Battery Storage Systems

Safety Regulations and Procedures for DTU Elektro at Lyngby and Risø Campus

1 Contents

2 Purpose

- To prevent accidents when working with cells and batteries
- Contribute to work safely with battery storage systems in lab environment
- Incorporate safe working procedures
- Proper storage of cells and batteries

2.1 Symbols used in this Safety regulation:

Prohibition or Compulsory symbol
Failure to observe instructions marked with this symbol is violating the safety regulations and may result in serious or fatal injury.

Danger symbol
Failure to observe instructions marked with a danger symbol may result in personal injury and/or damage to the unit.

2.2 Risk assessment

The following will guide the risk assessment and planning of the work. The guideline is a minimum requirement, it must always be considered if there are other hazards that should be taken into account

During the risk assessment, the following shall be considered by the person responsible for the test or other handling, for every potential risk:

- Potential hazard
- Likelihood
- Consequence
- Preventative measures

3 Application area

In this document the term “battery” and “batteries” applies to both single cells, and stacks of cells.

3.1 Equipment outside of the scope

CE-marked or similar approved equipment for the Danish market is outside of the scope of this safety regulation, if the equipment is used in the manufacturer’s scope of application.
This also excludes batteries for power tools etc. Please notice that the manufacturer’s instruction might include information about storage and regular inspection.

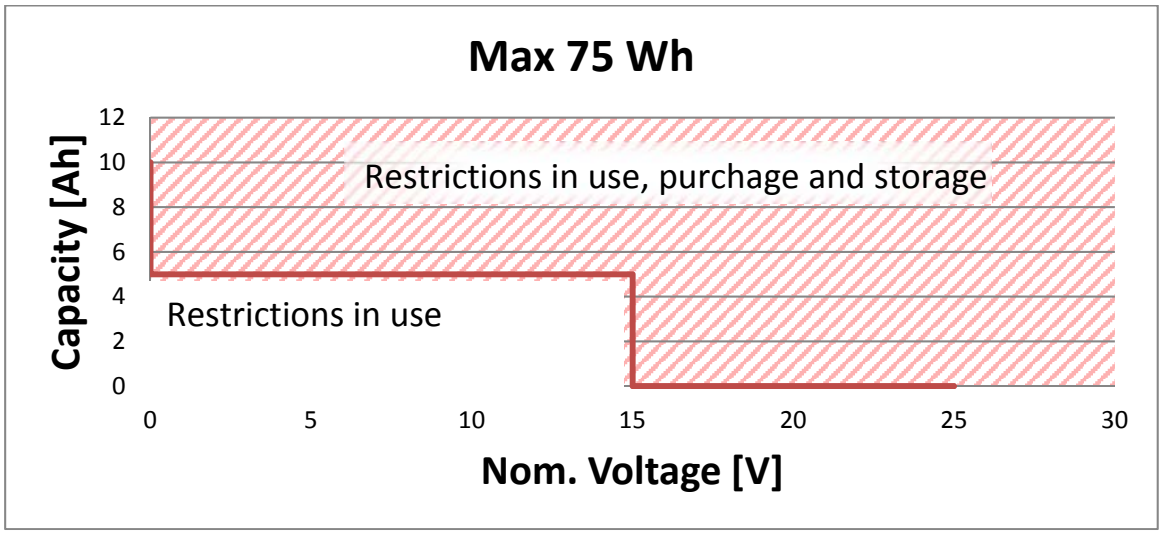
3.2 Working with battery cells in laboratory and workshop

The present safety regulation applies to use of all types of laboratory work where battery cells are involved, including but not limited to charging and discharging or measuring electrical, chemical or physical parameters.

3.3 Storage, purchase, disposal

The safety procedure for purchase and storage can be used for all sizes of batteries but are compulsory for batteries exceeding nominal values of:

15 VDC
5 Ah
75 Wh



4 Energy storage installations (Batteries)

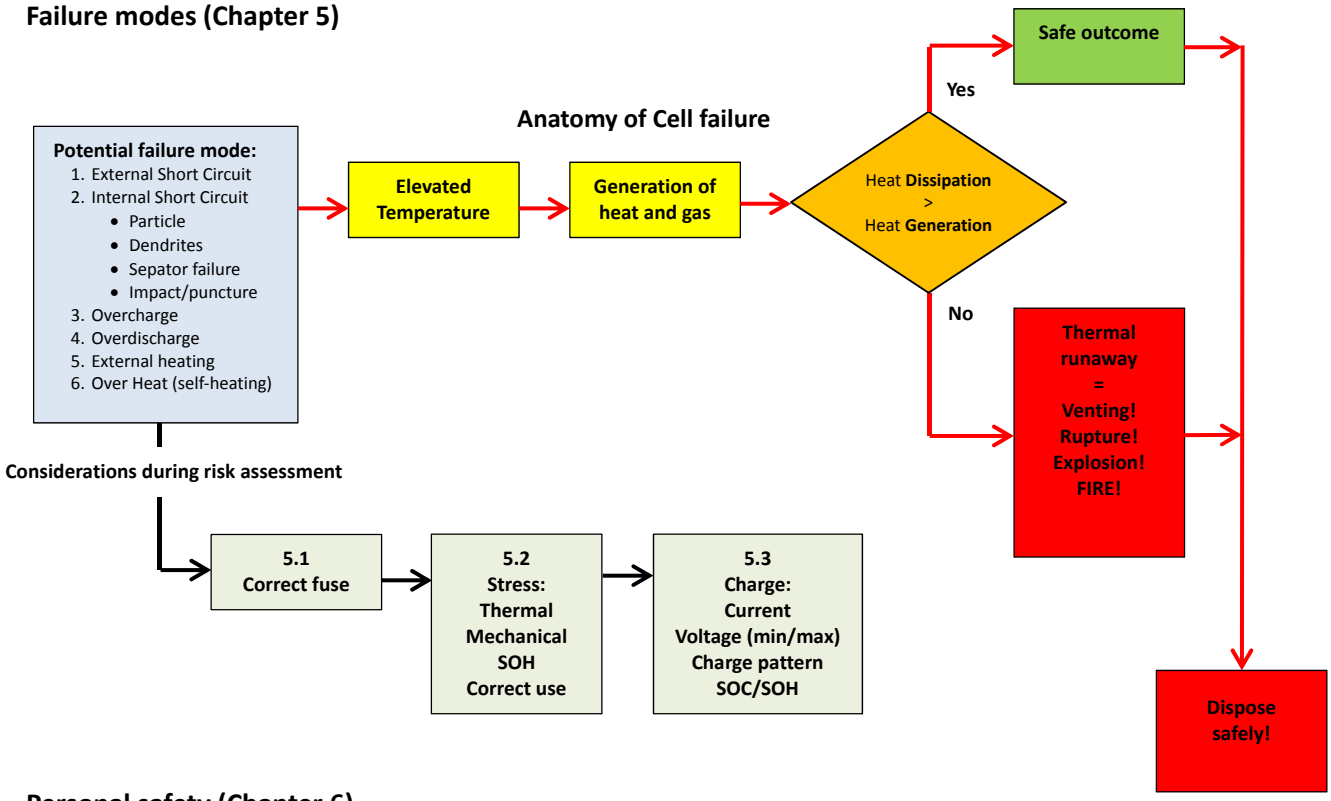
The following rules apply in addition to 'Safety Rules for Work in DTU Elektro Laboratories' and other local safety guide lines:

Chapter 2.1 Planning of test setups and assignment of laboratory space
Chapter 2.2 Design of the test setup

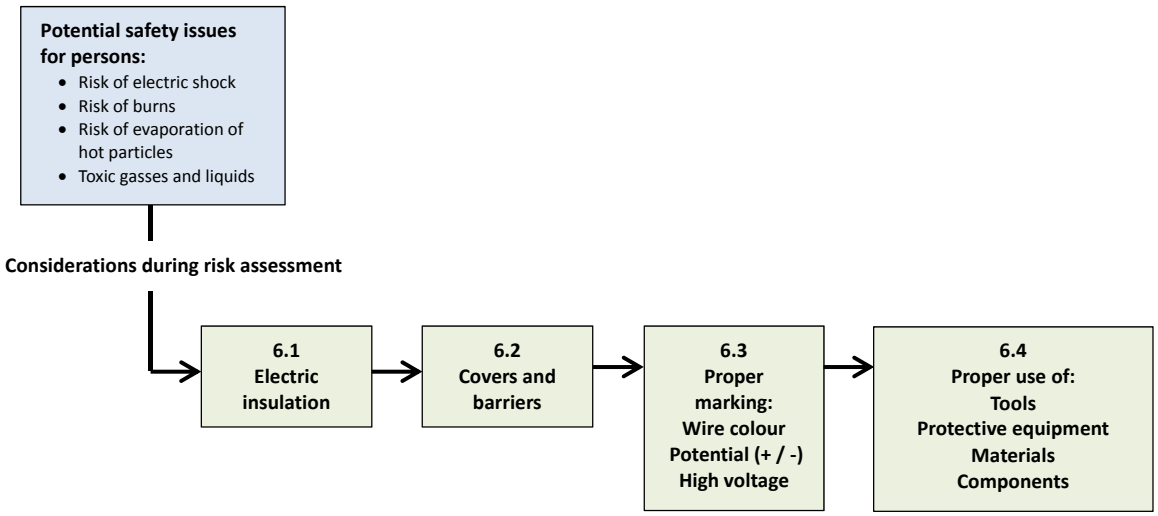
4.1 Risk assessment

Always when considering safety issues, a risk assessment must be worked out. For this purpose the below overview of anatomy of cell failure, personal safety issues and risk of property issues can be used as underlying basis.

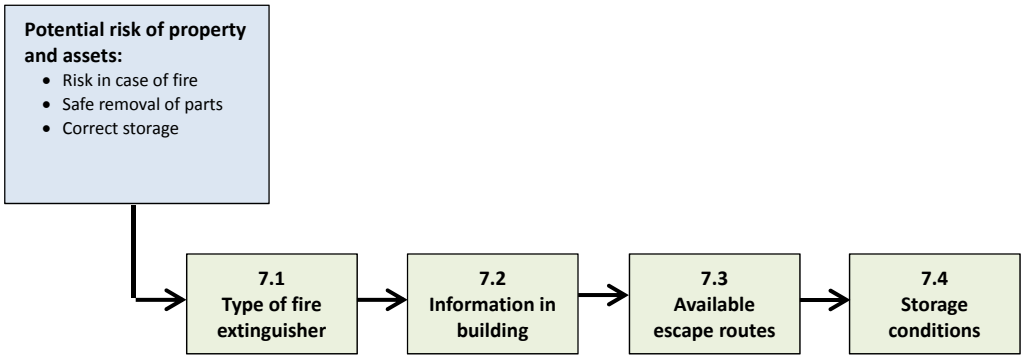
Failure modes (Chapter 5)



Personal safety (Chapter 6)



Risk of property (Chapter 7)



4.2 Working with batteries in the lab

Attention Live circuit:
Remember: That a battery is always ON – it is not possible to turn it off!

Attention Large Current:
Modern batteries has very large short circuit current due to low internal resistance

Attention Electric Arc:
An electric DC arc will not tend to be stopped periodically like an AC Electric arc, but can last as long as the battery is discharging and causing extreme temperatures (>5000 °C)

Duracel AA, 2 Ah Alka-line	LG HG 18650, 3 Ah Li-ion	Winston Thundersky 40 Ah LiFePO4
		
Initial prospective short circuit current: *12 A*	Initial prospective short circuit current: *185 A*	Initial prospective short circuit current: *1850 A*

4.2.1 Working with live voltage

When working with live voltage, special precautions must be taken, due to EN50110 (L-AUS)

Following headlines apply to live work.

General overall planning

General planning must at a minimum include the following:

a) development of instructions,
b) use of qualified personnel,
c) necessary authorization and permits,
d) organization and planning in connection with the purchase, use, storage, testing and maintenance of protective equipment and other safety equipment,
establishing routines for standard types of work, training, practice and instruction, and necessary first-aid preparations.

The job must be planned with the use of safety precautions, so the work can be carried out in a safe manner.

It’s important that the persons who makes the risk assessment, has sufficient knowledge and experience to recognize the dangers that electricity can cause, and thereby be able to take the necessary precautions.

5 Failure modes and battery operation

Depending on the type of battery, type of equipment and tasks to be performed, different safety strategies must be planned and followed.

In case of a standard product used as specified for normal use, do find and examine the instruction manual.

In case of a not standard product or abnormal use, please examine literature and ask other experts for advice.

As a minimum the following issues must be addressed

5.1 Fuse

It's compulsory to use fuselinks for both main and measuring circuits in battery and battery cell applications.

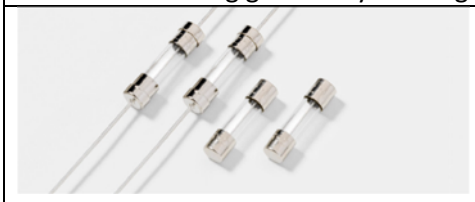
The fuses must be selected carefully according to the use:

1. Max voltage for the fuse
2. Type of supply, normally DC
3. The max prospective short circuit current
4. Avoid glass fuses or protect from flying parts
5. The fuses must be placed as close to the battery poles as practical possible

Examples of fuses:

Littlefuse, 218 Series (Not for DC applications!)

5×20mm Time-Lag glass body cartridge fuse designed to IEC specification.



Current rating	Interrupting Rating:
0,5 A	35 A @ 250 VAC VDC, N/A
5 A	50 A @ 250 VAC VDC, N/A
10 A	100 A @ 250 VAC VDC, N/A

Littlefuse, 477 Series

400Vdc/500Vac rated, 5x20mm, time-lag, surge withstand ceramic body cartridge fuse.

Current rating	Interrupting Rating:
0,5 A	100 A@500 VAC 1500 A@400 VDC
5 A	100 A@500 VAC 500 A@400 VDC
10 A	100 A@500 VAC 500 A@400 VDC

SIBA, URZ-DMI 10x38mm gR 1000 V

1000 Vdc/Vac rated, 10x38mm, time-lag, surge withstand ceramic body cartridge fuse.

Current rating	Interrupting Rating:
0,4 A	30 kA@1000 VAC 30 kA@1000 VDC
4 A	30 kA@1000 VAC 30 kA@1000 VDC
10 A	30 kA@1000 VAC 30 kA@1000 VDC

5.2 Stress

The Batteries and Battery cells must normally be used under conditions specified by the manufacturer.
In case of use outside normal specifications, or missing specifications, or in case of prototype etc., please make your own risk assessment and address the relevant failure modes.

Thermal Stress failure

1. Surface temperature
2. Ambient temperature (Maximum, minimum)
3. Terminal temperature
4. Visible signs of previous overheat
5. Risk of thermal runaway, - precautions

Mechanical stress

1. Signs of pressure in the battery
2. Correct mounting during operation
3. Risk of internal puncture by vibrations or shock
4. Risk of external puncture by vibrations or shock
5. Visible signs of previous mechanical stress: there shall be no such defects as:
    a. Deep scratch
    b. Crack
    c. Rust
    d. Discoloration
    e. Leakage

State of health (SOH)

1. Is there a risk of internal short circuit by unknown SOH?
2. Is it a new battery? Consider the state of charge/health
3. Is it an old battery? Consider the state of charge/health
4. Can the battery be fully charged?
5. Can the battery be fully discharged?

5.3 Correct charge and discharge

The Batteries must normally be used under conditions specified by the manufacturer. Battery management systems (BMS) are preferred for modern batteries, and must be configured by the manufacturer or according to the battery specifications.

Examples of specifications for correct use:
Maximum and minimum Charge current

1. Specified value for battery
2. Specified value due to charge pattern
3. Specified value due to max/min voltage
4. Specified value due to SOC
5. Specified value due to SOH
6. Specified value due to temperature

In case of use outside normal specifications, or missing specifications, or in case of prototype etc., please make your own risk assessment and address the relevant failure modes. It's mandatory to ask other experts for advice.

6 Potential safety issues for persons

When using in the labs, potential safety issues for persons must always be covered.

6.1 Electric insulation

It's compulsory to electric insulate live circuits or place out of vicinity zone.

All electric circuits must be insulated properly to avoid unintentional and accidental contact with persons, tools, interior etc.
In case of open accessible circuits during mounting and testing, care must be taken to avoid contact, by shielding, marking, etc.

1. Use EN 50110 (L-AUS) procedures
   1.1 Electric insulated tools
   1.2 Proper nonflammable clothing with long sleeves
2. Cover open terminals with rubber sheets so you only have one open terminal at a time
3. Cover terminals with proper electric insulation, also when storing batteries
4. For larger batteries, use manual switch disconnectors and mid-pack service disconnectors

6.2 Covers and barriers

All electric circuits must be covered properly to avoid unintentional and accidental contact with persons, tools, interior etc.
In case of failure in the system, it must be considered to protect from fire, flying parts, fumes, gasses etc.

1. Use cage, barriers, box or similar to keep the battery circuits out of touch. Secure the necessary distance from cover openings to circuit (eg. EN 60529, degrees of protection… (IP codes))
2. For larger setups, like EVs etc., use black yellow chains. Secure that distance to live object is 2 m.
3. Use metal, polycarbonate or similar cover to protect from flying parts in case of risk of rapture, venting, fire or explosion.
4. Secure proper ventilation in the room
5. Secure extract ventilation with fume hood or similar in case of risk of venting from the battery

6.3 Marking

High voltage DC main circuits (> 60 VDC) must be marked with Orange wire or Wire marking

Main DC potential must be clearly marked

"+" or colored "red" for positive potential
"-" or colored "blue" or black" for negative potential

All Battery circuits must be marked properly to avoid mistakes and misuse.
Electric insulation and covers is prioritized as safety guards. Use of warning signs is of secondary priority.

1. High voltage DC main circuits (>60 VDC) must be marked with orange wire or Wire marking
2. Battery poles and main circuits must be marked with colors or signs
   2.1 "+" or colored "red" for positive potential
   2.2 "-" or colored "blue" or "black" for negative potential
3. Fuse or fuse bases or other documentation must have markings that makes it possible to find replacement fuse (eg.: fuse make, type and size).
4. Covers, barriers and chains must have appropriate warning signs
5. Batteries must have information markings as described in "8.2 Storage Conditions for batteries"

6.4 Tools, Protective wear, materials and components

Tools and personal protective equipment must be selected due to European standard DS/EN50110 (L-AUS)

Protective eyewear or face shield must be used, when working with live circuits.

All tools, materials and components must be carefully selected according to the risk analysis.
Special attention must be taken:
- In case of risk of thermal runaway, where fire retardant materials are preferred
- When switching DC voltages where arcing can damage open contacts

1. Tools and measuring equipment used in the vicinity zone must be electric insulated (EN 60900 or similar)

2. Workwear must protect from heat, flames and molten metal splashes
3. By high risk of arcing, clothes must be according to IEC 61482-2:2009 or subsequent
4. Workbenches etc. must be non-conducting or electric insulated.

5. Switches in DC circuits must be proper selected according to voltage and utilization (IEC 947 Utilization categories can be used where applicable)

IEC Utilization categories	
DC-1	Non Inductive or slightly inductive loads, resistance furnaces, heaters
DC-3	Shunt-motors, starting, plugging(1), inching(2), dynamic braking of motors
DC-5	Series-motors, starting, plugging(1), inching(2), dynamic braking of motors
DC-6	Switching of incandescent lamps
DC-12	Control of resistive loads and solid state loads with opto-coupler isolation
DC-13	Control of D.C. electromagnetics
DC-14	Control of D.C. electromagnetic loads having economy resistors in the circuit
DC-20	Connecting and disconnecting under no-load conditions
DC-21	Switching of resistive loads, including moderate overloads
DC-22	Switching of mixed resistive and inductive loads, including moderate overloads (i.e. shunt motors)
DC-23	Switching of highly inductive loads (i.e. series motors)

7 Test area and setup

- Set up clear signs that show that the equipment can be voltage-generating.
- Set up clear signs that show the data for the pack
- Make sure the area is properly and clearly confined, or make sure that only instructed persons have access to the area
- The high voltage battery must be enclosed as a pack itself
- Avoid touching any voltage-carrying parts, including terminals, wires and other components that are associated with the battery, cover terminals

7.1 Fire extinguisher

Make sure there is access to the correct type of fire extinguisher before you start working with batteries.
Fire extinguishers can have limited effect on large battery fires. The fire department will use lot of water for this.

1. Make sure there is access to a fire extinguisher
2. Use the correct type of fire extinguisher
   2.1 Type “D” for battery fire (Metallic fire)
   2.2 Type “B” for other kinds of electric installations (CO2). Notice! Max 1000 V, 1 m

Metallic (Battery) fire	Electric installations
Type “D” fire extinguisher marking	Type “B” (CO2) fire extinguisher marking
	

7.2 Information in lab and on building

Information about danger must be located at main entrances, to inform fire brigade. Limitations formulated in "3 Application area"

Information about danger must be located at running experiments and in risk of open terminals. Limitations formulated in "3 Application area"

Caution battery charging area

7.3 Escape and rescue routes

The working area must always be clean and tidy, and have accessible escape routes

When planning and placing experiments, it must be considered how to remove batteries in case of fire

Depending on the type of equipment and type of test, it must be considered to plan and locate the experiment so it's possible to rescue persons, and eventually to remove damaged and/or burning parts.

1. Place the experiment close to entrance
2. Make sure the escape route is kept clear
3. For larger setups like EVs etc., consider if it's possible to remove burning batteries

7.4 Storage conditions

All batteries must be charged and surveilled due to manufacturer specification during storage

There are several potential risks for persons and assets when storing batteries. Care must be taken to mitigate deep discharge, leakage of gasses and toxic liquids that can destroy the batteries or other assets.

Batteries must be registered for storage due to requirements in Chapter 8

8 Purchage, storage, disposal of batteries.

Store a cell or battery according to the manufacturer instruction. The following is minimum requirements.

All stored batteries in the application area of this regulation must be registered in relevant lists pointed out by the “DTU Elektro safety group”.

8.1 Registration of batteries

All batteries must be registered in the list of batteries pointed out by “DTU Elektro safety group”.

8.2 Storage conditions for batteries

- Batteries should be kept in original shipping containers if possible. Do not store loosely
- Always cover the poles – use the original cover or proper electric insulating tape
- For storage of batteries for longer periods the SOC should be considered for the type of battery
- Maintenance must be planned, a considerable self-discharge must be expected

8.3 Storage area condition

- Storage areas should be clearly identified as a Battery storage area at rescue plans.
- The storage area should have access to a Class D fire extinguisher or other extinguisher designed for metallic fires.
- Care should be taken to ensure batteries are not exposed to a flammable environment.
- Batteries can release toxic material if crushed or broken open, large quantities should be stored in a remote area.
- Batteries should be stored in a secure, cool, well ventilated, dry environment.
- Temperatures should be kept above 10°C and below 25°C.
- To prevent performance problems, DO NOT STORE BATTERIES IN AREAS RECEIVING DIRECT SUNLIGHT.

8.4 Disposal of batteries

Batteries must be disposed due to manufacturer specification

APPENDIX 1 – REFERENCES

http://batteryuniversity.com

http://www.totalbatteryconsulting.com/industry-reports/Battery-safety-report/overview.html

DS/EN 50110-1:2013 Drift af elektriske installationer og elektriske anlæg - Del 1: Generelle krav

Revision log

Changes to this document have been done:

Version	Date	Description of revision
Version V0_3	2018-06-26	Draft version presented and approved with minor changes: PLDK Logo, blurred pictures updated, typography and list of content updated
Version V1_0	2018-11-06	First version accepted by DTU Elektro safety group
Version V1_1	2019-01-29	Minor updates as agreed with DTU Elektro safety group

Procedure for revision of this document:

1. Revisions to this document must only be done by the local safety group.
2. Revisions shall be approved by the DTU Elektro safety group before set into operation. The local safety group has the responsibility for this approval takes place. A confirmation from the chairman of the DTU Elektro safety group and minutes of meetings from a DTU Elektro safety group meeting is considered as sufficient documentation for approval.
3. When the document has been approved the local safety group has the obligation to immediately ensure that the old version of the document in the laboratories are removed and replaced with the newly approved version so a new updated version can be found in all laboratories. Furthermore the local safety group has the obligation to immediately ensure that the relevant webpages is updated with the new version and that an E-mail is send to all relevant staff with information about the availability of the new version and a link to the relevant webpage.