG lays down the duties of the system manufacturer.

The prime duty of the system user is the assessment of potential danger as well as the classification of potential danger within the system - so-called zones.

The system manufacturer has to carry out the classification and labeling of the systems according to the risk of igniting potentially explosive mixtures - so-called system categories. This duty links the system manufacturer with the system user.

Duties of the system user ...

According to operational safety standards the system user has to carry out the following duties:

1. Doing a danger assessment

The user has to do a danger assessment of the systems requiring supervision as well as the working appliances. The zones of explosion sensitive areas in the systems have to be determined. The identification of all existing materials as well as possible electrical and also non-electrical ignition sources and their assessment with regard to the risk of explosion is of highest importance.

Classification into zones

The assignment of the explosion sensitive areas into zones is for fixing and determination of the safety requirement and protection systems for the chambers. The respective zone determines the category according to which the chambers and components have to be designed and tested.

Definition of zones

Zone 0:
Area in which the presence of an explosive atmosphere as a mixture of flammable substances in the form of gas, steam or mist with air is permanent or long-term or frequent.

Zone 1:
Area in which explosive atmosphere as a mixture of flammable substances in the form of gas, steam or mist with air during normal operation is expected occasionally.

Zone 2:
Area in which during normal operation an explosive atmosphere as a mixture of flammable substances in the form of gas, steam or mist with air is not expected. However, if it still occurs, then for a short period of time only.

2. Compiling documentation for explosion protection

According to the individual dangers, the system user or the system manufacturer has to implement suitable explosion safety measures.

A plan has to be drawn up for the necessary safety measures for the used electronic and non-electronic accessories and has to be put down in the prescribed explosion safety document.
... and how are they put in to practice?

Duties of the system manufacturer...

**Classification into system categories**

According to guideline 94/9/EG Vötsch temperature and climatic test cabinets fall into the system group II. This group is divided into 3 categories:

**Category 1**

comprises systems which are designed to be operated in accordance with the characteristic values indicated by the manufacturer and guarantee a very high degree of safety.

Systems of this category have to guarantee the necessary degree of safety even during rarely occurring system failures and therefore contain explosion safety precautions. In the event of a technical safety precaution failure, at least a second independent technical safety precaution guarantees the required safety. The required safety is even guaranteed if two independent faults should occur.

**Category 2**

comprises systems which are designed to be operated in accordance with the characteristic values indicated by the manufacturer and guarantee a high degree of safety.

The technical explosion safety measures of this category guarantee the required degree of safety even during frequent system failures or errors which are usually to be expected.

**Category 3**

comprises systems which are designed to be operated in accordance with the characteristic values indicated by the manufacturer and guarantee a normal degree of safety.

Systems of this category are designed for use in areas in which an explosive atmosphere by gases, steam, mist or raised dust is not to be expected. However, in case it is, then temporarily and for a short period of time only.

**Additional notes:**

Classification into system category 2 does require an individual auditing of each system by a nominated body, e.g. TUEV for electric devices.

For a classification into system category 3 the necessary safety precautions can be selected by the system manufacturer on the basis of the documents provided by the customer as well as in conjunction with the safety department of the system user. An auditing by a nominated body (e.g. TUEV) is not explicitly required.

Temperature classes and explosion groups of gases and vapours

<table>
<thead>
<tr>
<th>Temperature Class</th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>T4</th>
<th>T5</th>
<th>T6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ignition Temperature</td>
<td>&gt; 450 °C</td>
<td>&gt; 300 - 450 °C</td>
<td>&gt; 200 - 300 °C</td>
<td>&gt; 135 - 200 °C</td>
<td>&gt; 100 - 135 °C</td>
<td>&gt; 85 - 100 °C</td>
</tr>
<tr>
<td>Explosion Group</td>
<td>Examples of Substances</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IA (ignition energy &gt; 180 µJ)</td>
<td>Acetone, Dimethyl Ammonium, Benzene, Acetic acid, Methane, Propane, Toluene, Methanol</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>n-Butane, n-Butyle alcohol, Natural gas, Vinylchloride</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Benzine, Diesel, Fuel oil, n-Hexane</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acetalddehyde</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IB (ignition energy 60 ... 180 µJ)</td>
<td>Cyrene hydrogen, Ethylene, Isoprene, Ethyl alcohol</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydrogen sulphide</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ether</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RC (ignition energy &lt;60 µJ)</td>
<td>Hydrogen, Acetylene</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon disulphide</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>
Explosion and fire hazard in regard to temperature and climatic test chambers

A danger can be present, when flammable substances are brought together with the device under test within or in the vicinity of the chamber. A flammable or explosive atmosphere (i.e. the test space or ambient atmosphere) can be created when these substances are released into the atmosphere to a certain concentration (lower explosion limit).

Critical components and areas in the test space:

- hot surfaces of resistance heaters or heat exchangers
- hot surfaces of light bulbs
- sparks at fan blades in case of a mechanical fault
- electrical sparks at faulty sensors
- hot surfaces of door heaters

These ignition sources can cause a deflagration, fire or explosion.

For overpressure systems (e.g. hydraulics) it has to be noted that aerosols or mists escaping from leakage points can be flammable (independent of the flash point) while getting in contact with hot surfaces.

The contact with hot surfaces is achieved when the pressurized aerosol is directly getting in touch with the corresponding parts or the diffusion with the test space air is carried to the hot surface.
Formation of a fire and explosion hazard

In general flammable mixtures are:

• gas-air mixtures
• aerosol-mist-air mixtures
• dust-air mixtures

The formation of these mixtures can be initiated by a fault in the customer's system which can be unwanted or rather deliberate by a constituent of a test.

A mixture is explosive if the concentration is within certain substance-specific limits.

These limits are designated as lower explosion limit and upper explosion limit and are indicated in corresponding charts.

A present fire or explosion hazard requires protective measures taken at the chamber and/or installation site depending on the danger level.

General protective measures

Top priority of the explosion protection is the primary explosion protection. The secondary explosion protection is only applied if sufficient safety cannot be guaranteed by the primary explosion protection or if the primary explosion protection cannot be applied. The tertiary explosion protection is only applied if both the primary and the secondary explosion protection cannot be applied demonstrably.

Classification of protective measures

Integrate Explosion Protection

1 Primary
- Preventing the formation of dangerous explosive atmospheres
- Avoidance of flammable substances. Inertisation. Limited concentration by natural or unforced ventilation

2 Secondary
- Preventing the ignition of explosive atmospheres
- Ignition protection measures i.e. avoidance of ignition sources and critical temperatures

3 Tertiary
- Reduce the consequences of an explosion to a harmless limit
- Burst panels, Relief flaps, Shut off flaps
Chamber specific implementation ...

1. Possible designs for system category 3 (zone 2)

1.1 Design with primary explosion protection

Nitrogen inertisation type SN

- inertisation with nitrogen with large and small cleansing amount
- supervision of the cleansing amount
- with door lock and
- key switch

Applicable to temperature test chambers of series VT, VLM, VTS, VTV.

Not applicable to tests with defined climatic conditions.

Possible application:
Tests with diesel fuel, brake fluids and hydraulic oils with systems under pressure.

1.2 Design with secondary explosion protection

Surface temperature limitation and supervision of resistance heaters (1) in combination with the following additional measures

- spark-safe fan (3)
- supervision of the fan motor (4)
- exterior lighting for design with observation window (5)

Applicable to temperature test chambers of series VT, VLM, VTS, VTV.

Application limits are tests with high heating rates (> 5 K/min).

Possible application:
Tests with brake fluids or hydraulic oils with systems under pressure.

Important:
Testing temperature has to be lower than flash point temperature of medium.
2. Possible designs for system category 2 (zone 1)

2.1 Design with primary explosion protection

Nitrogen inertisation with oxygen measurement type RO

- large and small cleansing amount
- control of nitrogen concentration
- heater temperature supervision
- supervision of fan
- door lock

Applicable to temperature test chambers of series VTS, VTV.

Not applicable to tests with defined climatic conditions.

Possible application:
Tests with gasoline, tests with ignition sources in the test space (occasional ignition sources in case of a malfunction).
2.2 Design with secondary explosion protection

Type approved systems with explosion protected test space

Available are temperature and climatic test cabinets of sizes 480, 800 and 1300 l.

The systems are approved for use up to temperature class T3 and explosion group IIB and fulfill the requirements of category 2 and 3.

Designation of the systems:
VT/VC ....II 2G Ex IIB T3

Labeling and certifications for systems in conformity with ATEX

- Type plate with model designation and CE mark
- CE Declaration of Conformity with extension for design according to explosion protection guideline 94/9/EG and filing of the following documentation:
  - factory-provided documentation for system category 3
  - type test certificate (e.g. ex-test cabinets) with test number

Project related engineering work

Vötsch Industrietechnik offers the following project related engineering work:

- support in safety and risk examination
- designing and drafting of safety installations
- close contact to nominated bodies
- experience and know-how

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www.v-it.com / www.voetsch.info

Nr. VIT-E 9/4 0C 11.05 VN - VIT

www.ckd-temperatur-feuchte.de
Li-Ion Batteries

Possible Safety Equipments

CO gas detection (6)
Pressure release flap (3)
Customer air exhaust
Door lock (1)
Optic and acoustic alarm (2)
Burst disc with release signal (8)
Inner container pressure resistant up to 80 mbar (8)
Installation room on site

CO₂ gas bottles (7)
O₂ gas measuring (5)
N₂/permanent inertisation (4)
Flushing (cooling) device (7)
Temperature sensor (6)

Test Chamber
with Safety Device

Battery Management and Test System
E-Mobility

Project Example: 2 x VT 4021/S

- Testing Cells and Modules
- Double cabinet in compact design
- Each test space 210 l
- Independent temperature control for each test space
- Temperature range: -40 °C to +180 °C
- Average temperature change rate according to IEC:
  - Heating: approx. 2.5 K/min
  - Cooling: approx. 3.1 K/min
- Heat compensation: max. 1000 W
- Possibility for incl. Kratzer battery test system
- Safety equipments for each test space up to Hazard level 0(7)
  - Door lock electrical and mechanical
  - Pressure release flap (Hot gas up to 200 l/s)
  - N2-permanent inertisation flow rate and pressure controlled
  - Pressure monitored
  - Interfaces for communication with the battery management and with the building monitoring system (e.g. Ethernet, RS-232/485, USB, Digital/I/O)

Project Example: WT 1170/70/D-S

- Testing Li-Ion Batteries
- Vacuum test cabinet
- Test space 1170 l
- Temperature range: -70 °C to +100 °C
- Average temperature rates of change with 100 kg test specimens, (at atmospheric pressure) measured in the supply
  - Heating: approx. 5.0 K/min in the range from -70 °C to +100 °C
  - Cooling: approx. 5.0 K/min in the range from +100 °C to -30°C
- Pressure range: atmospheric pressure to 100 mbar
- Safety equipments
  - Door lock electrical and mechanical
  - Optic and acoustic alarm
  - N2-permanent inertisation
  - O2 gas measuring
# Electrical Energy Storage Device

## Risk Evaluation Check List

**Customer:**  
**Project/Order:**

<table>
<thead>
<tr>
<th>Issued by:</th>
<th>Date:</th>
<th>Signature:</th>
</tr>
</thead>
</table>

### 1. Type of energy storage

(Energy content [Wh] or Capacity [Ah] at a Voltage of ____ Volt)

- [ ] Li-Ionen
- [ ] Supercap
- [ ] Metal Hydride
- [ ] Lead-acid

<table>
<thead>
<tr>
<th>Cells</th>
<th>Number of cells: ____________</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modules</td>
<td>Number of cells for each module: ____________</td>
</tr>
</tbody>
</table>

Battery system with BMS  
Number of cells for each battery: ____________

Dimensions / Weight: ____________________________________________________________

---

### 2. Type of Test

- [ ] Temperature  
- [ ] Climate  
- [ ] Vibration  

- without load and unloaded cycles  
- with load and unloaded cycles  
- Safety tests  
- Characterisation, durability, reliability  
- Test is conducted in limit range  
- Test is conducted within safe limits

Short description, if possible with drawing

---

Revision: 3  
Date: Checkliste 1 Energiespeicher  
Ersteller: Si  
Blatt: 1/3
3. Please indicate at what temperatures the tests are performed?

4. Exothermic Temperature
   - Exothermic temperature of the cell is: ...........°C
   - is not known

5. Risks to be expected (Hazard Level acc. to EUCAR)

<table>
<thead>
<tr>
<th>Level</th>
<th>Risks acc. to Hazard Level</th>
<th>W0</th>
<th>W1</th>
<th>W2</th>
<th>W3</th>
</tr>
</thead>
<tbody>
<tr>
<td>0,1,2</td>
<td>No safety critical error status</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
</tr>
<tr>
<td>3</td>
<td>Electrolyte disposal, &lt; UEG or not flammable</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>4</td>
<td>Gas disposal, &lt; UEG or not flammable</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>5</td>
<td>Fire, flame, direct from the energy storage</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td></td>
<td>Gas explosion due to external ignition (large quantity of flammable material is released, so after mixing with the test space air the lower (UEG) explosion limit is exceeded)</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>6</td>
<td>Breakage</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>7</td>
<td>Explosion of energy storage (Tests with W3 are not applicable for execution in a closed test chamber)</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>----</td>
</tr>
</tbody>
</table>

Other risks

- Disposal of hydrogen(H2)/oxygen(O2) by loading e.g. lead/acid and metal hydride battery
- External fire near the energy storage (e.g. cable fire)

6. What materials will be released?
   (Include safety data sheets if available) ☐ available
   ☐ flammable material   ☐ noxious material

Material / Quantity:
### 7. What quantity of gas will be released per time unit?
(Important indication for dimensioning of pressure compensation opening!)

\[ \text{.................. l/sec} \]

### 8. Safety device battery tester (customer provided)

- [ ] device to detect and monitor the charging/discharging condition is provided externally (by the customer)

Critical operational conditions of the electrical energy storage device are safely prevented by

- [ ] monitoring of the current (A) of each cells
- [ ] monitoring of the voltage (V) of each cells
- [ ] monitoring of the cell temperature – Number of measuring points: ...... QTY

### 9. Installation room
Where will the chamber be installed?

- [ ] in a special protected room with fire preventions
- [ ] in a laboratory to which only specially trained personnel will have access
- [ ] installation room described as follows:

### 10. Personnel access during tests

- [ ] In a side room with safe distance, to avoid personal injuries

(Conditions for Hazard Level > 4 )

### 11. Risks assessment

- [ ] additional safety devices required for test chamber
- [ ] no additional safety devices required for test chamber

The test does not generate hazards which would require additional safety devices for the test chamber.

### 12. Remarks
Proposals of safety equipments for tests with batteries

Schema of different safety concepts for battery testing

Safety equipments (options)
(1) electrical Door lock system
(2) optic and acoustic alarm
(3) pressure release flap
(6) Fire detection system using a CO gas detection sensor
(8) Flushing device using in case of fire

Remarks:
- Installation Room on site: the test unit(s) should be installed in a separate installation room which can be closed and locked. Access to the room during testing must not be allowed.

- Customer exhaust air: this is needed in any case unless option (4) is ordered. In combination with this option customer exhaust air duct is needed.

- Please note: all listed safety equipments are designed and provided for human safety. In spite of every safety equipments a damaging of the chamber could occur in the worst case.
EUCAR Hazard Level

<table>
<thead>
<tr>
<th>Hazard Level</th>
<th>Description</th>
<th>Classification Criteria &amp; Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No effect</td>
<td>No effect. No loss of functionality.</td>
</tr>
<tr>
<td>1</td>
<td>Passive protection activated</td>
<td>No defect; no leakage; no venting, fire or flame; no rupture; no explosion; no exothermic reaction or thermal runaway. Cell reversibly damaged. Repair of protection device needed.</td>
</tr>
<tr>
<td>2</td>
<td>Defect / Damage</td>
<td>No leakage; no venting, fire or flame; no rupture; no explosion; no exothermic reaction or thermal runaway. Cell irreversibly damaged. Repair needed.</td>
</tr>
<tr>
<td>3</td>
<td>Leakage</td>
<td>No venting, fire or flame*; no rupture; no explosion. Weight loss &lt; 50% of electrolyte weight (electrolyte = solvent + salt).</td>
</tr>
<tr>
<td>4</td>
<td>Venting</td>
<td>No fire or flame*; no rupture; no explosion. Weight loss ≥ 50% of electrolyte weight (electrolyte = solvent + salt).</td>
</tr>
<tr>
<td>5</td>
<td>Fire or Flame</td>
<td>No rupture; no explosion (i.e., no flying parts).</td>
</tr>
<tr>
<td>6</td>
<td>Rupture</td>
<td>No explosion, but flying parts of the active mass.</td>
</tr>
<tr>
<td>7</td>
<td>Explosion</td>
<td>Explosion (i.e., disintegration of the cell).</td>
</tr>
</tbody>
</table>

* The presence of flame requires the presence of an ignition source in combination with fuel and oxidizer in concentrations that will support combustion. A fire or flame will not be observed if any of these elements are absent. For this reason, we recommend that a spark source be used during tests that are likely to result in venting of cell(s). We believe that "credible abuse environments" would likely include a spark source. Thus, if a spark source were added to the test configuration and the gas or liquid expelled from the cell was flammable, the test sample would quickly progress from hazard level 3 or 4 to hazard level 5.

Safety equipments packages and reachable Hazard Levels

Package 2, consisting of:
1. electrical Door lock system
2. optic and acoustic alarm
3. pressure release flap
4. Fire detection system using a CO gas detection sensor
5. Flushing device using in case of fire (alternative to 4))

Meets the requirements for Hazard level 0 – 6*(7***)
*Consumption: rupture of cell(s) results in abrupt expelling of big gas amount
***Chambers are only useful for tests with Hazard Level 7 in case of a small (improbable) or a very small (tolerable remaining risk without any safety device) expected risk of Hazard Level 7.

Additional options or combinations are possible upon request.
(1) Electrical door lock

Safety interlock switch, closed at zero current. The safety interlock switch is installed on top of the test cabinet. The test space door will be locked after the digital channel START is activated. At programme end, if digital channel STOP is activated in automatic mode or in manual mode the test space door will be unlocked.

(2) Display of operating status with colour signal lamp and acoustic horn

Signal lamp with 3 colours: green, orange and red. The lamp is equipped with a magnetic base to place and fix it on top of the test cabinet.

(3) Pressure release flap Ø 80 mm

Special designed venting duct Ø 80 mm for connection to site air exhaust.

Dimensioning based on the following data:
- Max. possible gas outlet per cell
  max. 200 l/s (hot gas volume)

To be provided by customer:
- Exhaust air equipment with tension break

Note:
- The test space door will be equipped with 2 additional fasteners.
- Different design and dimensioning in case of bigger gas amount upon request.
- With this option the useable temperature range changes to:
  -55 °C to +155 °C.
(6) Fire detection system

using a CO gas detection sensor

**Supplies:**
- gas detection sensors for measuring of (CO) gas concentration,
  with gas suction system consisting of gas special pump, gas tempering,
  gas measuring sensor and evaluating unit
- Transmitter for warning threshold e.g. detent threshold and breakdown
  signal

*For Climate Cabinets*

**Attention:**
In combination with the CO gas detection the climate range of the basic chamber will be restricted to following data:

- Temperature range: +10 °C to +85 °C
- Climatic range: 10 % r. h. to 85 % r. h.
- Dew point range: -3 °C to +81 °C

*To be provided by customer:*
- Exhaust air equipment with tension break
- Continuous control and maintenance of the (CO) gas detection system

(8) Flushing device using in case of fire

By flushing the test space with carbon dioxide (CO₂) in case of fire detection for inerting of the test space.

**Consisting of:**
- CO₂ – connection and supply into the test space.
- Carbon dioxide (CO₂) bottles
- Outlet air adaptor in the ceiling of the test space to connect on-site exhaust equipment.

**Notes:**
The quick inertisation of the test space is the overriding importance of the flushing device. The cooling effect of the CO₂ is only secondary.

*To be provided by customer:*
- Exhaust air equipment with tension break
Carbon dioxide (CO₂) bottle

Carbon dioxide (CO₂) bottle for connection to the flushing device.

Supplies:
- 1 x 7.5 kg compressed gas cylinder filled with CO₂ and perfume addition placed next to the cabinet
- Quick-release valve with magnet activation, piping and injector

To be provided by customer:
- Continuous control and maintenance of the (CO₂) compressed gas cylinder.

Second Carbon dioxide (CO₂) bottle with manual activation

For connection to the flushing device.

Supplies:
- 1 x 7.5 kg compressed gas cylinder filled with CO₂ and perfume addition placed next to the cabinet
- Quick-release valve with magnet activation, piping and injector
- Button for manual activation

To be provided by customer:
- Continuous control and maintenance of the (CO₂) compressed gas cylinder

Fault signal lead onto potential-free contact

Ordering code: 64624940

A potential-free contact will be actuated in case a fault on the test chamber occurs. The contact is for max. 24 V / 0.5 A DC. Connection via the relays installed in switch cabinet.

External malfunction alarm

Integration of an external malfunction alarm in to our controller. The signal will be similar to the malfunction alarm of the test chamber:
- test chamber switches to malfunction and stops operation
- the malfunction has to be quitted by the user.

The potential free malfunction contact as close as possible to the chamber control, 1 = o.k., 0 = malfunction.
Shaker system for Battery Testing

e.g. UN Transportation shock tests 50g/11ms with up to 450 kg payload

Can be combined with a vibration climate chamber (chamber is not a part of the DP shaker system)

Shaker system consists of:

- **Watercooled Shaker** LE-5022 with 222kN sine force rating
  with externally supported and guided Head Expander HE-551 (1.3 x 1.3 m) and Slip table
  MST-51/86 (1.3 x 2.15 m), both equipped with thermal barriers for climate chamber adaption
  (note: usable slip table working area under climate chamber: 1.3 x 1.3 m).
- **Power Amplifier** DSA10-360k
  360 kVA output power, including shaker field supply and safety circuits & interlocks
- **Cooling unit** LE-CU200
  with heat exchanger, for cooling shaker armature & field coils
- **Chiller**
  for additional cooling of the shaker armature cooling water
- **Vibration controller** SignalCalc Vector DP760-16C15
  with 16 input channels, with Sine, Random, Shock, Sine-on-Random, Resonance-
  Serach/Dwell and MultiSine testing software, with remote control interfaces (ActiveX and
  relais I/O).

Subject to modification without notice - 04-2012
Climate Chamber adaption

Horizontal Operation:

Vertical Operation
**Installation considerations:**

(for information purposes only)

**Floor Load:**
Shaker system mass is ca. 19 tons (including monobase slip table system)  
Amplifier: 5 tons,  
Cooling unit and Chiller: less than 1 ton each.

**Electrical supply:**  
3 phase supply, ca 550 kVA  
1 phase supply for the vibration controller

**Cooling water supply**  
Cooling unit and Chiller 210 liters/min @ 15°C, 15 psi pressure drop

**Compressed air:**  
6 bar mit 1m³/min

**Heat Dissipation into room**  
50 to 70 kW (at full performance)

An overhead crane with minimum lifting capability of 3.5 tons should be installed for service and maintenance purposes and for loading and unloading test items onto the shaker system.
Shakersystem with Slip table and Head expander

Dimensions indicated in inches [mm]

Power amplifier:

Dimensions WxHxD: 370cm x 200cm x 110 cm
Mass: ca 5000 kg
Cooling unit
Dimensions Width: 69cm x 138cm x 107 cm
Mass: ca 370 kg

Chiller
Dimensions Width: 183cm x 122cm x 122 cm
Mass: ca 907 kg
Moog Hexapod with 6 DOF

HYDRAULIC SIMULATION TABLE
NEXT GENERATION TESTING

DESIGNED FOR LEADING EDGE AUTOMOTIVE TESTING APPLICATIONS REQUIRING UNSURPASSED PERFORMANCE, RELIABILITY AND VERSATILITY
STATE-OF-THE-ART HEXAPOD DESIGN FOR WORLDWIDE TEST APPLICATIONS

Unsurpassed innovation and technological expertise combined with close customer collaboration make Moog a leader in the design and development of high-performance 6 Degree-of-Freedom (DOF) electric and hydraulic motion platforms.

The proven technology expertise of Moog combined with the world class performance of Moog Actuators, Servo Valves and Digital Controllers deliver long-lasting solutions to meet your challenges today—and tomorrow.

Our total focus on meeting your unique test requirements means you can rest assured you’re using the most flexible, highest performance test equipment available anywhere.

The application of the latest testing techniques has become a cornerstone for creating successful new designs, ensuring shorter vehicle time-to-market, managing increased regulatory pressures and maintaining cost efficiencies.

Wherever test and development engineers are pushing the limits of automotive design, the Moog Simulation Table is an indispensable tool throughout the vehicle development process.
MEETING THE CHALLENGE OF A NEW TESTING GENERATION
WITH MAXIMUM VERSATILITY AND STIFFNESS

The hexapod configuration used by the Simulation Table is the optimum design to achieve simulation and test capability using acceleration, force and displacement inputs, and to reproduce data collected on proving grounds regardless of your test type, method or specimen.

By understanding today's test trends and challenges, and listening closely to the needs of customers around the world, we provide the right tools and proactive expertise to take automotive test applications further than you ever thought possible.

To meet the high demand for hydraulic Simulation Tables to accommodate loads up to 680 kg (1,500 lb), we developed a standard Simulation Table based on a new generation of hydrostatic actuators providing more stiffness and versatility.

KEY FEATURES TO SUPPORT YOUR TESTING NEEDS

**KEY FEATURES**

**Recommended tests**
Vibration, durability, squeak and rattle, noise and harshness.

**6 Degree of Freedom motion**
Translations: vertical, lateral, and longitudinal
Rotations: pitch, yaw, and roll

**Working in synchronization**
Six identical actuators performing synchronously for each motion resulting in higher forces and accelerations.

**Degree-of-Freedom Control**
DOF control allows you to simply put in the frequency and amplitude for a desired direction then the controller and kinematics take over to achieve the expected movement result.

**Performance**
The industry’s most innovative engineering design incorporates proprietary software and digital control, along with the highest quality components to ensure optimal performance.

**USER BENEFITS**

**High versatility**
Specific architecture and design (for example, no bellcranks or tie-rods) to reach higher test frequencies, providing significantly higher system strength and stiffness, so a wide range of tests can be run.

**User-friendly**
Minimal moving parts make the Simulation Table quick to install and commission, easy to maintain, and user friendly when accessing the table and specimen. The design also makes it simple to run tests efficiently through integrated control hardware and software.

**Extremely small footprint**
Using only one third of the space required by classic systems, this small footprint makes it an integrated solution that is easy to position, run and control anywhere in your test lab.

**Maximum flexibility**
Accommodates integration of environmental chambers for temperature and humidity testing in connection with vibration testing.

**Increased productivity in a testing laboratory environment**
The geometry of the assembly of actuators offers a convenient working height for the operator to mount and inspect the test specimen. (No work platform required.)
# STANDARD SIMULATION TABLES FOR STIFFNESS AND VERSATILITY

Moog's Standard Simulation Tables are the industry's most innovative engineering design incorporating proprietary software and digital control. Our high quality components ensure optimal performance for test capability using acceleration, force and displacement inputs regardless of your test type, method or specimen.

## STANDARD SIMULATION TABLE

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>Standard Simulation Table</th>
</tr>
</thead>
<tbody>
<tr>
<td>System Payload</td>
<td>680 kg (1,500 lb)</td>
</tr>
<tr>
<td>Table Mass</td>
<td>758 kg (1,670 lb)</td>
</tr>
<tr>
<td>Total Payload (combined)</td>
<td>1,440 kg (3,170 lb)</td>
</tr>
<tr>
<td>Table Size (LxW)</td>
<td>2.175 x 1.870 mm (7.1 x 6.1 ft)</td>
</tr>
<tr>
<td>Table Mounting Pattern</td>
<td>150 x 150 mm (5.9 x 5.9 in)</td>
</tr>
<tr>
<td>Table Mounting Hole Size</td>
<td>M12</td>
</tr>
<tr>
<td>Actuator Peak Force</td>
<td>54 kN (12.2 kip)</td>
</tr>
<tr>
<td>Degree of Freedom</td>
<td>6 DOF Stewart Hexapod</td>
</tr>
<tr>
<td>Frequency</td>
<td>100 Hz</td>
</tr>
<tr>
<td>Noise Level</td>
<td></td>
</tr>
</tbody>
</table>

### Excursion

| (Z) Heave (Vertical)  | ±1.22 mm (4.8 in) |
| (Y) Lateral          | ±1.74 mm (0.69 in) |
| (X) Longitudinal     | ±1.76 mm (0.69 in) |
| Roll                 | ±9 deg (0.16 rad)  |
| Pitch                | ±8.5 deg (0.15 rad) |
| Yaw                  | ±12 deg (0.21 rad) |

### Velocity

| (Z) Heave (Vertical)  | ±1.65 m/sec (65 in/sec) |
| (Y) Lateral          | ±1.62 m/sec (64 in/sec) |
| (X) Longitudinal     | ±1.65 m/sec (65 in/sec) |
| Roll                 | ±1.20 deg/sec (2.09 rad/sec) |
| Pitch                | ±119 deg/sec (2.08 rad/sec) |
| Yaw                  | ±145 deg/sec (2.53 rad/sec) |

### Acceleration

| (Z) Heave (Vertical)  | ±1.08 m/sec² (11.1 g) |
| (Y) Lateral          | ±0.64 m/sec² (6.6 g)  |
| (X) Longitudinal     | ±0.57 m/sec² (5.8 g)  |
| Roll                 | ±10,000 deg/sec² (174 rad/sec) |
| Pitch                | ±8,500 deg/sec² (148 rad/sec) |
| Yaw                  | ±7,500 deg/sec² (131 rad/sec) |

This technical data is based on current available information and is subject to change at any time by Moog. Specifications for specific systems or applications may vary.
Moog's wide array of technologies and design expertise mean your Simulation Table can be tailored to meet your specific performance needs. Our solutions address your specific requirements whether it is higher frequency, payload, footprint, performance, climatic chamber, acoustic chamber, hydrotstatic bolt joints or fixed based actuator design.

**CUSTOMIZED SIMULATION TABLES DESIGNED FOR YOUR UNIQUE REQUIREMENTS**

This technical data is based on current available information and is subject to change at any time by Moog. Specifications for specific systems or applications may vary.

**CUSTOMIZED SIMULATION TABLE WITH CLIMATIC CHAMBER**

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>Example of a customized Simulation Table</th>
</tr>
</thead>
<tbody>
<tr>
<td>System Payload</td>
<td>600 kg (1,322 lb)</td>
</tr>
<tr>
<td>Table Mass</td>
<td>742 kg (1,635 lb)</td>
</tr>
<tr>
<td>Total Payload (combined)</td>
<td>1,342 kg (2,950 lb)</td>
</tr>
<tr>
<td>Table Size (LxW)</td>
<td>2,300 x 2,000 mm (7.5 x 6.6 ft)</td>
</tr>
<tr>
<td>Table Mounting Pattern</td>
<td>200 x 200 mm (8 x 8 in)</td>
</tr>
<tr>
<td>Table Mounting Hole Size</td>
<td>M16</td>
</tr>
<tr>
<td>Actuator Peak Force</td>
<td>53 kN (12 kip)</td>
</tr>
<tr>
<td>Degree of Freedom</td>
<td>6 DOF Stewart Hexapod</td>
</tr>
<tr>
<td>Frequency</td>
<td>150 Hz</td>
</tr>
<tr>
<td>Noise Level</td>
<td>60 dB(A)</td>
</tr>
</tbody>
</table>

**Excursion**

<table>
<thead>
<tr>
<th>Component</th>
<th>Range (mm/in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Z (Vertical)</td>
<td>±183/-140 mm (6.4/-5.5 in)</td>
</tr>
<tr>
<td>Y (Lateral)</td>
<td>±163 mm (6 in)</td>
</tr>
<tr>
<td>X (Longitudinal)</td>
<td>±118 mm (4.66 in)</td>
</tr>
<tr>
<td>Roll</td>
<td>±7.6 deg (0.13 rad)</td>
</tr>
<tr>
<td>Pitch</td>
<td>±7.2/-8.4 deg (0.13/-0.15 rad)</td>
</tr>
<tr>
<td>Yaw</td>
<td>±5.3 deg (0.09 rad)</td>
</tr>
</tbody>
</table>

**Velocity**

<table>
<thead>
<tr>
<th>Component</th>
<th>Range (m/sec/in/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Z (Vertical)</td>
<td>±1.753/1.218 m/sec (69 in/sec)</td>
</tr>
<tr>
<td>Y (Lateral)</td>
<td>±1.405 m/sec (55 in/sec)</td>
</tr>
<tr>
<td>X (Longitudinal)</td>
<td>±0.956 deg/sec (1.67 rad/sec)</td>
</tr>
<tr>
<td>Roll</td>
<td>±88.9 deg/sec (1.55 rad/sec)</td>
</tr>
<tr>
<td>Pitch</td>
<td>±62.5 deg/sec (1.09 rad/sec)</td>
</tr>
</tbody>
</table>

**Acceleration**

<table>
<thead>
<tr>
<th>Component</th>
<th>Range (m/sec²/in/sec²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Z (Vertical)</td>
<td>±109/-89.5 m/sec² (11.1/-9.9 g)</td>
</tr>
<tr>
<td>Y (Lateral)</td>
<td>±63.7 m/sec² (8.5 g)</td>
</tr>
<tr>
<td>X (Longitudinal)</td>
<td>±80.5 m/sec² (8.2 g)</td>
</tr>
<tr>
<td>Roll</td>
<td>±4.175 deg/sec (72.9 rad/sec)</td>
</tr>
<tr>
<td>Pitch</td>
<td>±4.210/-5.130 deg/sec² (73.5/-89.5 rad²/sec)</td>
</tr>
<tr>
<td>Yaw</td>
<td>±8.900 deg/sec² (155 rad²/sec)</td>
</tr>
</tbody>
</table>
GENUINE TEST CONTROLLERS TO ENSURE BEST PERFORMANCE

Moog delivers the flexibility, innovation and trusted solutions you need for a smart approach to automotive testing. The heart of all our solutions is the control hardware and software that sets the pace for the industry.

TEST CONTROLLERS

One advanced control for all your tests, the Simulation Table utilizes the same Automotive Test Controller as other Moog solutions.

- Advanced control loop technology
- Unique control algorithm
- Function generator—Play out cyclic commands including sine, triangle, square wave and more.
- Random Wave—create random waveform that allows variable PSD with multiple break points across the frequency spectrum.
- Sweep function generator—sweep through a sine function with closed loop control of defined amplitudes at various frequencies.
- Random time history iteration and durability test playback.

| Channels | 6 channels expandable up to 32 channels |
| Housing  | 19 inch cabinet 1.8 m (70.9 in) high |
|          | Integrated 17” full VGA color display |
|          | Climate controlled cabinet |
| Servo Controller | Up to 2.5 kHz control loop |
|          | (software selectable) |
|          | Integrated DOF control |
|          | Delta P compensation included |
|          | Moog unique control loop |
|          | Three variable control possibility |
|          | (Velocity, Position, Acceleration) |
| Function Generator | Frequency range 0.01 to 500 Hz |
|          | Waveforms: sine, sawtooth, block/square, ramp, rounded ramp, exponential |
|          | Analogue input can be used as command |
|          | Complex simulation spectrum support |
|          | Including spectral density (psd frequency definition) |
|          | Constant amplitude and phase matching |
| Standard Inputs (Per Channel) | 2x High resolution (0.03 %) with selectable gain and bridge excitation. |
|          | Pot meter input (0.05 %) (± 5 V Sma) or LVDT input (0.03 %) with LVDT excitation (5 V RMS @ 3.5 kHz) |
|          | Encoder, absolute (SSI) maximum 32 bit or relative 10 bit |
|          | 16 bit input (+/- 10 V) |
| Standard Outputs (Per Channel) | 16 bits ± 100 mA valve driver output, with a limit in software from 0 to 100% or |
|          | (hardware selectable) +/− 10 V output |
|          | 2 x 16 bit D/A converters, +/- 10 V |
| Optional Items | Digital I/O board containing |
|          | 8 inputs and 8 outputs |
|          | Analog input board containing 16 inputs |
|          | Strain amplifier board (6 channels, 1/4, 1/2 and full bridge 120/350 ohm) |
|          | Add onboard for 3 stage Servo Valve |
|          | Accelerometer input board 6 channels |
|          | Uninterruptable Power Supply (UPS) |
OPTIONAL FOR MULTICHANNEL TESTING

Manifold Control Unit and Matrix Driver Unit

In case more than one Hydraulic Service Manifold (HSM) needs to be controlled independently and multiple station functionality is required, the Manifold Control Unit and the Matrix Driver Unit (MDU) can be used. The Manifold Control Unit (MCU) contains 4 connections for an HSM manifold (low/high pressure).

The Matrix Driver Unit can be used as a device to connect the safety systems for user defined configurations in stations of the Automotive Test system. In the Automotive Test system you can create your own station assignments and manage the associated safety system with the rotary switches on the MDU.

INTEGRATED TEST SOFTWARE TO ENSURE BEST FLEXIBILITY

Moog provides open architecture control software developed specifically for your unique test needs in durability and fatigue, simulation, vibration, measurement and analysis.

The Moog Integrated Test Suite offers a unique straightforward approach to inherently complex processes.

For example, it makes simulation using iteration, a notoriously complex and time-consuming test technique, easy and fast to use through one of its existing modules (Moog Runner).

The Moog Integrated Test Suite gives access to different modules: Runner, Replication, Sinesweep and Random Vibration and to specific advanced features as required.
MODULES BASED ON THE INTEGRATED TEST SUITE

The same module can be used for different test systems in your test labs and test data can be centrally accessed, dramatically reducing time.

The Integrated Test Suite gives access to all modules: Runner, Replication, Sinesweep and Random Vibration and to specific advanced features as required.

**Runner Module**
Run and control your durability tests.

**Random Vibration Module**
Realize a predefined frequency spectrum using fully randomized time signals.

**Sinesweep Module**
Investigate the resonance frequencies of your test specimen.
Run Sinesweep durability test.

**Replication Module**
State-of-the-art algorithms are at work to replicate time history files in an easy yet powerful way.
COMPONENTS TO ENSURE BEST PRECISION

Each Moog Simulation Table incorporates world class performance of Moog components. Every element of the Simulation Table is thoughtfully integrated in the engineering design to offer unsurpassed performance, reliability and longevity.

SERVO VALVES

The Simulation Table incorporates 6 three-stage Moog Servo Valves (one per actuator). Moog Servo Valves are known for their exact tolerances, high performance and durability. These three-stage Servo Valves were developed for applications that require high flow rates and performance. Our Servo Valves are the preferred choice of leading test engineers and set the world standard for hydraulic Servo Valve performance.

BALL JOINTS

Actuator joints ensure the smoothest possible movement and significant angular displacement via a spherical ball swivel joint on each actuator end. These ball joints are designed to allow large angular displacement with minimum stiffness and zero backlash.

Ball joint design

A “superbolt” or “multi-jackbolt tensioner” is used as a direct hex nut replacement. They spin onto your existing stud and provide an improved way to assemble the joint, as they are used to tighten the joint in pure tension. Ordinary hand tools are used to tighten.

TEST ACTUATORS

Six fatigue-rated actuators described as hydrostatic bearings hydraulic test actuators. They are engineered to deliver consistent performance over hundreds of millions of cycles for our next generation Simulation Table. They provide increased reliability, stiffness and increased side load capabilities. They have a robust design which offers low maintenance due to improved seal life (advanced rod coating), and improved cushion design (improved energy dissipation).

Hydraulic Actuator Design

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design Pressure</td>
<td>210 bar (3,000 psi)</td>
</tr>
<tr>
<td>Actuator Peak Force</td>
<td>54 kN (12.2 kip)</td>
</tr>
<tr>
<td>Total Stroke (Incl. Cushions)</td>
<td>272 mm (10.7 in)</td>
</tr>
<tr>
<td>Working Stroke</td>
<td>204 mm (8.0 in)</td>
</tr>
<tr>
<td>Cushion Length</td>
<td>15 mm (0.59 in)</td>
</tr>
<tr>
<td>Hydrostatic Bearing Design</td>
<td>8 pockets</td>
</tr>
</tbody>
</table>

- Innovative 8 pocket hydrostatic bearing for improved side load test capabilities and less energy needs
- Higher level of dynamic performance, reliability and longevity
- Advanced rod coating ensures improved seal wear for longer life and less maintenance
- Advanced cushion design allows improved energy dissipation for higher reliability and safety
- Innovative design for less maintenance

TEST MANIFOLDS

The Test Manifold is used to control the Simulation Table hexapod. It is fully integrated with the motion base, but includes a self-contained service test manifold for flexibility in installing the Simulation Tables. The hydraulic circuit logic and functionality can be engineered to meet your exact performance, safety and mounting requirements. Application specific circuits enhance machine performance, reduce system cost and increase safety.

The Moog Test Manifold systems deliver proven performance in a wide variety of test environments. These are designed to facilitate the use of multiple test rigs from a common hydraulic supply. They provide total flexibility and efficient operation in automotive test labs around the world.

A Manifold Control Unit can be used to control the manifolds, and a Matrix Driver Unit can be used to connect the safety systems for user defined configurations.
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**TEST DISTRIBUTION MANIFOLD**

The Test Distribution Manifold is fully integrated into the Simulation Table assembly and creates an optimum configuration for the layout of the hoses to the actuators. Optional items can be connected to this Test Distribution Manifold for convenience and flexibility.

**TEST SERVICE MANIFOLD**

The Test Service Manifold used on the Simulation Table is capable of a peak flow of 1,140 lpm (300 gpm) at 210 bar (3,000 psi).

It contains a 3 micron filter in the pilot line, and 25 micron filters for the pressure line. Pulsation dampener accumulators are installed in the pressure, pilot and tank lines.

Control valves are used to control pressure and flow to ensure the system meets all safety requirements.
A HIGHER LEVEL OF SUPPORT

Five point inspection process

Our number one goal is to eliminate downtime and make repairs that will deliver reliability and cost savings for years to come. When you send in your repair, it must work like new when you get it back. This is the Moog Global Support™ promise.

• Incoming inspection will provide the customer details on the performance of the actuator assembly such as leakage and response. The inspection will also provide details to our technicians in regards to critical performance specs that need to be addressed.

• Technicians will then review engineering notes for any design improvements that may have been initiated since inception.

• Actuator assembly will get completely disassembled to piece parts. Aqueous Ultrasonic cleaners are used to thoroughly clean each component before inspection and dimensional checks. Any components found to worn will be replaced with OEM parts. Critical components such as fitted rod and bearings will be dimensionally checked to ensure the component meets the print criteria. A complete seal kit replacement will be installed to insure integrity of the structure.

• The Servo Valve will be removed and sent through the same rigorous evaluation, disassembly and test.

• Finally, the assembly will be tested to original specs to ensure the overhaul unit meets all design and performance criteria as new.

Moog engineering on call for you

Delivering world-class motion control products and solutions means taking customer support far beyond the initial sale. It requires a dedicated approach to solving your problems, addressing your machine challenges and helping you achieve maximum productivity on a daily basis. In today’s competitive manufacturing environment, machine performance plays a significant role in determining your bottom line. Moog Global Support™ is key to achieving cost-effective machine operation, day in and day out.

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Moog Global Support™ is designed to keep your critical machines up and running at peak performance with only 100% genuine Moog replacement parts. Only Moog replacement parts can deliver the reliability, versatility and long life that you would expect from a world leader in motion control solutions. Each Moog part delivers essential components with precise dimensions, close tolerances and specific materials specifications. Because we understand the key role our parts play in the overall operation of your machine, we carefully inspect and test each repair to identify only those components that need replacement.

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Isn’t it time you worked with a partner who can offer both the world-class products and collaborative expertise you need to reach the next level of performance? Contact us today and see for yourself the difference the right partner can make.
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Hydraulic Simulation Table
Moog/Rev.5, December 2010, ID: CDL28939-en
20. Appendix 6 FAA Fire

Flammability Assessment of Lithium-Ion and Lithium-Ion Polymer Battery Cells Designed for Aircraft Power Usage

Steven M. Summer

January 2010
Final Report

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FLAMMABILITY ASSESSMENT OF LITHIUM-ION AND LITHIUM-ION POLYMER BATTERY CELLS DESIGNED FOR AIRCRAFT POWER USAGE

16. Abstract

Tests were performed at the Federal Aviation Administration William J. Hughes Technical Center by the Fire Safety Team of the Airport and Aircraft Research and Development Division to examine the fire safety hazards that cylindrical- and polymer-type lithium-ion batteries may pose onboard aircraft. Tests were conducted on individual, manufacturer-supplied battery cells to determine how the cells would react in a fire situation, as well as what potential fire hazard the battery cells themselves may pose and the effectiveness of a typical hand held extinguisher on a fire involving the battery cells. The battery cells that were tested were all commercial off-the-shelf products that are being considered by manufacturers for aircraft power-related usage.

The results of the tests showed that the lithium-ion and lithium-ion polymer battery cells can react violently when exposed to an external fire. Under test conditions, when the battery cells failed, flammable electrolyte was released and ignited, which further fueled the existing fire. This release and ignition of the electrolyte resulted in significant temperature and pressure increases within the test fixtures.

Tests conducted with a hand-held Halon 1211 fire extinguisher showed that the halon was able to extinguish all three battery-type fires. However, even after several attempts, the halon extinguishing agent was not able to prevent the lithium-ion polymer battery cells, which are of a different chemistry, as well as a much higher energy density and power capacity, from reigniting.

17. Key Words

Lithium, Lithium-ion, Lithium polymer, Rechargeable, Battery, Cell, Flammability, Halon 1211
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<td>Federal Aviation Administration</td>
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<td>Li-ion</td>
<td>Lithium-ion</td>
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<td>Li-Po</td>
<td>Lithium-ion polymer</td>
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<tr>
<td>mAh</td>
<td>Milliampere-hour</td>
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<td>PED</td>
<td>Personal electronic devices</td>
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<td>SOC</td>
<td>State of charge</td>
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EXECUTIVE SUMMARY

Rechargeable lithium-ion batteries offer many advantages over current battery technologies. They possess a high-energy density per unit volume, relatively constant voltage during discharge, low maintenance, good low-temperature performance, and a long shelf life. There is, however, a certain amount of hazard associated with the use of these batteries due to their high-energy content and potential thermal instability. Their proposed use onboard aircraft as power sources for starting aircraft engines or auxiliary power units, as well as other avionics, emergency, and standby systems, require the examination of the safety of their design. How these batteries will react in a fire situation and what type of fire hazard they pose themselves must be examined. Tests must be performed to ensure the batteries provide an appropriate level of safety. Current regulatory and test requirements may need to be updated to address the hazards associated with this new technology.

Tests were performed at the Federal Aviation Administration William J. Hughes Technical Center by the Fire Safety Team of the Airport and Aircraft Safety Research and Development Division to examine the fire safety hazards that cylindrical and polymer type lithium-ion batteries may pose onboard aircraft. Tests were conducted on individual, manufacturer-supplied battery cells to determine how the cells would react in a fire situation. Tests were also conducted to determine what potential fire hazard the battery cells themselves may pose and to determine the effectiveness of a typical hand-held extinguisher on a fire involving the battery cells. The battery cells that were tested were all commercial off-the-shelf products that are being considered by manufacturers for aircraft power-related usage.

The results of the tests showed that the lithium-ion and lithium-ion polymer battery cells can react violently when exposed to an external fire. The cylindrical cells vented in a manner by which the electrolyte would spray out forcefully and ignite, increasing both temperature and pressure. The lithium-ion polymer battery cells had 3.5 to 7 times the capacity of the cylindrical cells and did not have vent locations. Instead, they were designed with a seam around the perimeter of the cell that would open, thereby exposing the flammable electrolyte. The failure of these battery cells greatly fueled the existing fire as the full amount of the electrolyte was exposed instantaneously to the fire source. In both single- and multiple-cell tests, the lithium-ion polymer battery cells, which are of a different chemistry and had a much higher energy density and power capacity (8 ampere-hour (Ah) per cell versus 1.2 and 2.3 Ah for the cylindrical cells), resulted in significantly higher temperature and pressure increases compared to the cylindrical cells.

Attempts to cause the battery cells to reach their thermal runaway point via short circuiting were unsuccessful on all three battery types.
Autoignition tests showed that battery cells failed, venting their flammable electrolyte at temperatures ranging between 330° and 527°F.

Tests conducted with a hand-held Halon 1211 fire extinguisher showed that the halon was able to extinguish all three battery type fires. However, for the lithium-ion polymer battery cells, even after several attempts, the halon extinguishing agent was not able to prevent the cells from reigniting.
1. INTRODUCTION.

1.1 BACKGROUND.

Rechargeable lithium-ion (Li-ion) batteries offer many advantages over current battery technologies. They possess a high-energy density per unit volume, relatively constant voltage during discharge, low maintenance, good low-temperature performance, and a long shelf life. There is, however, a certain amount of hazard associated with the use of these batteries due to their high-energy content and potential thermal instability. Their proposed use onboard aircraft as power sources for starting aircraft engines or auxiliary power units, as well as other avionics, emergency and standby systems, require the examination of the safety of their design. How these batteries will react in a fire situation and what type of fire hazard they pose themselves must be examined. Tests must be performed to show that they provide an appropriate level of safety. Current regulatory and test requirements may need to be updated to address the hazards associated with this new technology.

1.2 PREVIOUS RESEARCH AND REGULATIONS.

The Federal Aviation Administration (FAA) previously conducted research regarding the bulk shipment of both primary (i.e., nonrechargeable) lithium [1] and rechargeable Li-ion batteries [2]. The results stated that a relatively small fire source was sufficient to cause the battery cells to vent flammable electrolyte. In addition, it was determined that Halon 1301 did not prevent the further release of electrolyte from the heated cells, and a fire involving a bulk-packed Li-ion shipment may in fact compromise the integrity of the cargo compartment, due to the pressure increase that is observed when the cells begin to vent.

As a result of these findings, large, palletized shipments of primary lithium batteries are no longer permitted onboard passenger aircraft. In addition, the Pipeline and Hazardous Materials Safety Administration (PHMSA) released a rule in January 2008, which among other things, prohibits the transportation of loose Li-ion batteries used for personal electronic devices (PED) in checked baggage.

In addition to these tests, the FAA also determined the most effective method of extinguishing a cabin fire involving Li-ion batteries in PEDs. These tests resulted in a training video that provides guidance to flight crew on how to respond to such a fire. The training video is available online at http://www.fire.te.faa.gov.

1.3 SCOPE.

Tests were performed at the FAA William J. Hughes Technical Center by the Fire Safety Team of the Airport and Aircraft Safety Research and Development Division to examine the fire safety hazards that Li-ion batteries may pose onboard aircraft. Tests were conducted on individual, manufacturer-supplied battery cells to determine how the cells would react in a fire situation. Tests were also conducted to determine what potential fire hazard the battery cells themselves may pose and to determine the effectiveness of a typical hand-held extinguisher on a fire involving the battery cells. The battery cells that were tested were all commercial off-the-shelf
products that are being considered by manufacturers for aircraft power-related usage. The results of these cell-level tests are to be used to determine the necessary safety and test requirements of a battery system designed for aircraft usage. These safety systems may include vent hole sizing and positioning, thermal protection circuits, hardened casings, and physical barriers placed between adjacent cells. It should also be noted that battery technology is constantly evolving. There are several different chemistries used in these batteries. Two of the major chemistries, those with oxide- or phosphate-based cathodes, were examined in this research.

2. TEST EQUIPMENT.

2.1 BATTERY CELLS.

Three battery cell types were obtained for testing purposes, all with varying chemistries, dimensions, and power characteristics. Two cells were cylindrical in shape and varied in size. The first was 18 mm in diameter, and the second was 26 mm in diameter. Both were 65.0 mm in height. Typical notation for a cylindrical battery cell consists of a five-digit code, where the first two digits represent the diameter of the cell, and the last three digits represent the height. As such, these two cells are considered to be 18650- and 26650-sized cells, respectively. The third battery cell type was a lithium-ion polymer (Li-Po) battery, which instead of being cylindrical, was a nearly flat rectangular-shaped cell measuring 3.5" by 4" by 1/4".

The 18650 cell had a lithium iron phosphate-based chemistry with a capacity of 1150 milliampere-hours (mAh). The nominal voltage per cell for this battery type was 3.3 V, and the recommended charge voltage was 3.85 V.

The 26650 cell also had a lithium iron phosphate-based chemistry with a capacity of 2300 mAh. The nominal voltage per cell for this battery type was 3.3 V, and the recommended charge voltage was 3.6 V.

The Li-Po cell had a lithium cobalt dioxide-based chemistry with a capacity of 8000 mAh. The nominal voltage per cell for this battery type was 3.7 V, and the recommended charge voltage was 4.2 V.

Table 1 summarizes the characteristics of each cell, and figure 1 shows the battery cells that were tested.
Table 1. Summary of Battery Specifications

<table>
<thead>
<tr>
<th>Battery type</th>
<th>Battery Cell 1</th>
<th>Battery Cell 2</th>
<th>Battery Cell 3</th>
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<tr>
<td>Battery size</td>
<td>18650</td>
<td>26650</td>
<td>3 1/2” x 4” x 1/4”</td>
</tr>
<tr>
<td>Chemistry</td>
<td>Lithium Iron Phosphate</td>
<td>Lithium Iron Phosphate</td>
<td>Lithium Cobalt Dioxide</td>
</tr>
<tr>
<td>Capacity (mAh)</td>
<td>1150</td>
<td>2300</td>
<td>8000</td>
</tr>
<tr>
<td>Nominal voltage</td>
<td>3.3</td>
<td>3.3</td>
<td>3.7</td>
</tr>
<tr>
<td>Charge voltage</td>
<td>3.85</td>
<td>3.6</td>
<td>4.2</td>
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Figure 1. Battery Cells Used in the Tests (a) 18650, (b) 26650, and (c) Li-Po Cell

2.2 FIRE TEST CHAMBER.

A 64-ft$^3$ fire test chamber was constructed to evaluate the flammability of the test cells. The fire test chamber was constructed of 1/8” steel and measured 4’ by 4’ by 4’. The front side of the fire test chamber was fitted with a hinged door to provide access to the inside of the chamber. This door had a large Plexiglass window to view and videotape the test in progress. The fire test chamber was equipped with variable 3” vent holes located on the centerline of the sidewalls, 2” above the floor. Horizontal slots, 3” by 30”, were cut near the top of the sides and back wall. These slots were sealed with aluminum foil to act as blowout panels to prevent any overpressure from damaging the structure. The fire test chamber was also fitted with a nozzle at the top center of the structure to allow for the injection of Halon 1211 for extinguishing purposes.

A steel angle frame was constructed to support a basket made from 0.5” wire mesh. This mesh basket was used to support the cells at a height of 4” over a 5.25” square fire pan. Four type-K thermocouples were placed along the centerline of the fire test chamber. The first was placed at a height of approximately 12” from the floor of the fire test chamber, with each subsequent
thermocouple spaced vertically approximately 12” apart from each other. Figure 2 shows a diagram of the fire test chamber.

Figure 3 shows the results of the baseline fire conditions to which the battery cells were exposed, which consisted of 50 ml of 1-propanol ignited with a propane torch. The peak temperature recorded was approximately 450°F, measured 12” above the fire pan, roughly 3 minutes into the test. The temperature at the ceiling of the fire test chamber rose only to approximately 215°F.

Figure 2. Fire Test Chamber
2.3 PRESSURE FIRE MODELING FACILITY.

The pressure fire modeling facility houses a 5-ft-diameter, 350 ft³ pressure vessel capable of withstanding a maximum working pressure of 650 psi. A steel angle frame was constructed to support a basket made from 0.5” wire mesh. This mesh basket was used to support the cells at a height of 4” over a 5.25” square fire pan. This fire pan and support basket were placed in the center of the pressure vessel. Three type-K thermocouples were placed in the vessel to record temperature throughout the test. One was placed at the location of the fire pan, and one was approximately 42” away from the fire pan in either direction. Each thermocouple was placed at a height of 18” above the support basket. In addition, a pressure transducer was used to record the pressure pulse within the pressure vessel. Figure 4 shows an external view of the pressure fire modeling facility.
Figure 4. External View of the Pressure Fire Modeling Facility

Figure 5 shows the results of the baseline fire conditions to which the battery cells were exposed. The peak temperature recorded was approximately 310°F, measured 18'' above the location of the battery support basket. The temperature readings at the front and rear of the pressure vessel reached just over 110°F, and the pressure rose by roughly 0.4 psi.
2.4 AUTOIGNITION TEST CHAMBER.

The autoignition test chamber was a 1-ft$^3$ insulated, steel box. A steel angle frame was constructed to support a basket made from 0.5" wire mesh, which was used to support the battery cells in the center of the test chamber. Two type-K thermocouples were placed inside; one near the top of the autoignition test chamber and one in the direct vicinity of the battery cell. An oxygen-acetylene torch, fitted with a rosebud nozzle, was attached to a support structure to provide an external heat source for the autoignition test chamber. Figure 6 shows the test chamber and torch setup.
3. TEST PROCEDURES.

3.1 FIRE EXPOSURE TESTS.

The fire exposure tests were designed to evaluate the results that occur when a battery cell or a group of battery cells is exposed to an external fire. For each battery type, the fire exposure test was conducted with a single cell, a group of four cells, and a group of eight cells. In the multiple-cell tests, the cells were packaged in a tight configuration and secured with safety wire. All cells were charged to 100% state of charge (SOC) and placed in the mesh basket inside the fire test chamber. The cylindrical battery cells were positioned with the vent locations pointing in an upward direction. The Li-Po battery cells were positioned vertically with the positive and negative terminals pointing upward. All the battery cells were positioned directly above the center of the fire pan.

The test was initiated by loading 50 ml of 1-propanol into the fire pan and igniting it with a propane torch. The fire test chamber door was then closed and sealed. The behavior of the
battery cell(s) was monitored throughout the test, along with temperature readings from the four fire test chamber thermocouples.

3.2 PRESSURE PULSE TESTS.

The pressure pulse tests were designed to determine and evaluate the pressure pulse resulting from the failure of a battery cell or groups of battery cells. For each battery type, the pressure pulse test was conducted with a single cell, a group of four cells, and a group of eight cells. In the multiple-cell tests, the cells were packaged in a tight configuration and secured with safety wire. All cells were charged to 100% SOC and placed in the mesh basket inside the pressure vessel.

The test was conducted similar to the fire exposure tests and was initiated by loading 50 ml of 1-propanol into the fire pan. The pressure vessel door was then closed and sealed. A remotely triggered oil burner spark igniter was used to ignite the 1-propanol. The behavior of the battery cell(s) was monitored throughout the test, along with all temperature and pressure readings within the sealed pressure vessel.

3.3 HALON 1211 SUPPRESSION TESTS.

The Halon 1211 suppression tests were designed to evaluate the effectiveness of a typical hand-held fire extinguisher in extinguishing and suppressing a fire involving Li-ion battery cells. For each battery type, the suppression tests were conducted with a group of eight cells packaged in a tight configuration and secured with safety wire. All cells were charged to 100% SOC and placed in the mesh basket inside the fire test chamber. The tests were conducted in the exact same manner as the fire exposure tests.

At the point of failure of a single battery cell, Halon 1211 was discharged into the fire test chamber until the fire was extinguished. The behavior of the battery cells was monitored throughout the test, along with temperature readings from the four fire test chamber thermocouples. In the event that subsequent cells either ignited or vented, additional Halon 1211 was discharged into the fire test chamber. At the end of the tests, the battery cells and the fire test chamber were allowed to cool to ensure no further ignition or venting would occur.

3.4 EXTERNAL SHORT-CIRCUIT TESTS.

The external short-circuit tests were designed to evaluate the effect of a short circuit on an individual cell. For each battery type, a single cell was charged to 100% SOC and was placed in the mesh basket inside the fire test chamber. A 14-gauge wire was used to connect the positive and negative terminals of the battery cell. In addition to the thermocouples inside the fire test chamber, a thermocouple was placed on the external casing of the battery cell itself to monitor the actual cell surface temperature. The test was conducted to observe if any fire, explosion, or venting of the battery would occur. If no fire, explosion, or venting was observed, the test was continued until the battery cell temperature peaked and began to decline, which indicated the battery cell had fully discharged without resulting in a fire or explosion.
3.5 AUTOIGNITION TESTS.

The autoignition tests were designed to evaluate the risk of a battery cell reaching thermal runaway and either venting or exploding due to an external heat source such as a suppressed smoldering cargo fire. For each battery type, an individual battery cell at 100% SOC was placed in the mesh basket inside the autoignition test chamber. An oxy-acetylene torch fitted with a rosebud nozzle was used as the heat source. The torch was positioned so the flame impinged on the bottom surface of the autoignition test chamber, creating a steady temperature rise within the autoignition test chamber. The autoignition test chamber temperature was increased until the battery cell either ignited or vented. The temperature within the autoignition test chamber was monitored and recorded until battery failure.

4. DISCUSSION.

4.1 FIRE EXPOSURE TEST RESULTS.

The fire exposure test was conducted with a single cell, a group of four cells, and a group of eight cells for each battery type. In the multiple-cell tests, all cells were packaged in a tight configuration and secured with safety wire. The cylindrical battery cells were positioned with the vent locations pointing in an upward direction. The Li-Po battery cells were positioned vertically with the positive and negative terminals pointing upward.

Figure 7 shows typical temperature versus time curves resulting from the single-cell fire exposure tests. These are plots of the thermocouple closest to the battery cells, located approximately 12” from the floor of the test chamber. These are not representative of the actual battery cell temperatures. The full results from the single-cell, four-cell, and eight-cell battery tests are summarized in tables 2-4.
Figure 7. Typical Temperature vs Time Curves Resulting From Single-Cell Fire Exposure Tests

Table 2. Fire Exposure Test Results—Single Cell

<table>
<thead>
<tr>
<th>Battery Cell Type</th>
<th>Approximate Time to First Event (min)</th>
<th>Peak Temperature (°F)</th>
<th>Approximate Time to Reach Peak Temperature (min)</th>
<th>Fire Duration (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.00</td>
<td>450</td>
<td>1.25</td>
<td>4.00</td>
</tr>
<tr>
<td>2</td>
<td>1.00</td>
<td>605</td>
<td>1.50</td>
<td>3.25</td>
</tr>
<tr>
<td>3</td>
<td>0.75</td>
<td>780</td>
<td>0.75</td>
<td>2.75</td>
</tr>
</tbody>
</table>

Table 3. Fire Exposure Test Results—Four Cells

<table>
<thead>
<tr>
<th>Battery Cell Type</th>
<th>Approximate Time to First Event (min)</th>
<th>Peak Temperature (°F)</th>
<th>Approximate Time to Reach Peak Temperature (min)</th>
<th>Fire Duration (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.75</td>
<td>560</td>
<td>1.5</td>
<td>4.5</td>
</tr>
<tr>
<td>2</td>
<td>2.00</td>
<td>700</td>
<td>2.00</td>
<td>4.5</td>
</tr>
<tr>
<td>3</td>
<td>0.75</td>
<td>900</td>
<td>1.00</td>
<td>1.75</td>
</tr>
</tbody>
</table>
Typically, the cylindrical cells exhibited similar failure characteristics when exposed to the 1-propanol flame source. As the battery cell heated, pressure buildup within the cells caused the vent location to open, resulting in a forceful spray of flammable electrolyte. The vented electrolyte ignited, resulting in an associated pressure pulse and temperature rise within the test chamber.

During the battery type 2 single-cell test, the vents failed to open, resulting in an explosion. It is believed that this is a result of the cell’s internal pressure increasing at a rate that exceeded the capability of the cell’s relief mechanism. This did not occur for the multiple-cell tests for either cylindrical battery type, because the increase in overall thermal mass resulted in a slower rate of temperature and pressure rise for each individual battery cell.

Figures 8 through 11 show the postignition damage of the cylindrical battery cells.
Figure 9. Results From the Single-Cell Test of Battery Type 2

Figure 10. Results From the Eight-Cell Test of Battery Type 1
The Li-Po battery cells do not have pressure release vent locations. Instead, they are designed such that under overpressure conditions, the seam around the perimeter of the cell opens up, releasing the flammable electrolyte. Due to the large surface area of the opening, there was no observable pressure pulse as with the cylindrical batteries. These cells however, did greatly fuel the existing fire once they failed as the full amount of the electrolyte was exposed all at once to the fire source. This resulted in higher peak temperatures as well as an increased burn rate of the pan fire. It is also important to keep in mind however, that these battery cells also had a much higher power capacity than the other cells, which also contributes to the high temperatures that were observed.

Figures 12 and 13 show the postignition damage of the Li-Po battery cells.
4.2 PRESSURE PULSE TEST RESULTS.

The pressure pulse test was conducted with a single cell, a group of four cells, and a group of eight cells for each battery type. In the multiple-cell tests, the cells were packaged in a tight configuration and secured with safety wire. The cylindrical battery cells were positioned with the vent locations pointing in an upward direction. The Li-Po battery cells were positioned vertically with the positive and negative terminals pointing upward.
The results of the data obtained from these tests are summarized in tables 5-7, which show results for the single-cell, four-cell, and eight-cell battery tests, respectively. It should be noted that there is no peak temperature recorded for the eight-cell test of battery type 3, due to a failed thermocouple.

<table>
<thead>
<tr>
<th>Battery Cell Type</th>
<th>Peak Pressure Rise (psi)</th>
<th>Approximate Time to Reach Peak Pressure (min)</th>
<th>Peak Temperature (°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.70</td>
<td>3</td>
<td>420</td>
</tr>
<tr>
<td>2</td>
<td>1.40</td>
<td>4</td>
<td>500</td>
</tr>
<tr>
<td>3</td>
<td>2.15</td>
<td>1.75</td>
<td>770</td>
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Table 6. Pressure Pulse Test Results—Four Cells

<table>
<thead>
<tr>
<th>Battery Cell Type</th>
<th>Peak Pressure Rise (psi)</th>
<th>Approximate Time to Reach Peak Pressure (min)</th>
<th>Peak Temperature (°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.10</td>
<td>5</td>
<td>470</td>
</tr>
<tr>
<td>2</td>
<td>1.50</td>
<td>4.5</td>
<td>585</td>
</tr>
<tr>
<td>3</td>
<td>4.10</td>
<td>2</td>
<td>1065</td>
</tr>
</tbody>
</table>

Table 7. Pressure Pulse Test Results—Eight Cells

<table>
<thead>
<tr>
<th>Battery Cell Type</th>
<th>Peak Pressure Rise (psi)</th>
<th>Approximate Time to Reach Peak Pressure (min)</th>
<th>Peak Temperature (°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.35</td>
<td>6.5</td>
<td>480</td>
</tr>
<tr>
<td>2</td>
<td>1.10</td>
<td>5</td>
<td>515</td>
</tr>
<tr>
<td>3</td>
<td>5.30</td>
<td>3.5</td>
<td>N/A</td>
</tr>
</tbody>
</table>

From this data, it can be observed that the two cylindrical batteries (types 1 and 2) behaved in a somewhat similar manner, resulting in somewhat comparable increases in temperature and pressure. The Li-Po battery (type 3) however, resulted in much more severe increases of temperature and pressure. In addition, the Li-Po battery cells failed more rapidly, thus leading to a faster rise in pressure. It should again be noted that these battery cells have a much higher power capacity than the other cells, which contributes to the high temperatures and pressures that were observed.
4.3 HALON 1211 SUPPRESSION TEST RESULTS.

The Halon 1211 suppression tests were conducted with a group of eight cells packaged in a tight configuration and secured with safety wire for all battery types. All cells were charged to 100% SOC and placed in the mesh basket inside the test chamber. The cylindrical battery cells were positioned with the vent locations pointing in an upward direction. The Li-Po battery cells were positioned vertically with the positive and negative terminals pointing upward. The cells were exposed to the small alcohol fire, and at the point of failure of a single battery cell, Halon 1211 was discharged into the fire test chamber until the fire was extinguished.

Figures 14 and 15 show the temperature data from these tests for the two cylindrical battery cells. The initial venting event for both battery type 1 and 2 occurred at a temperature of approximately 125°F, measured 12" above the fire pan. After this initial event, the temperature at this location rose rapidly to just over 180°F until the fire was extinguished with the halon agent. Once the fire was extinguished, no further ignition or venting of the battery cells was observed.

![Figure 14. Halon 1211 Suppression Test Results—Battery Type 1](image)

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Figure 15. Halon 1211 Suppression Test Results—Battery Type 2

Figure 16 shows the temperature data from this test for the Li-Po battery cells. The initial venting event occurred at a fire test chamber temperature of approximately 95°F. After this initial event, the temperature in the fire test chamber continued to rise rapidly to just over 210°F, at which point the fire was extinguished with the halon agent. Once the fire was extinguished however, there were multiple reignitions that occurred within the fire test chamber. At each point of reignition, additional Halon 1211 agent was injected into the fire test chamber until the fire extinguished. The reignition events continued for 4 minutes past the time of the initial injection of the extinguishment agent. At this time, the full contents of the 2.5-lb hand-held fire extinguisher were discharged into the fire test chamber. Due to decreased visibility caused by the smoke in the fire test chamber, it was difficult to ascertain whether the reignition events were subsequent battery cells venting or if they were due to a reignition of the remaining 1-propanol in the fire pan.
4.4 EXTERNAL SHORT-CIRCUIT TEST RESULTS.

The external short-circuit tests were conducted with a single-cell battery, charged to 100% SOC. The battery cell was placed in the mesh basket located within the fire test chamber. A 14-gauge wire was used to connect the positive and negative terminals of the battery cell.

None of the battery cells tested resulted in any venting or explosion. In the case of all three battery types, the temperature, measured on the outside casing of the cell, rose steadily throughout the test until the battery was fully discharged and then gradually began to cool to room temperature. The peak temperature reached for battery type 1 was 200°F. Battery type 2 reached a temperature of 167°F, and battery type 3 reached a temperature of 110°F.

4.5 AUTOIGNITION TEST RESULTS.

For each battery type, an individual battery cell at 100% SOC was placed in the mesh basket located in the 1-ft³ autoignition test chamber. An acetylene torch fitted with a rosebud nozzle was used as the heat source. The torch was positioned so the flame impinged on the bottom surface of the autoignition test chamber, creating a steady temperature rise within the autoignition test chamber. Failure of the battery cell was detected by a rapid rise in the autoignition test chamber temperature, as shown in figure 17.
Two test trials were conducted for each battery type, and the results shown in Table 8 display reasonable agreement between the tests, with the ignition temperature of the battery cells varying, at most, by 50°F. Ignition temperatures for the two cylindrical battery cells ranged from 440° to 527°F, while ignition temperatures for the Li-Po battery cell were at 330° and 340°F for the two tests.

**Table 8. Autoignition Test Results**

<table>
<thead>
<tr>
<th>Battery Cell Type</th>
<th>Trial 1</th>
<th></th>
<th>Trial 2</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ignition Temperature (°F)</td>
<td>Peak Temperature (°F)</td>
<td>Resulting Temperature Increase (°F)</td>
<td>Ignition Temperature (°F)</td>
<td>Peak Temperature (°F)</td>
<td>Resulting Temperature Increase (°F)</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>440</td>
<td>572</td>
<td>132</td>
<td>490</td>
<td>649</td>
<td>159</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>480</td>
<td>664</td>
<td>184</td>
<td>527</td>
<td>639</td>
<td>112</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>340</td>
<td>741</td>
<td>401</td>
<td>330</td>
<td>788</td>
<td>458</td>
<td></td>
</tr>
</tbody>
</table>

Peak temperatures for battery type 1 were 572° and 649°F. These temperatures compare similarly to the results of battery type 2, which were recorded as 664° and 639°F. The Li-Po battery cells achieved somewhat higher temperatures of 741° and 788°F. This, again, can be attributed to the significantly higher power capacity of these battery cells.
5. SUMMARY.

The results of the tests show that the Li-ion and Li-Po battery cells can react violently when exposed to an external fire. During the single-cell test for battery type 2, the vents failed to open, resulting in an explosion of the battery cell. It is believed that this is a result of the cell’s internal pressure increasing at a rate that exceeded the capability of the cell’s relief mechanism. All other tests resulted in venting the highly flammable electrolyte, as expected. The cylindrical cells vented in a manner by which the electrolyte would spray forcefully and ignite, resulting in increased temperature and pressure. The cylindrical batteries test results are consistent with previous data that was obtained by examining batteries that are used in PED applications [2].

The Li-Po battery cells did not have vent locations; instead, they were designed so the seam around the perimeter of the cell would open, thus exposing the flammable electrolyte. The failure of the Li-Po battery cells greatly fueled the existing fire as the full amount of the electrolyte was exposed all at once to the fire source. In both single- and multiple-cell tests, the Li-Po battery cells, which have a much higher energy density and power capacity (8 Ah per cell versus 1.2 and 2.3 Ah for the cylindrical Li-ion cells), resulted in significantly higher temperature and pressure increases when compared to either of the two cylindrical cell types.

Attempts to cause the battery cells to reach their thermal runaway point via short circuiting the terminals were unsuccessful on all three battery types. The autoignition tests showed that battery cells reached thermal runaway and failed at temperatures ranging between 330° and 527°F. The Li-Po battery cells autoignited at lower temperatures and created far greater temperature increases than the Li-ion battery cells.

Tests conducted with a hand-held Halon 1211 fire extinguisher showed that the halon was able to successfully extinguish the fires resulting from all three battery types. However, for the Li-Po battery cells, even after several attempts, the halon extinguishing agent was not able to prevent reignitions in the fire test chamber. Due to decreased visibility, however, it was difficult to ascertain whether the re-ignition events were subsequent battery cells venting or if they were due to a re-ignition of the remaining 1-propanol in the fire pan.

6. REFERENCES.


21. Appendix 7 Important Standards

IEC 61430 ED1.0

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Batteries de démarrage au plomb

Secondary cells and batteries –
Test methods for checking the performance
of devices designed for reducing
explosion hazards –
Lead-acid starter batteries
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Secondary cells and batteries –
Test methods for checking the performance
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Lead-acid starter batteries
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INTERNATIONAL ELECTROTECHNICAL COMMISSION

SECONDARY CELLS AND BATTERIES –
TEST METHODS FOR CHECKING THE PERFORMANCE OF DEVICES
DESIGNED FOR REDUCING EXPLOSION HAZARDS –
LEAD-ACID STARTER BATTERIES

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- type 1, when the required support cannot be obtained for the publication of an International Standard, despite repeated efforts;
- type 2, when the subject is still under technical development or where for any other reason there is the future but not immediate possibility of an agreement on an International Standard;
- type 3, when a technical committee has collected data of a different kind from that which is normally published as an International Standards, for example "state of the art".

Technical reports of types 1 and 2 are subject to review within three years of publication to decide whether they can be transformed into International Standards. Technical reports of type 3 do not necessarily have to be reviewed until the data they provide are considered to be no longer valid or useful.

IEC 61430 which is a technical report of type 2 has been prepared by IEC technical committee 21: Secondary cells and batteries.
The text of this technical report is based on the following documents:

<table>
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<tbody>
<tr>
<td>21/410/CDV</td>
<td>21/432/RVC</td>
</tr>
</tbody>
</table>

Full information on the voting for the approval of this technical report can be found in the report on voting indicated in the above table.

This document is issued in the type 2 technical report series of publications (according to G.3.2.2 of part 1 of the IEC/ISO Directives) as a "prospective standard for provisional application" in the field of secondary cells and batteries and more specifically devices designed for reducing explosion hazards on lead-acid starter batteries because there is an urgent requirement for guidance on how standards in this field should be used to meet an identified need.

This document is not to be regarded as an "International Standard". It is proposed for provisional application so that information and experience of its use in practice may be gathered. Comments on the content of this document should be sent to the IEC Central Office.

A review of this type 2 technical report will be carried out not later than three years after its publication, with the options of either extension for a further three years or conversion to an International Standard or withdrawal.

Annexes A and B form an integral part of this technical report.
INTRODUCTION

Lead-acid starter batteries contain an aqueous electrolyte of dilute sulphuric acid. They can emit hydrogen and/or oxygen gas during use, particularly during charging. Hydrogen-air or hydrogen-oxygen mixtures will explode, if ignited, over a wide concentration range of hydrogen (4 % V/V to 96 % V/V H2). When such explosion occurs inside a battery, a rupture of the container associated with ejection of electrolyte and solid objects takes place.

The use of an effective flame arrester in the battery venting system will prevent an external explosion propagating into the battery.

No alterations should be made to the venting system of the battery for they may significantly affect the level of protection. Users wishing to make any change or addition to the battery assembly should seek advice from the battery manufacturer.
Publications de la CEI préparées par le Comité d’Etudes n° 21

60095: — Batteries d'accumulateurs de démarrage au plomb.
60095-1 (1988)  
Première partie: Prescriptions générales et méthodes d'essais.  

60095-2 (1984)  
Deuxième partie: Dimensions des batteries et dimensions et marquage des bornes.  

60095-4 (1989)  
Quatrième partie: Dimensions des batteries pour poids lourds.  

60254: — Batteries de traction au plomb.
60254-1 (1997)  
Partie 1: Prescriptions générales et méthodes d'essai.

60254-2 (1997)  
Partie 2: Dimensions des éléments et des bornes et indication de la polarité sur les éléments.

60285 (1993)  
Accumulateurs alcalins – Éléments individuels cylindriques rechargeables étanches au nickel-cadmium.  

60509 (1988)  
Éléments individuels boutons rechargeables, étanches, au nickel-cadmium.

60622 (1988)  
Éléments individuels parallélogrippées rechargeables étanches au nickel-cadmium.  

60623 (1990)  
Éléments individuels parallélogrippées rechargeables ouverts au nickel-cadmium.  

60896: — Batteries stationnaires au plomb – Prescriptions générales et méthodes d'essai.
60896-1 (1987)  
Première partie: Batteries au plomb de type ouvert.  
Amendement n° 2 (1996).

60896-2 (1995)  
Partie 2: Batteries étanches à soupapes.

60952: — Batteries d'avion.
60952-1 (1988)  
Première partie: Procédures générales d'essais et niveaux de performances.

60952-2 (1991)  
Partie 2: Exigences de conception et de construction.

60952-3 (1993)  
Partie 3: Connecteurs électriques externes.

60993 (1989)  
Electrolyte pour éléments ouverts au nickel-cadmium.

61044 (1990)  
Charge opportune des batteries de traction au plomb.

61056: — Éléments et batteries au plomb portatives (Types à soupapes).
61056-1 (1991)  
Partie 1: Prescriptions générales et caractéristiques fonctionnelles – Méthodes d'essai.

61056-2 (1994)  
Partie 2: Dimensions, bornes et marquage.

61056-3 (1991)  
Partie 3: Recommandations de sécurité relatives à leur utilisation dans les matériels électriques.

IEC publications prepared by Technical Committee No. 21

60095: — Lead-acid starter batteries.
60095-1 (1988)  
Part 1: General requirements and methods of test.  
Amendment 1 (1993).  

60095-2 (1984)  
Part 2: Dimensions of batteries and dimensions and marking of terminals.  

60095-4 (1989)  
Part 4: Dimensions of batteries for heavy tracks.  
Amendment 1 (1996).

60254: — Lead-acid traction batteries.
60254-1 (1997)  
Part 1: General requirements and methods of test.

60254-2 (1997)  
Part 2: Dimensions of cells and terminals and marking of polarity on cells.

60285 (1993)  
Alkaline secondary cells and batteries – Sealed nickel-cadmium cylindrical rechargeable single cells.  

60509 (1988)  
Sealed nickel-cadmium button rechargeable single cells.

60622 (1988)  
Sealed nickel-cadmium prismatic rechargeable single cells.  
Amendment No. 1 (1989).  

60623 (1990)  
Vented nickel-cadmium prismatic rechargeable single cells.  

60896: — Stationary lead-acid batteries – General requirements and methods of test.
60896-1 (1987)  
Part 1: Vented types.  
Amendment No. 1 (1988).  
Amendment No. 2 (1990).

60896-2 (1995)  
Part 2: Valve regulated types.

60952: — Aircraft batteries.
60952-1 (1988)  
Part 1: General test requirements and performance levels.

60952-2 (1991)  
Part 2: Design and construction requirements.

60952-3 (1993)  
Part 3: External electrical connectors.

60993 (1989)  
Electrolyte for vented nickel-cadmium cells.

61044 (1990)  
Opportunity-charging of lead-acid traction batteries.

61056: — Portable lead-acid cells and batteries (Valve-regulated types).
61056-1 (1991)  
Part 1: General requirements, functional characteristics – Methods of test.

61056-2 (1994)  
Part 2: Dimensions, terminals and marking.

61056-3 (1991)  
Part 3: Safety recommendations for use in electric appliances.

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<td>Secondary cells and batteries containing alkaline or other non-acid electrolytes – Sealed nickel-cadmium small prismatic rechargeable single cells.</td>
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Electrically propelled road vehicles — Test specification for lithium-ion traction battery systems —

Part 1: High power applications

Véhicules routiers à propulsion électrique — Spécifications d’essai pour des installations de batterie de traction aux ions lithium —

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ICS 43.120
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ISO/DIS 12405-1

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75% of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 12405-1 was prepared by Technical Committee ISO/TC 22, Road vehicles, Subcommittee SC 21, Electrically propelled road vehicles.

ISO 12405 consists of the following parts, under the general title Electrically propelled road vehicles — Test specification for lithium-ion traction battery packs and systems:

— Part 1: High power applications
— Part 2: High energy applications
Introduction

Lithium Ion based battery systems are an efficient alternative energy storage system for electrically propelled vehicles. The requirements for Lithium Ion based battery systems to be used as power source for the propulsion of electric road vehicles are significantly different to those batteries used for consumer electronics or stationary usage.

This International Standard provides specific test procedures for Lithium Ion battery packs and systems specially developed for propulsion of road vehicles. This International Standard specifies such tests and related requirements to ensure that a battery pack or system is able to meet the specific needs of the automobile industry. It enables vehicle manufactures to choose test procedures to evaluate the characteristics of a battery pack or system for their specific requirements.

A coordination of test specifications for battery cells, packs and systems for automotive application is necessary for practical usage of standards.

Specifications for battery cells or modules are given in IEC 61982, Parts 4 and 5.

Some tests as prescribed within this specification are based on existing specifications i.e. from USABC, EU-CAR, FreedomCar and other sources.
Electrically propelled road vehicles — Test specification for lithium-ion traction battery systems —
Part 1: High power applications

1 Scope

This part of ISO 12405 specifies test procedures for lithium-ion battery packs and systems, to be used in electrically propelled road vehicles.

The specified test procedures enable the user of this part of ISO 12405 to determine the essential characteristics on performance, reliability and abuse of lithium-ion battery packs and systems. The user is also supported to compare the test results achieved for different battery packs or systems.

Therefore the objective of this part of ISO 12405 is to specify standard test procedures for the basic characteristics on performance, reliability and abuse of lithium-ion battery packs and systems.

This part of ISO 12405 enables setting up a dedicated test plan for an individual battery pack or system subject to an agreement between customer and supplier. If required, the relevant test procedures and/or test conditions of lithium-ion battery packs and systems may be selected from the standard tests provided in this part of ISO 12405 to configure a dedicated test plan.

Part 1 specifies the tests for high power battery packs and systems.

NOTE 1 Typical applications for high power battery packs and systems are HEV and FCV.

NOTE 2 Testing on cell level is under consideration in IEC.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 6469-1: Electrically propelled road vehicles -- Safety specifications -- Part 1: On-board rechargeable energy storage system (RESS)

ISO 6469-3: Electrically propelled road vehicles -- Safety specifications -- Part 3: Protection of persons against electric shock

ISO 16750-1: Road vehicles Environmental conditions and testing for electrical and electronic equipment -- Part 1 General

ISO 16750-3: Road vehicles Environmental conditions and testing for electrical and electronic equipment -- Part 3: Mechanical Loads

ISO 16750-4: Road vehicles Environmental conditions and testing for electrical and electronic equipment -- Part 4: Climatic loads
ISO/DIS 12405-1

IEC 60068-2-30, Basic environmental testing procedures — Part 2: Tests; Test Db and guidance: Damp heat, cyclic (12 + 12-hour cycle)

IEC 60068-2-47 Environmental testing — Tests - Mounting of specimens for vibration, impact and similar dynamic tests

IEC 60068-2-64 Environmental testing — Part 2: Test procedure; test Flh: Wide band random vibration, (digitally controlled) and instructions

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1 battery control unit
BCU
electronic device that controls or manage or detect or calculate electric and thermal functions of the battery system and that provides communication between the battery system and other vehicle controllers

NOTE See also 5.5.1 for further explanation.

3.2 battery pack
energy storage device that includes cells or cell assemblies normally connected with cell electronics, high voltage circuit and over current shut-off device including electrical interconnections, interfaces for external systems (e.g. cooling, high voltage, auxiliary low voltage and communication)

NOTE See 5.4 and Annex A, A.2 for further explanation.

3.3 battery system
energy storage device that includes cells or cell assemblies or battery pack(s) as well as electrical circuits and electronics (e.g. BCU, contactors)

NOTE See 5.5.2, 5.5.3 and Annex A, A.3.1 and A.3.2 for further explanation. Battery system components can also be distributed in different devices within the vehicle.

3.4 capacity
total number of ampere-hours that can be withdrawn from a fully charged battery under specified conditions

3.5 cell electronics
electronic device that collects and possibly monitors thermal and electrical data of cells or cell assemblies and contains electronic for cell balancing, if necessary

NOTE The cell electronics may include a cell controller. The functionality of cell balancing may be controlled by the cell electronics or it may be controlled by the BCU.

3.6 customer
party which is interested to use the battery pack or system and therefore order or perform the test

EXAMPLE vehicle manufacturer

3.7 device under test
DUT
within this part of ISO 12405 a battery pack or battery system

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3.8 energy density
amount of stored energy related to the battery pack or system volume and expressed in Wh/l

NOTE The battery pack or system includes the cooling system, if any, to the point of a reversible attachment of the coolant lines or air ducts, respectively.

3.9 energy round trip efficiency
the ratio of the net DC energy (Wh discharge) delivered by a DUT during a discharge test to the total DC energy (Wh charge) required to restore the initial SOC by a standard charge

3.10 high energy application
characteristic of device or application, for which the ratio between maximum allowed electric power output and electric energy output at a 1C discharge rate at RT for a battery pack or system is typically lower than 10

NOTE Typically high energy battery packs and systems are designs for applications in BEVs.

3.11 high power application
characteristic of device or application, for which by the ratio between maximum allowed electric power output and electric energy output at a 1C discharge rate at RT for a battery pack or system is typically equal or higher than 10

NOTE Typically high power battery packs and systems are designs for applications in HEVs and FCVs.

3.12 rated capacity
suppliers specification of the total number of ampere-hours that can be withdrawn from a fully charged battery pack or system for a specified set of test conditions such as discharge rate, temperature, discharge cut-off voltage, etc.

3.13 room temperature
RT
temperature of (25 ± 2) °C

3.14 sign of battery current
discharge current is specified as positive and the charge current as negative

3.15 specific energy
amount of stored energy related to the battery pack or system mass and expressed in Wh/kg

NOTE The battery pack or system shall include the cooling system, if any, to the point of a reversible attachment of the coolant lines or air ducts, respectively. For liquid cooled systems the coolant mass inside the battery pack or system shall be included.

3.16 state of charge
SOC
available capacity in a battery pack or system expressed as a percentage of rated capacity

3.17 supplier
party which provides battery systems and packs

EXAMPLE battery manufacturer
4 Symbols and abbreviated terms

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Definition</th>
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<tbody>
<tr>
<td>BCU</td>
<td>battery control unit</td>
</tr>
<tr>
<td>BEV</td>
<td>battery electric vehicle</td>
</tr>
<tr>
<td>BOL</td>
<td>beginning of life</td>
</tr>
<tr>
<td>C</td>
<td>capacity, expressed in ampere hours (Ah)</td>
</tr>
<tr>
<td>$nC$</td>
<td>Current rate equal to $n$ times the one hour discharge capacity expressed in ampere (e.g. 5C is equal five times the 1h current discharge rate, expressed in A)</td>
</tr>
<tr>
<td>DUT</td>
<td>device under test</td>
</tr>
<tr>
<td>EODV</td>
<td>end of discharge voltage</td>
</tr>
<tr>
<td>EUCAR</td>
<td>European Council for Automotive Research</td>
</tr>
<tr>
<td>EV</td>
<td>electric vehicle</td>
</tr>
<tr>
<td>FCV</td>
<td>fuel cell vehicle</td>
</tr>
<tr>
<td>HEV</td>
<td>hybrid electric vehicle</td>
</tr>
<tr>
<td>HV</td>
<td>high voltage (voltage class B: max. working voltage is ($&gt; 60$ and $\leq 1500$) V d.c., see ISO 6469-1)</td>
</tr>
<tr>
<td>IEC</td>
<td>International Electrotechnical Commission</td>
</tr>
<tr>
<td>ISO</td>
<td>International Organization for Standardization</td>
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<td>LV</td>
<td>low voltage (voltage class A: max. working voltage is $\leq 60$ V d.c., see ISO 6469-3)</td>
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<td>OCV</td>
<td>Open Circuit Voltage</td>
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<td>PNGV</td>
<td>Partnership for a new generation of vehicles</td>
</tr>
<tr>
<td>PSD</td>
<td>Power Spectral Density</td>
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<tr>
<td>RESS</td>
<td>rechargeable energy storage system</td>
</tr>
<tr>
<td>RMS</td>
<td>root mean square</td>
</tr>
<tr>
<td>RT</td>
<td>Room Temperature ($25 \pm 2$) °C</td>
</tr>
<tr>
<td>SC</td>
<td>Standard cycle</td>
</tr>
<tr>
<td>SCH</td>
<td>Standard charge</td>
</tr>
<tr>
<td>SDCH</td>
<td>Standard discharge</td>
</tr>
<tr>
<td>SOC</td>
<td>State of charge</td>
</tr>
<tr>
<td>USABC</td>
<td>United States Advanced Battery Consortium</td>
</tr>
<tr>
<td>$\eta$</td>
<td>efficiency</td>
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</table>

5 General requirements

5.1 General conditions

A battery pack or system to be tested according to this part of ISO 12405 shall fulfil the following requirements:

- electrical safety design shall be approved according the requirements given in ISO 6469-1 and ISO 6469-3;
- necessary documentation for operation and needed interface parts for connection to the test equipment (i.e. connectors, plugs including cooling) shall be delivered together with the DUT.

A battery system shall enable the specified tests, i.e. via specified test modes implemented in the BCU and shall be able to communicate with the test bench via common communication buses.
The battery pack subsystem as a DUT shall comprise of all parts specified by the customer (e.g. including mechanical and electrical connecting points for mechanical test).

If not otherwise specified, before each test the DUT shall be stabilised at the test temperature for a minimum of 12 h and the BCU, if any, shall be switched off. This period may be reduced if the thermal stabilisation of the DUT is reached. Thermal stabilisation is fulfilled, when after a period of 1 h the change among all available cell temperature measuring points is lower than 4 K.

If not otherwise specified, each charge and each SOC change shall be followed by a rest period of 30 min.

The accuracy of external measurement equipment shall be at least within the following tolerances:

- voltage ± 0.5 %
- current ± 0.5 %
- temperature ± 1 K

The overall accuracy of externally controlled or measured values, relative to the specified or actual values, shall be at least within the following tolerances:

- voltage ± 1 %
- current ± 1 %
- temperature ± 2 K
- time ± 0.1 %
- mass ± 0.1 %
- dimensions ± 0.1 %

All values (time, temperature, current and voltage) shall be noted at least every 5 % of the estimated discharge and charge time, except if it is noted otherwise in the individual test procedure.

5.2 Test sequence plan

The test sequence for an individual battery pack or system, or a battery pack subsystem shall be based on agreement between customer and supplier with consideration of tests in 5.3.

An example for a list of test conditions, to be agreed between customer and supplier is provided in Annex C, Table C.1.

5.3 Tests

An overview about the tests is given in Figure 1, where the references to the specific clauses are also given.
### Overview of tests

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<th>Performance tests</th>
<th>Reliability tests</th>
<th>Abuse tests</th>
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<td>(Clause 7)</td>
<td>(Clause 8)</td>
<td>(Clause 9)</td>
</tr>
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<td>Pre-conditioning cycles (Clause 6.1)</td>
<td>Energy and capacity at RT (Clause 7.1)</td>
<td>Dewing (Clause 8.1)</td>
<td>Short circuit protection (Clause 9.2)</td>
</tr>
<tr>
<td>Standard cycle (Clause 6.2)</td>
<td>Energy and capacity at different temperature and discharge rates (Clause 7.2)</td>
<td>Thermal shock cycling (Clause 8.2)</td>
<td>Overcharge protection (Clause 9.3)</td>
</tr>
<tr>
<td>Standard discharge (Clause 6.2.2.2)</td>
<td>Power and internal resistance (Clause 7.3)</td>
<td>Vibration (Clause 8.3)</td>
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</tr>
<tr>
<td>Standard charge (Clause 6.2.2.3)</td>
<td>No load SOC loss (Clause 7.4)</td>
<td>Mechanical shock (Clause 8.4)</td>
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<td></td>
<td>SOC loss at storage (Clause 7.5)</td>
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<td>Cranking power at low temperature (Clause 7.6)</td>
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<td>Cranking power at high temperature (Clause 7.7)</td>
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<td></td>
<td>Energy efficiency (Clause 7.8)</td>
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<tr>
<td></td>
<td>Cycle life (Clause 7.9)</td>
<td></td>
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</tr>
</tbody>
</table>

**Figure 1 — Test plan - overview**

### 5.4 Battery pack - typical configuration

**Figure 2 — Typical configuration of battery pack**
A battery pack represents an energy storage device that includes cells or cell assemblies, cell electronics, high voltage circuit and over current shut-off device including electrical interconnections, interfaces for cooling, high voltage, auxiliary low voltage and communication. The high voltage circuit of the battery pack may include contactors. For a battery pack of 60 V d.c. or higher, a manual shut-off function (service disconnect) may be included. All components are typically placed in a normal use impact resistance case.

5.5 Battery system - typical configuration

5.5.1 BCU

The BCU calculates state-of-charge and state-of-health and provides battery system operational limits to the vehicle management unit. The BCU may have direct access to the main contactors of the battery system in order to interrupt the high voltage circuit under specified conditions, e.g. over current, over voltage, low voltage, high temperature. The BCU may vary in design and implementation, it may be a single electronic unit integrated into the battery system or it may be placed outside the battery pack and connected via a communication bus or input/output lines to the battery pack. The BCU functionalities may be integrated functions of one or more vehicle control units.

5.5.2 Battery system with integrated battery control unit (BCU)

A battery system represents an energy storage device that includes cells or cell assemblies, cell electronics, battery control unit, high voltage circuit with contactors and over current shut-off device including electrical interconnections, interfaces for cooling, high voltage, auxiliary low voltage and communication. For a battery system of 60 V d.c. or higher, a manual shut-off function (service disconnect) may be included. All components are typically placed in a normal use impact resistance case. In this example, the battery control unit is integrated inside the normal use impact resistance case and connected concerning its control functionalities to the battery pack.
5.5.3 Battery system with external battery control unit (BCU)

A battery system represents an energy storage device that includes cells or cell assemblies, cell electronics, battery control unit, high voltage circuit with contactors and over current shut-off device including electrical interconnections, interfaces for cooling, high voltage, auxiliary low voltage and communication. For a battery system of 60 V d.c. or higher, a manual shut-off function (service disconnect) may be included. All components are typically placed in a normal use impact resistance case. In this example, the battery control unit is placed outside the normal use impact resistance case and connected concerning its control functionalities to the battery pack.

5.6 Preparation of battery pack and system for bench testing

5.6.1 Preparation of battery pack

If not otherwise specified, the battery pack shall be connected with HV and LV connections to the test bench equipment. Contactors, available voltage, current and temperature data shall be controlled according to the battery pack suppliers requirements and according to the given test specification by the test bench equipment. The passive over current protection device shall be operational in the battery pack. Active overcurrent protection shall be maintained by the bench test equipment, if necessary via disconnection of the battery pack main contactors. The cooling device may be connected to the bench test equipment and operated according to the suppliers requirements.

5.6.2 Preparation of battery system

If not otherwise specified, the battery system shall be connected with HV, LV and cooling connections to the test bench equipment. The battery system shall be controlled by the BCU, the bench test equipment shall follow the operational limits provided by the BCU via bus communication. The bench test equipment shall maintain the on/off requirements for the main contactors and the voltage, current and temperature profiles according to the requested requirements of the given test procedure. The battery system cooling device and the corresponding cooling loop at the bench test equipment shall be operational according to the given test specifications and the controls by the BCU. The BCU shall enable the bench test equipment to perform the requested test procedure within the battery system operational limits. If necessary, the BCU program shall be adapted by the supplier for the requested test procedure. The active and passive over current protection device shall be operational by the battery system. Active overcurrent protection shall be maintained by the bench test equipment, too, if necessary via request of disconnection of the battery system main contactors.
A battery system represents an energy storage device that includes cells or cell assemblies, cell electronics, battery control unit, high voltage circuit with contactors and over current shut-off device including electrical interconnections, interfaces for cooling, high voltage, auxiliary low voltage and communication. For a battery system of 60 V d.c. or higher, a manual shut-off function (service disconnect) may be included. All components are typically placed in a normal use impact resistance case. In this example, the battery control unit is placed outside the normal use impact resistance case and connected concerning its control functionalities to the battery pack.

A.4 Overview on tests

Table A.1 recommends which tests should be carried out on which level.

<table>
<thead>
<tr>
<th>Test Procedure</th>
<th>Energy &amp; Capacity</th>
<th>Power &amp; Internal Resistance</th>
<th>No Load SOC tests</th>
<th>No Load BOC tests</th>
<th>Cooling Power at Low Temperature</th>
<th>Cooling Power at High Temperature</th>
<th>Battery efficiency</th>
<th>Cycle Life</th>
<th>Etching</th>
<th>Vibration</th>
<th>Mechanical Stress</th>
<th>Short Circuit</th>
<th>Overcharge Protection</th>
<th>Undercharge Protection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Battery system (Battery pack with integrated BCU)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>V</td>
<td>V</td>
<td>V</td>
</tr>
<tr>
<td>System</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>V</td>
<td>V</td>
</tr>
<tr>
<td>Battery system (Battery pack with external BCU)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>V</td>
<td>V</td>
</tr>
<tr>
<td>Pack</td>
<td>U</td>
<td>U</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>W</td>
<td>-</td>
</tr>
</tbody>
</table>

*1 BCU not included, external BCU not operating. Cooling not operating, main contactors controlled manually.

X relevant test
- test not relevant
U adapted / reduced procedure
V functional test including active BCU
W fuse test

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Annex B
(informative)

Examples of data sheet for battery pack and system testing

The following tables might be taken as examples to report about the test results. They should be filled in by the test institute and included in the test report. In addition diagrams of capacity versus constant current discharge (at different ambient temperatures) and power versus constant power discharge (at different ambient temperatures) might also be included in the test report. The battery supplier should provide all necessary information and technical data to support the tests itself.

Table B.1 — Battery pack / system - General supplier data

<table>
<thead>
<tr>
<th>Supplier</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Company</td>
<td></td>
</tr>
<tr>
<td>Address</td>
<td></td>
</tr>
<tr>
<td>Internet address</td>
<td></td>
</tr>
<tr>
<td>Contact person</td>
<td></td>
</tr>
<tr>
<td>Name</td>
<td></td>
</tr>
<tr>
<td>Tel.</td>
<td></td>
</tr>
<tr>
<td>E-mail</td>
<td></td>
</tr>
<tr>
<td>Fax</td>
<td></td>
</tr>
</tbody>
</table>
### Table B.2 — Battery pack / system

<table>
<thead>
<tr>
<th>Type of chemistry</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturers trade name</td>
<td></td>
</tr>
<tr>
<td>Date of manufacturing</td>
<td></td>
</tr>
<tr>
<td>Nominal pack / system voltage [V]</td>
<td></td>
</tr>
<tr>
<td>Nominal capacity @ 1C [Ah]</td>
<td></td>
</tr>
<tr>
<td>Nominal cell voltage [V]</td>
<td></td>
</tr>
<tr>
<td>Number of cells</td>
<td></td>
</tr>
<tr>
<td>Number of cell assemblies (modules)</td>
<td></td>
</tr>
<tr>
<td>Type of cathode material</td>
<td></td>
</tr>
<tr>
<td>Type of anode material</td>
<td></td>
</tr>
<tr>
<td>Type of separator material</td>
<td></td>
</tr>
<tr>
<td>Type of electrolyte</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cell:</th>
<th>Cell assembly (module):</th>
<th>Pack / system:</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Mass [kg]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Volume [dm³]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Length [mm]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Width [mm]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Height [mm]</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Date of received battery pack / system at customer [YYYY-MM-DD]:**

### Peripherals and Instruction

<table>
<thead>
<tr>
<th>Aspect</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>BCU</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thermal management</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Safety devices</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Operating manual</td>
<td>Yes</td>
<td>No</td>
</tr>
</tbody>
</table>

### Table B.3 — Battery pack / system - Auxiliary equipment

<table>
<thead>
<tr>
<th>Aspect</th>
<th>BCU</th>
<th>Cooling</th>
<th>Connectors</th>
<th>Other</th>
<th>Tray</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Mass [kg]</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Volume [dm³]</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Length [mm]</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Width [mm]</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Height [mm]</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power consumption</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Table B.4 — Battery pack / system - Operating conditions

<table>
<thead>
<tr>
<th>Charging</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Method</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Charging time</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature limits [°C]</td>
<td>min:</td>
<td>max:</td>
</tr>
<tr>
<td>Max. continuous charge current [A]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max. charge current [A], duration [s]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max. battery temperature during charge [°C]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max. voltage during charge [V]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Full description of the charging procedure including a charge diagram shall be given in an appendix.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Discharging</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature limit [°C]</td>
<td>min:</td>
<td>max:</td>
</tr>
<tr>
<td>Max. continuous discharge current [A]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max. discharge current [A], duration [s]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Min. voltage during discharge [V]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cut off voltage [V]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Full description of the requirements for current and voltage limits depending on SOC and temperature during discharging shall be given in an appendix.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Table B.5 — Battery pack / system - Performance characteristics

<table>
<thead>
<tr>
<th>Test Temperature [°C]</th>
<th>1C:</th>
<th>2C:</th>
<th>10C:</th>
<th>C at ( I_{\text{max}} ):</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity [Ah]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy [Wh]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Specific Energy [Wh/kg]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy Density [Wh/l]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>80 % SOC:</td>
<td>65 % SOC:</td>
<td>50 % SOC:</td>
<td>35 % SOC:</td>
</tr>
<tr>
<td>0,1 s Discharge Resistance [mOhm]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 s Discharge Resistance [mOhm]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 s Discharge Resistance [mOhm]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18 s Discharge Resistance [mOhm]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0,1 s Discharge Power [W]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 s Discharge Power [W]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 s Discharge Power [W]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18 s Discharge Power [W]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0,1 s Charge Resistance [mOhm]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 s Charge Resistance [mOhm]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 s Charge Resistance [mOhm]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0,1 s Regenerative Power [W]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 s Regenerative Power [W]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 s Regenerative Power [W]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Open circuit voltage [V]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Annex C
(informative)

Example of test conditions

As described in the scope of this part of ISO 12405, relevant test procedures and test conditions may be selected from this part of ISO 12405 based on the agreement between customer and supplier.

This annex provides the users of this part of ISO 12405 with an example of test conditions, see Table C.1.

<table>
<thead>
<tr>
<th>Test</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.1 Energy and capacity at RT</td>
<td>Discharge rate 1C, 10C</td>
</tr>
<tr>
<td>7.3 Power and internal resistance</td>
<td>Temperature 40 °C, RT, 0 °C at 50 % SOC, SOC 80 %, 50 %, 20 % at RT</td>
</tr>
<tr>
<td>7.4 No load SOC loss</td>
<td>Temperature RT</td>
</tr>
<tr>
<td>7.5 SOC loss at storage</td>
<td>All conditions specified in 7.5</td>
</tr>
<tr>
<td>7.6 Cranking power at low temperature</td>
<td>Temperature -18 °C</td>
</tr>
<tr>
<td>7.7 Cranking power at high temperature</td>
<td>All conditions specified in 7.7</td>
</tr>
<tr>
<td>7.8 Energy efficiency</td>
<td>Temperature RT, 40 °C, 0 °C at 50 % SOC, SOC 80 %, 50 %, 20 % at RT, Discharge rate $I_{\text{max}}$, Charge rate $-0.75 I_{\text{max}}$</td>
</tr>
<tr>
<td>7.9 Cycle life test</td>
<td>End of test criteria As specified in 7.9.2.7, or after 3 months</td>
</tr>
<tr>
<td>8.1 Dewing test (temperature change)</td>
<td>All conditions specified in 8.1</td>
</tr>
<tr>
<td>8.2 Thermal shock cycling</td>
<td>All conditions specified in 8.2</td>
</tr>
<tr>
<td>8.3 Vibration test</td>
<td>Temperature RT</td>
</tr>
<tr>
<td>8.4 Mechanical shock</td>
<td>All conditions specified in 8.4</td>
</tr>
<tr>
<td>9.2 Short circuit protection</td>
<td>All conditions specified in 9.2</td>
</tr>
<tr>
<td>9.3 Overcharge protection</td>
<td>All conditions specified in 9.3</td>
</tr>
<tr>
<td>9.4 Overdischarge protection</td>
<td>All conditions specified in 9.4</td>
</tr>
</tbody>
</table>
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[6] FreedomCar: Electrical energy storage system – Abuse test manual for electric and hybrid electric vehicle applications; June 2005
[7] USABC (United States Advanced Battery Consortium): Development of advanced high power batteries for hybrid electric vehicle applications
[9] System design requirements specification (VDA Initiative Circle "Energy Storage System", Source VDA)
Electrically propelled road vehicles — Test specification for lithium-ion traction battery systems —

Part 2:
High energy applications

Véhicules routiers à propulsion électrique — Spécifications d’essai pour des installations de batterie de traction aux ions lithium —
Partie 2: Applications à haute énergie

ICS 43.120

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To expedite distribution, this document is circulated as received from the committee secretariat. ISO Central Secretariat work of editing and text composition will be undertaken at publication stage.
Pour accélérer la distribution, le présent document est distribué tel qu’il est parvenu du secretariat du comité. Le travail de rédaction et de composition de texte sera effectué au Secrétariat central de l’ISO au stade de publication.
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ISO/DIS 12405-2

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 12405-2 was prepared by Technical Committee ISO/TC 22, Road vehicles, Subcommittee SC 21, Electrically propelled road vehicles.

ISO 12405 consists of the following parts, under the general title Electrically propelled road vehicles — Test specification for lithium-ion traction battery packs and systems:

— Part 1: High power application
— Part 2: High energy application
Introduction

Lithium-ion based battery systems are an efficient alternative energy storage system for electrically propelled vehicles. The requirements for lithium-ion based battery systems to be used as power source for the propulsion of electric road vehicles are significantly different to those batteries used for consumer electronics or stationary usage.

This International Standard provides specific test procedures for lithium-ion battery packs and systems specially developed for propulsion of road vehicles. This International Standard specifies such tests and related requirements to ensure that a battery pack or system is able to meet the specific needs of the automobile industry. It enables vehicle manufacturers to choose test procedures to evaluate the characteristics of a battery pack or system for their specific requirements.

A coordination of test specifications for battery cells, packs and systems for automotive application is necessary for practical usage of standards.

Specifications for battery cells are given in IEC 62660, Parts 1 and 2.

Some tests as prescribed within this specification are based on existing specifications i.e. from USABC, EUCAR, FreedomCar and other sources.
Electrically propelled road vehicles — Test specification for lithium-ion traction battery systems —

Part 2:

High energy applications

1 Scope

This standard specifies test procedures for lithium-ion battery packs and systems, to be used in electrically propelled road vehicles.

The specified test procedures enable the user of this standard to determine the essential characteristics on performance, reliability and abuse of lithium-ion battery packs and systems. The user is also supported to compare the test results achieved for different battery packs or systems.

Therefore the objective of this standard is to specify standard test procedures for the basic characteristics on performance, reliability and abuse of lithium-ion battery packs and systems.

This standard enables setting up a dedicated test plan for an individual battery pack or system subject to an agreement between customer and supplier. If required, the relevant test procedures and/or test conditions of lithium-ion battery packs and systems may be selected from the standard tests provided in this standard to configure a dedicated test plan.

Part 2 specifies the tests for high energy battery packs and systems.

NOTE 1 Typical applications for high energy battery packs and systems are BEV and PHEV.

NOTE 2 Testing on cell level is specified in IEC 62660, Parts 1 and 2.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 6498-1: Electrically propelled road vehicles – Safety specifications – Part 1: On-board rechargeable energy storage system (RESS)


ISO 16750-1: Road vehicles – Environmental conditions and testing for electrical and electronic equipment – Part 1: General

ISO 16750-3: Road vehicles – Environmental conditions and testing for electrical and electronic equipment – Part 3: Mechanical loads

ISO 16750-4: Road vehicles – Environmental conditions and testing for electrical and electronic equipment – Part 4: Climatic loads
IEC 60068-2-30: Basic environmental testing procedures – Part 2: Tests; Test Db and guidance: Damp heat, cyclic (12 + 12-hour cycle)

IEC 60068-2-47: Environmental testing – Part 2-47: Tests; Mounting of specimens for vibration, impact and similar dynamic tests

IEC 60068-2-64 Environmental testing – Part 2: Test procedure; test Fh: Wide band random vibration, (digitally controlled) and instructions

5.3 Tests
An overview about the tests is given in Figure 1, where the references to the specific clauses are also given.

![Overview of tests diagram](image)

<table>
<thead>
<tr>
<th>General tests (Clause 6)</th>
<th>Performance tests (Clause 7)</th>
<th>Reliability tests (Clause 8)</th>
<th>Abuse tests (Clause 9)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-conditioning cycles (Clause 6.1)</td>
<td>Energy and capacity at RT (Clause 7.1)</td>
<td>Dewing (Clause 8.1)</td>
<td>Short circuit protection (Clause 9.2)</td>
</tr>
<tr>
<td>Standard cycle (Clause 6.2)</td>
<td>Energy and capacity at different temperature and discharge rates (Clause 7.2)</td>
<td>Thermal shock cycling (Clause 8.2)</td>
<td>Overcharge protection (Clause 9.3)</td>
</tr>
<tr>
<td>Standard discharge (Clause 6.2.2.2)</td>
<td>Power and internal resistance (Clause 7.3)</td>
<td>Vibration (Clause 8.3)</td>
<td>Overdischarge protection (Clause 9.4)</td>
</tr>
<tr>
<td>Standard charge (Clause 6.2.2.3)</td>
<td>Energy efficiency at fast charging (Clause 7.4)</td>
<td>Mechanical shock (Clause 8.4)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>No load SOC loss (Clause 7.5)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>SOC loss at storage (Clause 7.6)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cycle life (Clause 7.7)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 1 — Test plan – overview
## Table B.2 — Battery pack / system

<table>
<thead>
<tr>
<th>Type of chemistry</th>
<th>Manufacturers trade name</th>
<th>Date of manufacturing</th>
<th>Nominal battery voltage [V]</th>
<th>Nominal capacity @ C/3 [Ah]</th>
<th>Nominal cell voltage [V]</th>
<th>Number of cells</th>
<th>Number of cell assemblies</th>
<th>Type of cathode material</th>
<th>Type of anode material</th>
<th>Type of separator material</th>
<th>Type of electrolyte</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td></td>
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</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Cell:</th>
<th>Cell assembly:</th>
<th>Pack / system:</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Mass [kg]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Volume [dm³]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Length [mm]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Width [mm]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Height [mm]</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Date of received battery pack / system at customer [YYYY-MM-DD]:**

### Peripherals and Instruction

<table>
<thead>
<tr>
<th></th>
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<th>No:</th>
</tr>
</thead>
<tbody>
<tr>
<td>BCU</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thermal management</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Safety devices</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operating manual</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

## Table B.3 — Battery pack / system — Auxiliary equipment

<table>
<thead>
<tr>
<th></th>
<th>BCU</th>
<th>Cooling</th>
<th>Connectors</th>
<th>Other</th>
<th>Tray</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Mass [kg]</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>- Volume [dm³]</td>
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<td>- Length [mm]</td>
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<tr>
<td>- Height [mm]</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power consumption</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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Table B.4 — Battery pack / system — Operating conditions

<table>
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<th>Charging</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Method</td>
<td></td>
</tr>
<tr>
<td>Charging time</td>
<td></td>
</tr>
<tr>
<td>Temperature limits [°C]</td>
<td>min: max:</td>
</tr>
<tr>
<td>Max. continuous charge current [A]</td>
<td></td>
</tr>
<tr>
<td>Max. charge current [A], duration [s]</td>
<td></td>
</tr>
<tr>
<td>Max. battery temperature during charge [°C]</td>
<td></td>
</tr>
<tr>
<td>Max. voltage during charge [V]</td>
<td></td>
</tr>
<tr>
<td>Full description of the charging procedure including a charge diagram shall be given in an appendix.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Discharging</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature limit [°C]</td>
<td>min: max:</td>
</tr>
<tr>
<td>Max. continuous discharge current [A]</td>
<td></td>
</tr>
<tr>
<td>Max. discharge current [A], duration [s]</td>
<td></td>
</tr>
<tr>
<td>Min. voltage during discharge [V]</td>
<td></td>
</tr>
<tr>
<td>Cut off voltage [V]</td>
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<tr>
<td>Full description of the requirements for current and voltage limits depending on SOC and temperature during discharging shall be given in an appendix.</td>
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### Table B.5 — Battery pack / system – Performance characteristics

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<td>2C:</td>
<td>C at I_d max:</td>
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<table>
<thead>
<tr>
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<th>70 %</th>
<th>50 %</th>
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<th>20 %</th>
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<tr>
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<td>2 s Discharge Resistance [mOhm]</td>
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</tr>
<tr>
<td>5 s Discharge Resistance [mOhm]</td>
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<td></td>
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</tr>
<tr>
<td>10 s Discharge Resistance [mOhm]</td>
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<td></td>
</tr>
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<td>18 s Discharge Resistance [mOhm]</td>
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<td>60 s Discharge Resistance [mOhm]</td>
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<td>Overall Discharge Resistance [mOhm]</td>
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<tr>
<td>0.1 s Discharge Power [W]</td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>2 s Discharge Power [W]</td>
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</tr>
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<td>5 s Discharge Power [W]</td>
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<td>10 s Discharge Power [W]</td>
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<tr>
<td>18 s Discharge Power [W]</td>
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<td>18.1 s Discharge Power [W]</td>
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<td>20 s Discharge Power [W]</td>
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<td>60 s Discharge Power [W]</td>
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<td>90 s Discharge Power [W]</td>
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<td>120 s Discharge Power [W]</td>
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<tr>
<td>2 s Charge Resistance [mOhm]</td>
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<td>10 s Charge Resistance [mOhm]</td>
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<td>20 s Charge Resistance [mOhm]</td>
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<td></td>
<td></td>
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<td>Overall Charge Resistance [mOhm]</td>
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<td>Parameter</td>
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<td>Value 3</td>
<td>Value 4</td>
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<tr>
<td>0.1 s Charge Power [W]</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>2 s Charge Power [W]</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>10 s Charge Power [W]</td>
<td></td>
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<td></td>
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<tr>
<td>20 s Charge Power [W]</td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>Open circuit voltage [V]</td>
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</table>
Annex C
(informative)

Example of test conditions

As described in the scope of this standard, relevant test procedures and test conditions may be selected from this standard based on the agreement between customer and supplier.

This annex provides the users of this standard with an example of test conditions, see Table C1.

Table C1 — Example for a list of test conditions

<table>
<thead>
<tr>
<th>Test</th>
<th>Condition</th>
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<tbody>
<tr>
<td>7.1 Energy and capacity at RT</td>
<td>Discharge rate</td>
</tr>
<tr>
<td>7.3 Power and internal resistance</td>
<td>Temperature</td>
</tr>
<tr>
<td></td>
<td>SOC</td>
</tr>
<tr>
<td>7.4 No load SOC loss</td>
<td>Temperature</td>
</tr>
<tr>
<td>7.6 SOC loss at storage</td>
<td>All conditions specified in 7.6</td>
</tr>
<tr>
<td>7.7.2.1 Cycle life - Dynamic discharge application</td>
<td>End of test criteria</td>
</tr>
<tr>
<td>8.1 Dewing (temperature change)</td>
<td>All conditions specified in 8.1</td>
</tr>
<tr>
<td>8.2 Thermal shock cycling</td>
<td>All conditions specified in 8.2</td>
</tr>
<tr>
<td>8.3 Vibration</td>
<td>Temperature</td>
</tr>
<tr>
<td>8.4 Mechanical shock</td>
<td>All conditions specified in 8.4</td>
</tr>
<tr>
<td>9.2 Short circuit protection</td>
<td>All conditions specified in 9.2</td>
</tr>
<tr>
<td>9.3 Overcharge protection</td>
<td>All conditions specified in 9.3</td>
</tr>
<tr>
<td>9.4 Overdischarge protection</td>
<td>All conditions specified in 9.4</td>
</tr>
</tbody>
</table>
Bibliography


[5] FreedomCar: Electrical energy storage system – Abuse test manual for electric and hybrid electric vehicle applications; June 2005


[8] System design requirements specification (VDA Initiative Circle "Energy Storage System", Source VDA)

[9] USABC (United States Advanced Battery Consortium): Development of advanced high power batteries for hybrid electric vehicle applications

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Electrically propelled road vehicles — Test specification for lithium-ion battery packs and systems — Part 3: Safety performance requirements

1 Scope

This International Standard specifies test procedures and provides acceptable safety criteria for voltage class B lithium-ion battery packs and systems, to be used as traction batteries in electrically propelled road vehicles.

Therefore, the objective of this standard is to specify standard test procedures for the basic characteristics on safety performance of lithium-ion battery packs and systems.

This International Standard is related to test the safety performance of battery packs and systems for their intended use in a vehicle. This International Standard is not intended to be applied for the evaluation of the safety of battery packs and systems during transport and storage.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 12405 1, Electrically propelled road vehicles — Test specification for lithium-ion traction battery packs and systems — Part 1: High-power applications

ISO 12405 2, General title of series of parts — Part 2: High energy application

ISO 6469 1, Electrically propelled road vehicles — Safety specifications — Part 1: On-board rechargeable energy storage system (RESS)

ISO 6469 3, Electrically propelled road vehicles — Safety specifications — Part 3: Protection of persons against electric shock

ISO 16750 3, Road vehicles — Environmental conditions and testing for electrical and electronic equipment — Part 3: Mechanical loads

ISO 20653, Road vehicles — Degrees of protection (IP-Code) -- Protection of electrical equipment against foreign objects, water and access

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1 battery control unit BCU

Electronic device that controls or manages or detects or calculates electric and thermal functions of the battery systems and other vehicle controllers.

NOTE See also Annex A for further explanation.
ISO/CD 12405-3

3.2 rupture
loss of mechanical integrity of DUT casing resulting in openings not fulfilling protection degree IPXXB according to ISO 20653

NOTE The kinetic energy of released material is not sufficient to cause physical damage external to the RESS. Fume, gas, liquid release might be part of the rupture.

3.3 battery pack
energy storage device that includes cells or cell assemblies normally connected with cell electronics, voltage class B circuit and overcurrent shut-off device including electrical interconnections, interfaces for external systems (e.g. cooling, voltage class B, auxiliary voltage class A and communication) in a single assembly with a surrounding enclosure

NOTE See Annex A, for further explanation.

3.4 battery system
energy storage device that includes cells or cell assemblies or battery pack(s) as well as BCU

NOTE See Annex A, for further explanation. Battery system components can also be distributed in different devices within the vehicle.

3.5 capacity
total number of ampere-hours that can be withdrawn from a fully charged battery under specified conditions

3.6 cell electronics
electronic device that collects and possibly monitors thermal or electric data of cells or cell assemblies and contains electronics for cell balancing, if necessary

NOTE The cell electronics may include a cell controller. The functionality of cell balancing may be controlled by the cell electronics or it may be controlled by the BCU.

3.7 device under test DUT
within this part of ISO 12405 a battery pack or battery system

3.8 explosion
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 DUT

NOTE The kinetic energy of flying debris from the battery pack or system may be sufficient to cause damage as well.

3.9 fire
continuous emission of flames from a DUT (approximately more than one second)

NOTE Sparks and arcing are not considered as flames.

3.10 high energy application
characteristic of device or application, for which the numerical ratio between maximum allowed electric power output (power in W) and electric energy output (energy in Wh) at a 1 C discharge rate at RT for a battery pack or system is typically lower than 10
NOTE Typically high energy battery packs and systems are designed for applications in BEVs.

3.11 high power application
characteristic of device or application, for which by the numerical ratio between maximum allowed electric
power output (power in W) and electric energy output (energy in Wh) at a 1 C discharge rate at RT for a
battery pack or system is typically equal or higher than 10

NOTE Typically high power battery packs and systems are designed for application in HEVs and FCVs.

3.12 isolation resistance
resistance between live parts of voltage class B electric circuit and the electric chassis as well as the voltage
class A system

3.13 maximum working voltage
highest value of a.c. voltage (rms) or of d.c. voltage which may occur in an electrical system under any normal
operating conditions according to manufacturer’s specifications, disregarding transients

3.14 rated capacity
supplier’s specification of the total number of ampere-hours that can be withdrawn from a fully charged battery
pack or system for a specified set of test conditions such as discharge rate, temperature, discharge cut-off
voltage, etc.

3.15 room temperature
RT
temperature of (25 ± 2)°C

3.16 state of charge SOC
available capacity in a battery pack or system expressed as a percentage of rated capacity

3.17 venting
the controlled release of excessive pressure from a DUT intended by design to preclude rupture or explosion

3.18 Leakage
escape of liquid or gas from a DUT except for venting

3.19 voltage class A
classification of an electric component or circuit with a maximum working voltage of ≤ 30 V a.c. or ≤ 60 V d.c.,
respectively

NOTE For more details, see ISO 6469-3.

3.20 voltage class B
classification of an electric component or circuit with a maximum voltage of (> 30 and ≤ 1000) V a.c. or (> 60
and ≤ 1500) V d.c., respectively

NOTE For more details, see ISO 6469-3.
4 Symbols and abbreviated terms

a.c. alternating current
BCU battery control unit
BEV battery electric vehicle
d.c. direct current
DUT device under test
EV electric vehicle
FCV fuel cell vehicle
HEV hybrid electric vehicle
RESS rechargeable energy storage system
RT room temperature (25 ± 2) °C
SOC state of charge
UNECE United Nations Economic Commission for Europe

5 General requirements

5.1 General conditions

A battery pack or system to be tested according to this standard shall fulfil the following requirements:

— The necessary documentation for operation and needed interface parts for connection to the test equipment (i.e. connectors, plugs including cooling) shall be delivered together with the DUT.

— A battery system shall enable the specified tests, i.e. via specified test modes implement in the BCU and shall be able to communicate with the test bench via common communication buses.

The battery pack subsystem as a DUT shall comprise all parts specified by the customer (e.g. including mechanical and electrical connecting points for mechanical test).

If not otherwise specified, before each test the DUT shall be equilibrated at the test temperature. The thermal equilibration is reached, if during a period of 1 h without active cooling the deviations between test temperature and temperature of all cell temperature measuring points are lower than ± 2 K.

If not otherwise specified, before each test the DUT shall be charged to the 50 % SOC for high-power applications and maximum SOC at normal operation for high-energy applications.

If not otherwise specified, each charge and each SOC change shall be followed by a rest period of 30 min.

If not otherwise specified, all battery system electronic control units have to be connected and in operation or "off" state, as recommended by the manufacturer during testing.

If not specified otherwise in the corresponding test procedure, the conduction of component based testing or vehicle based testing is optional. The selection of either of the described options shall be up to the agreement between customer and supplier.
The accuracy of external measurement equipment shall be at least within the following tolerances:

- voltage ± 0.5 %
- current ± 0.5 %
- temperature ± 1 K

The overall accuracy of externally controlled or measured values, relative to the specified or actual values, shall be at least within the following tolerances:

- voltage ± 1 %
- current ± 1 %
- temperature ± 2 K
- time ± 0.1 %
- mass ± 0.1 %
- dimensions ± 0.1 %

All values (time, temperature, current and voltage) shall be noted at least every 5 % of the estimated discharge and charge time, except if it is noted otherwise in the individual test procedure.

If any test in this standard is performed on vehicle, the same test on battery pack or system level is not necessary.

5.2 Test sequence plan

The test sequence for an individual battery pack or system, or a battery pack subsystem shall be based on agreement between the customer and the supplier.

The re-use of the battery system and/or components in multiple tests is acceptable based on the agreement between customer and supplier.

5.3 Preparation of battery pack and system for bench testing

5.3.1 Preparation of battery pack

If not otherwise specified, the battery pack shall be connected with voltage class B and voltage class A connections to the test bench equipment. Contactors, available voltage, current and temperature data shall be controlled according to the suppliers requirements and according to the given test specification by the test bench equipment. The passive overcurrent protection shall be maintained by the test bench equipment, if necessary via disconnection of the battery pack main contactors. The cooling device may be connected to the test bench equipment and operated according to the suppliers requirements.

5.3.2 Preparation of battery system

If not otherwise specified, the battery system shall be connected with voltage class B, voltage class A and cooling system and BCU to the test bench equipment. The battery system shall be controlled by the BCU. The test bench equipment shall follow the operational limits provided by the BCU via bus communication. The test bench equipment shall maintain the on/off requirements for the main contactors and the voltage, current and temperature profiles according to the requested requirements of the given test procedure. The battery system cooling device and the corresponding cooling loop at the test bench equipment shall be operational according to the given test specifications and the controls by the BCU. The BCU shall enable the test bench equipment
Arbeitskreis Standardschnittstellen für Kombinationsanlagen in der Umweltsimulation

Aktueller Stand 03-2010

Kombinationsanlagen sind ...

"Kombinierte Prüfstände und Fertigungseinrichtungen, bei denen z.B. Temperatur und Feuchtigkeit zusammen mit einer Schwingungsregelung ein Profil durchlaufen"

"Shaker kombiniert mit Klimakammer"
Anwendungsbeispiele

Temperaturzyklus mit Vibrationsprüfung
- Während Ablauf eines Temperaturprofils wird zyklisch eine Vibrationsbelastung an/ausgeschaltet.
- Bei Bedarf werden zusätzlich externe Schaltfunktionen gesteuert (Meßfunktionen, Prüflingsansteuerung etc)

"Wochenendabschaltung"
- Wenn ein Teilsystem ausfällt, werden die anderen dadurch ebenfalls gestoppt
- Vorteile: Energieeinsparung, definierter Testabbruch, Prüfling wird nicht unnötig belastet etc ...

Problemstellung

- Keine Schnittstelle definiert, es existiert noch kein Standard
- Jede Anlage ist eine individuelle Lösung
- Kostenintensiv, da Einzellösung
- Schwer erweiterbar, muss einzeln gepflegt werden
- Unflexibel bei Anlagenkonfiguration
- Herstellerabhängig
- Bei Systemwechsel nicht kompatibel
Ziele des GUS-Arbeitskreis (Auszug)

- Ein Anforderungsprofil hinsichtlich der notwendigen Funktionen erstellen
- Eine Schnittstelle für kombinierte Prüfanlagen definieren.
- Entwurf einer offenen Industrienorm
- Die erarbeiteten Ergebnisse können als Grundlage zur Umsetzung einer CEN- oder ISO-Norm herangezogen werden
**Schnittstellenkonzept des Arbeitskreises**

- Master/Slave-Konzept
- Softwarelösung
- Drittsysteme mit einbeziehen (über Relaiskarten etc)
- Beschränkung auf "Testebene"
- Befehlsbeschreibungen abstrakt, d.h. implementationsunabhängig
- Eindeutige Kennzeichnung der Befehle (Vorsilbe "GUS")
- Praktische Umsetzung: ActiveX
  (verwendbar aus: Visual Basic, C++, LabView, MSExcel und, und, und ...)

**Befehlskatalog des Arbeitskreises**

**Applikationsbefehle**

- Geräte-/Applikationsauswahl
- Testauswahl
- Test schließen
- Programm beenden

**Testbefehle**

- Start
- Stop
- Pause
- Continue
- Schnell-Aus (mit Signal nach extern)
**Befehlskatalog des Arbeitskreises**

**Rückmeldungen**
- Test bereit (Standby)
- Test läuft
- Pause
- Test beendet (erfolgreich)
- Störmeldung (Alarm, Abbruch, allg.)
- Trigger

**Sonstige Befehle**
- (nach Bedarf)

---

**Befehlsdefinition des Arbeitskreises**

Eine Definition der benötigten Befehle wurde vom Arbeitskreis erstellt, hinsichtlich folgender Kriterien:

- Anlagenzustand, in dem der Befehl relevant ist
- Beschreibung der Wirkung des Befehls
- Angabe der Aufruf- und Rückgabeparameter des Befehls
GUS-Befehlsatzdefinition (Auszug, Stand Nov 2009)

GUS Arbeitskreis Standardschnittstellen

Beispielprogramm unter MS Excel

Vorteile für Anwender:
- Funktionsfähiges Beispielprogramm,
- Kann leicht für eigene Einsatzzwecke geändert oder erweitert werden

Vorteile für Hersteller:
- Kann als Referenz verwendet werden, zur Prüfung ob die jeweilige Schnittstellen-Implementation GUS-konform ist.

Arbeitskreis plant Beispielprogramme für weitere SW-Plattformen zu erstellen (LabView etc)
Ansprechpartner
für GUS-Arbeitskreis Standardschnittstellen

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GUS
Gesellschaft für Umweltsimulation e.V.
www.gus-ev.de
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Beispielprogramm
für Standardschnittstellen für
Kombinationsanlagen in der
Umweltsimulation

© 2010 Data Physics (Deutschland) GmbH
Kombinationsanlagen sind ...

Kombinierte Prüfstände und Fertigungseinrichtungen, bei denen z.B. Temperatur und Feuchtigkeit zusammen mit einer Schwingungsregelung ein Profil durchlaufen, d.h. in der Regel: "Shaker kombiniert mit Klimakammer"

Warum eine Standardschnittstelle?

- Bisher keine Schnittstelle definiert, es existiert noch kein Standard
- Jede Anlage ist eine individuelle Lösung
- Kostenintensiv, da Einzellösung
- Schwer erweiterbar, muss einzeln gepflegt werden
- Unflexibel bei Anlagenkonfiguration
- Herstellerabhängig
- Bei Systemwechsel nicht kompatibel
Schnittstellenkonzept des GUS-Arbeitskreises

- Master/Slave-Konzept
- Softwarelösung
- Drittsysteme mit einbeziehen (über Relaiskarten etc)
- Beschränkung auf "Testebene"
- Befehlsbeschreibungen abstrakt, d.h. implementationsunabhängig
- Eindeutige Kennzeichnung der Befehle (Vorsilbe "GUS")
- Praktische Umsetzung: ActiveX
  (verwendbar aus: Visual Basic, C++, LabView, MSExcel und, und, und ...)
Schnittstellenkonzept des GUS-Arbeitskreises

Befehlsebene

- Detaillierte Befehlsprogrammierung und Parametereinstellung
- Speicherung und Dokumentation der Ergebnisse

-> wird in den jeweiligen Systemen durchgeführt
   (Einzelfunktionen werden bei Bedarf in die GUS-Schnittstelle mit aufgenommen)

Testebene

- Steuerung durch Aufrufen und Steuern von vordefinierten Tests,
  mit entsprechenden Statusabfragen und Rückmeldungen

-> GUS-Schnittstelle

---

**GUS-Befehlsatzdefinition (Auszug, Stand Nov 2009)**

<table>
<thead>
<tr>
<th>Funktion</th>
<th>Kommando</th>
<th>Wirkung</th>
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</thead>
<tbody>
<tr>
<td>Applikationsbefehle</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Applikationsauswahl</td>
<td>GUS_Open_App</td>
<td>Kommunikationssoftware wird geladen</td>
</tr>
<tr>
<td>Angeschlossene Geräte deaktivieren</td>
<td>GUS_Scan_Devices</td>
<td>Suche nach verfügbaren Geräten, liefert Identifier zurück</td>
</tr>
<tr>
<td>Geräteereignisse auslösren</td>
<td>GUS_GetDeviceInfo</td>
<td>to be defined</td>
</tr>
<tr>
<td>Geräteaufwahl</td>
<td>GUS_OpenDevice</td>
<td>Gerät mit dem kommuniziert, werden soll wird festgelegt, Betriebs- und Kommunikationssoftware wird geladen, Kommunikation wird initialisiert</td>
</tr>
<tr>
<td>Geräteabwahl</td>
<td>GUS_CloseDevice</td>
<td>Verbindung zum Gerät wird getrennt (damit Gerät frei wird für andereverwendungssteuerung, laufender Geräteprozess wird dabei nicht beeinflusst)</td>
</tr>
<tr>
<td>Applikation deaktivieren</td>
<td>GUS_CloseApp</td>
<td>Kommunikation wird beendet, Betriebs- und Kommunikationssoftware der Geräte wird geschlossen</td>
</tr>
</tbody>
</table>
## GUS-Befehlssatzdefinition (Auszug, Stand Nov 2009)

<table>
<thead>
<tr>
<th>Testbefehle</th>
<th>GUS-Befehlserklärungen</th>
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</thead>
<tbody>
<tr>
<td>Testauswahl und -vorbereitung</td>
<td>GUS_PrepareTest</td>
</tr>
<tr>
<td>Start</td>
<td>GUS_StartTest</td>
</tr>
<tr>
<td>Continue</td>
<td>GUS_ContinueTest</td>
</tr>
<tr>
<td>Schnell-Aus</td>
<td>(GUS_Abort)</td>
</tr>
</tbody>
</table>

## GUS-Befehlssatzdefinition (Auszug, Stand Nov 2009)

<table>
<thead>
<tr>
<th>Rückmeldungen</th>
<th>GUS-GetStatus</th>
<th>Abfrage des Geräte-STATUS (Ready, Stop, Pause, Run, Busy). siehe Detailliste unten</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gerätstatus (Betriebszustand) abfragen</td>
<td>GUS_GetStatus</td>
<td>Abfrage des Geräte-STATUS (Ready, Stop, Pause, Run, Busy). siehe Detailliste unten</td>
</tr>
<tr>
<td>Gerätinfo abfragen</td>
<td>GUS_GetInfo</td>
<td>Abfrage von weiteren Geräteinfos (noch nicht definiert)</td>
</tr>
<tr>
<td>Störmeldung (Alarm, Abbruch, etc.) abfragen</td>
<td>GUS_GetError</td>
<td>Abfrage des aktuellen Fehlerzustandes bzw. der letzten Fehlermeldung (noch nicht definiert)</td>
</tr>
<tr>
<td>Trigger</td>
<td>GUS_Trigger</td>
<td>Abfrage ob Triggerkriterium vorliegt (noch nicht definiert)</td>
</tr>
</tbody>
</table>

### Sonstiges

(noch nicht definiert)
Beispielprogramm: Systemkonfiguration

MASTER: Beispielprogramm unter MS Excel
"externe" Steuersoftware

SLAVE 1: Schwingregelsystem

Bediensoftware auf PC

Klimakammer

SLAVE 2: KlimakammersteuerSoftware

Bediensoftware auf PC

Klimaregelsystem

Wird vom Arbeitskreis frei zur Verfügung gestellt

Vorteile für Anwender:
- Funktionsfähiges Beispielprogramm,
- Kann leicht für eigene Einsatzzwecke geändert oder erweitert werden

Vorteile für Hersteller:
- Kann als Referenz verwendet werden, zur Prüfung ob die jeweilige Schnittstellen-Implementation GUS-konform ist.
Beispielprogramm unter MS Excel

Code für Befehlaufrufe nur 1x geschrieben:
je nach Objektaufruf wird Klimakammer oder Shakersystem angesprochen:

```vbscript
Private Sub CommandButton2_Click()
    "APP laden"
    Set Device1 = CreateObject("SIGNALSTAR_GUS.Application")
    Set Device2 = CreateObject("SIGNALL_T_GUS")
End Sub

Private Sub OptionButton1_Click()
    "Gerät 1 anwählen"
    Set Test = Device1
End Sub

Private Sub OptionButton2_Click()
    "Gerät 2 anwählen"
    Set Test = Device2
End Sub

Private Sub CommandButton4_Click()
    "START"
    Call Test.GUS_StartTest
    StatusTextAnzeigen
End Sub

Private Sub CommandButton5_Click()
    "STOP"
    Call Test.GUS_StopTest
    StatusTextAnzeigen
End Sub
```

SignalStar und Simpex sind eingetragene Warenzeichen der Firmen Data Physics Corp. bzw. Weiss/tech.

Ansprechpartner für GUS-Arbeitskreis "Standardschnittstellen"

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P. Gollob, Sicherheitsaspekte im Umgang mit Lithium Batterien, AVL Hybrid Tech Day, Technische Universität Darmstadt, 22.03.2011


DKE_Roadmap_SmartGrid_230410_English[}
25. List of standards

When looking at the electric vehicles standardisation activities, the respective scope of the standards to the categories of vehicles is taken into account.

Tabelle 1: Übersicht über aktuelle Normungsaktivitäten mit Bezug zum Elektrofahrzeug

<table>
<thead>
<tr>
<th>Bezeichnung</th>
<th>Themengebiet</th>
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<tbody>
<tr>
<td>IEC 62660</td>
<td>Secondary batteries for the propulsion of electric road vehicles</td>
<td>FDIS 2011</td>
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<tr>
<td>ISO 6722-1</td>
<td>Road vehicles – 60 V and 600 V single-core cables – Part 1: Dimensions, test methods and requirements for copper conductor cables</td>
<td>DIS 2011</td>
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<tr>
<td>ISO 6722-2</td>
<td>Road vehicles – 60 V and 600 V single-core cables – Part 2: Dimensions test methods and requirements for aluminium conductor cables</td>
<td>CD 2011</td>
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<tr>
<td>ISO TR 8713</td>
<td>Electric road vehicles – Vocabulary</td>
<td>DTR 2011</td>
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<tr>
<td>ISO 11452-4</td>
<td>Road vehicles – Component test methods for electrical disturbances from narrowband radiated electromagnetic energy – Part 4: Bulk current injection (BCI)</td>
<td>CD 2012</td>
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<tr>
<td>ISO 12405-1</td>
<td>Electrically propelled road vehicles – Test specification for Li-Ion traction battery systems – Part 1: High power applications</td>
<td>FDIS 2010</td>
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<tr>
<td>ISO 12405-2</td>
<td>Electrically propelled road vehicles – Test specification for Li-Ion traction battery systems – Part 2: High energy applications</td>
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<td>ISO 12405-3</td>
<td>Electrically propelled road vehicles – Test specification for Li-Ion traction battery systems – Part 3: Safety performance requirements</td>
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<td>ISO 14572</td>
<td>Road vehicles – Round, sheathed, 60 V and 600 V screened and unscreened single- or multi-core cables – Test methods and requirements for basic and high-performance cables</td>
<td>DIS 2011</td>
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<td>ISO/IEC 15118, Parts 1 – 4</td>
<td>Road vehicles – Communication protocol between electric vehicle and grid</td>
<td>CD 2012</td>
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<td>Norm oder Standard</td>
<td>nationales Gremium</td>
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<tr>
<td>ISO 26262 Parts 1 – 10</td>
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<td>Road vehicles – Functional safety</td>
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**Normen und Standards**

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<th>Status</th>
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<tr>
<td>EN 55012 (CISPR 12)</td>
<td>K 767</td>
<td>Vehicles, motorboats and internal combustion engines – Radio disturbance characteristics – Limits and methods of measurement for the protection of off-board receivers</td>
<td>Domäne Energiespeicher Ladeinfrastruktur</td>
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<td>EN 55025 (CISPR 25)</td>
<td>K 767</td>
<td>Vehicles, motorboats and internal combustion engines – Radio disturbance characteristics – Limits and methods of measurement for the protection of on-board receivers</td>
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<td>IEC 60364-5-54</td>
<td>UK 221.1</td>
<td>Errichten von Niederspannungsanlagen – Teil 5–54: Auswahl und Errichtung elektrischer Betriebsmittel – Erdungsanlagen, Schutzleiter und Schutzpotentialausgleichsleiter</td>
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<td>AK 221.1.11</td>
<td>Low voltage electrical installations: Requirements for special installations or locations – Supply of Electrical Vehicle</td>
<td>NP</td>
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<td>IEC 60364-4-41</td>
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<td>Wirkungen des elektrischen Stromes auf Menschen und Nutztiere – Teil 1: Allgemeine Aspekte</td>
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<td>(VDE 0140-479-1)</td>
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<tr>
<td>IEC 61508</td>
<td>GK 914</td>
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<td>952</td>
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NICHT EINGEARBEITET
Themenfelder der Normung zur E-Mobility

E. Fritzsche,