Lithium batteries

Safety Aspects In Battery Packs

Are Lithium batteries safe to use?

- Used daily by billions of people in many types of applications
  - Consumer electronic devices
  - Power tools
  - Medical devices
  - Automotive applications
  - Large-scale energy storage
- Statistical failure rate is low - The statistical failure rate of this technology is very low. The risk of failure is comparable to the same risk as getting struck by lightning during a lifetime - it is rare.
- The risk of a battery failure can be minimized by correct handling

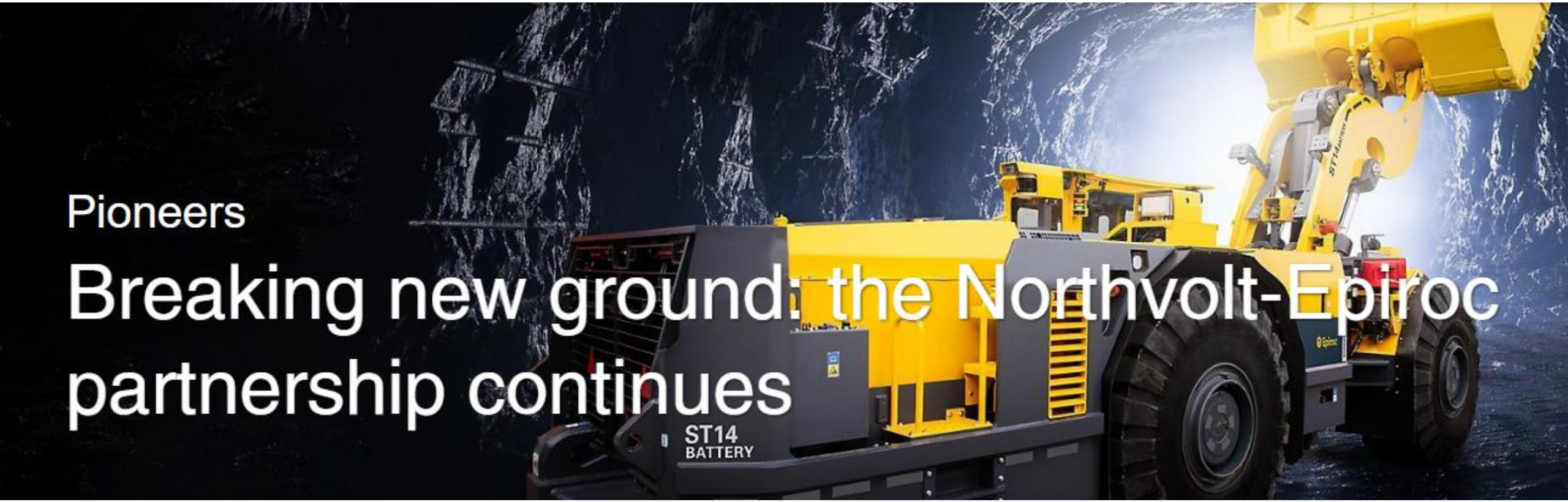
Battery machines & safety

Epiroc

Rocvolt 2020

Northvolt battery system safety

2023-02-16



- Oscar Fors, President for Northvolt Battery Systems, says: “By meeting the highest functional and safety standards required by the demanding environment in an underground mine, we have developed a standard solution that can meet most industrial customer’s needs as well.”

Second Generation

ST14 Battery

Drill Rigs M,E family

Boomer, Simba & Bolterc

MT42 Battery

Epiroc's battery system

Cell

4.2 V
0.0676 kg

Module

100 V
59 kg
672 Cells
24s28p

Sub-pack

800 V
640 kg
5 376 cells

- In partnership with Northvolt
- Designed with safety as the primary focus
- The latest technology
- Economy of scale

Battery packs

MT42

5 Sub-packs

ST14

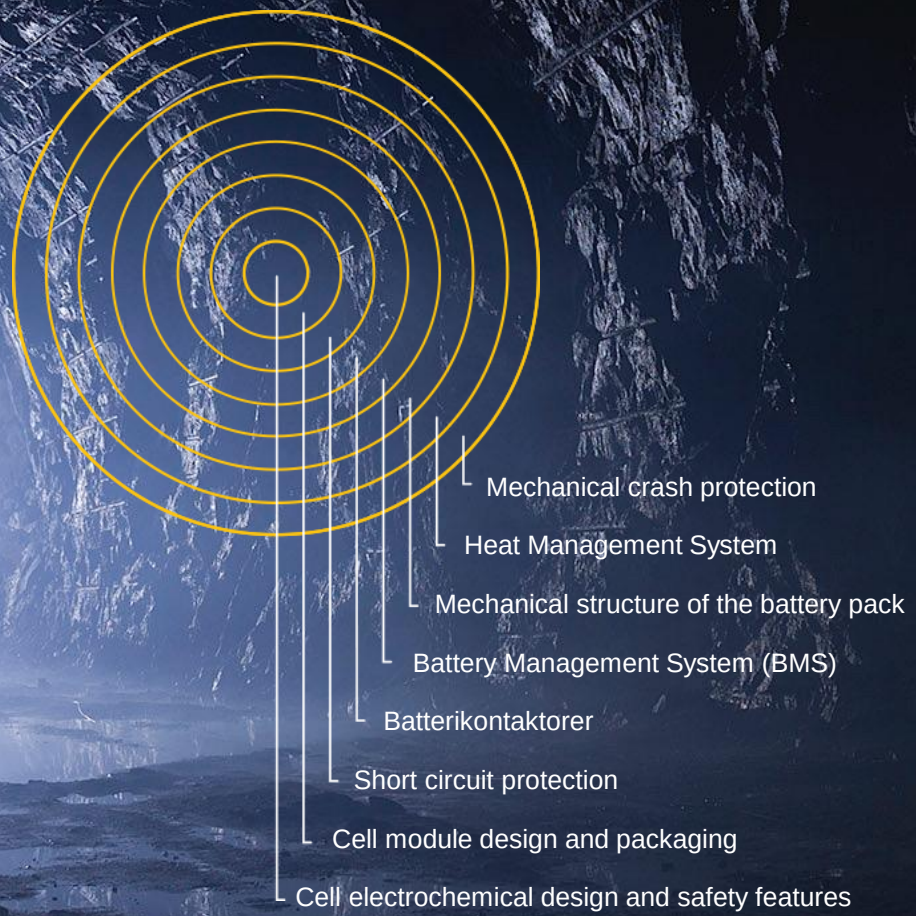
4 Sub-packs

Drill Rigs

2 Sub-packs

Advanced battery safety

Summary



Protection against fire

- Safe cell design to minimize exothermic effects
- Small cylindrical cells
- Fuse (CID) and overpressure ventilation for each cell
- Overload protection on each cell (wire bond)
- All cells are liquid cooled and thermally insulated
- Thermal insulation in several layers
- Three levels of battery management system (BMS)
- Fire retardant ceramic mica layer in modules.

Protection against external fire

- Fire protection on machine for external fire
- Fire extinguishing system in battery pack electronics.

Protection against electric shock)

- REST - Never voltage with open contacts or lids
- Shielded cables
- Insulation monitoring and equipotential bonding
- Automatic and manual contactors with health monitoring
- Manual service disconnect switch (Lock-out / Tag-out).

Protection agains rock fall

- Thick top plate
- Cooling system as demolition protection
- Cables, hydraulics etc. as a demolition buffer..

Designed for mining

- Thick steel casing
- Sealed (IP65) sub-pack
- Condensation-adapted
- Designed for the same vibration as machine
- Redundancy in "limp home" battery modules
- Certified for global standards

Epiroc

Proven chemistry

Greater power density and just as safe as LFP

- Compact, high energy density batteries for large payload machines
- Longer drive times and balanced charging time
- Greener production than LFP batteries
- Active and Passive safety systems onboard
- No instances of thermal runaway to date in the field

Batteries Certified: IEC 62619; UL 1642; UN 38.3

Li-ion batteries

General design - Cell chemistries

Positive electrode material (cathode)

Comment	Generic name
Less stable than other alternatives	LCO
High rate capability	LMO
Improved stability compared to LCO	NCA
Improved stability compared to LCO	NMC* Epiroc
High stability, but lower cell voltage	LFP

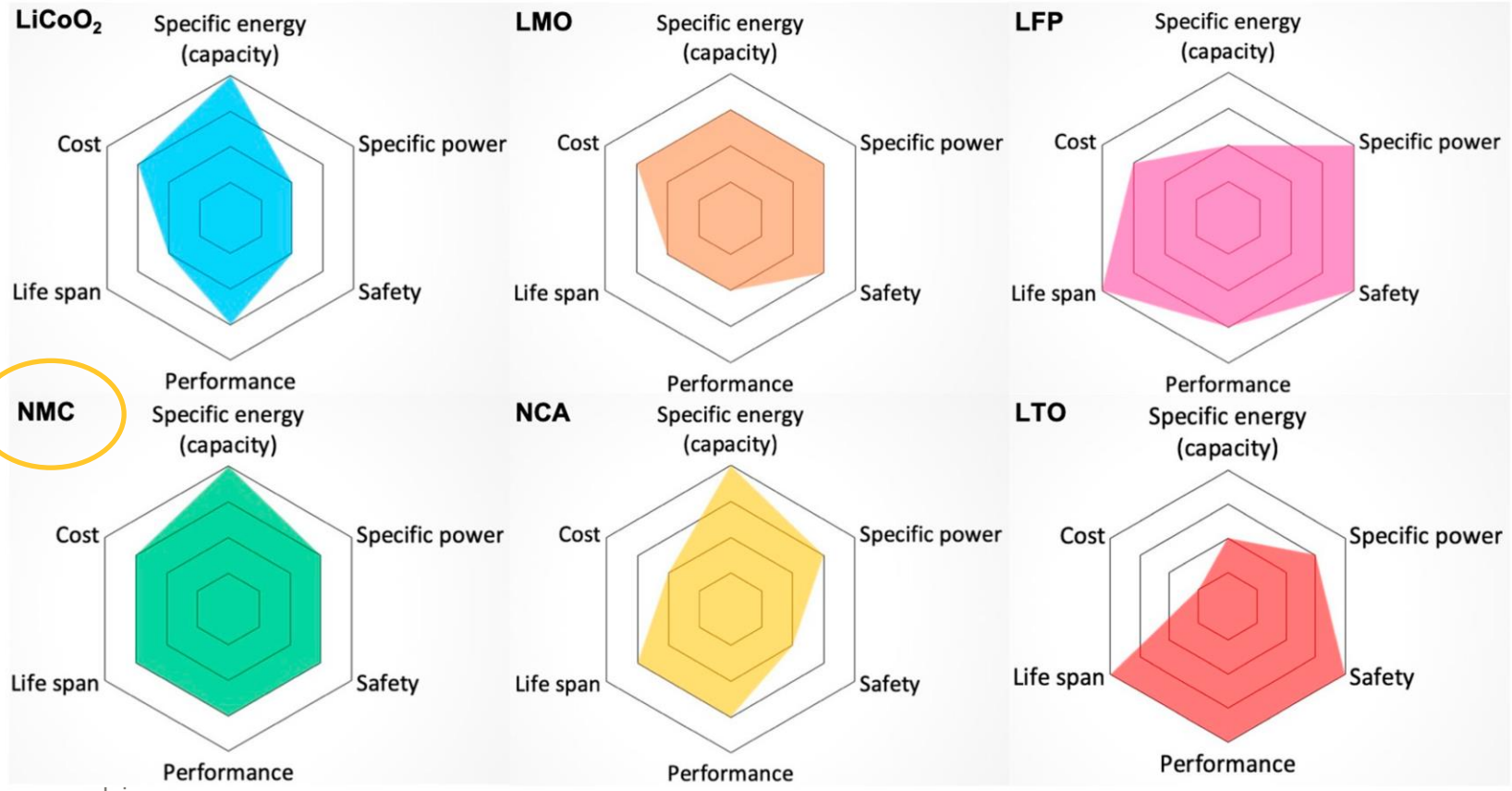
Negative electrode material (anode)

Comment	Generic name
Most common anode material	C* Epiroc
Extremely high capacity, but poor life time	Si
High rate capability, but lower cell voltage	LTO
Extremely high capacity, but safety issues	Li

Typical applications for different chemistries

***NMC** vs. **Graphite** is the increasingly popular combination

Li-ion batteries



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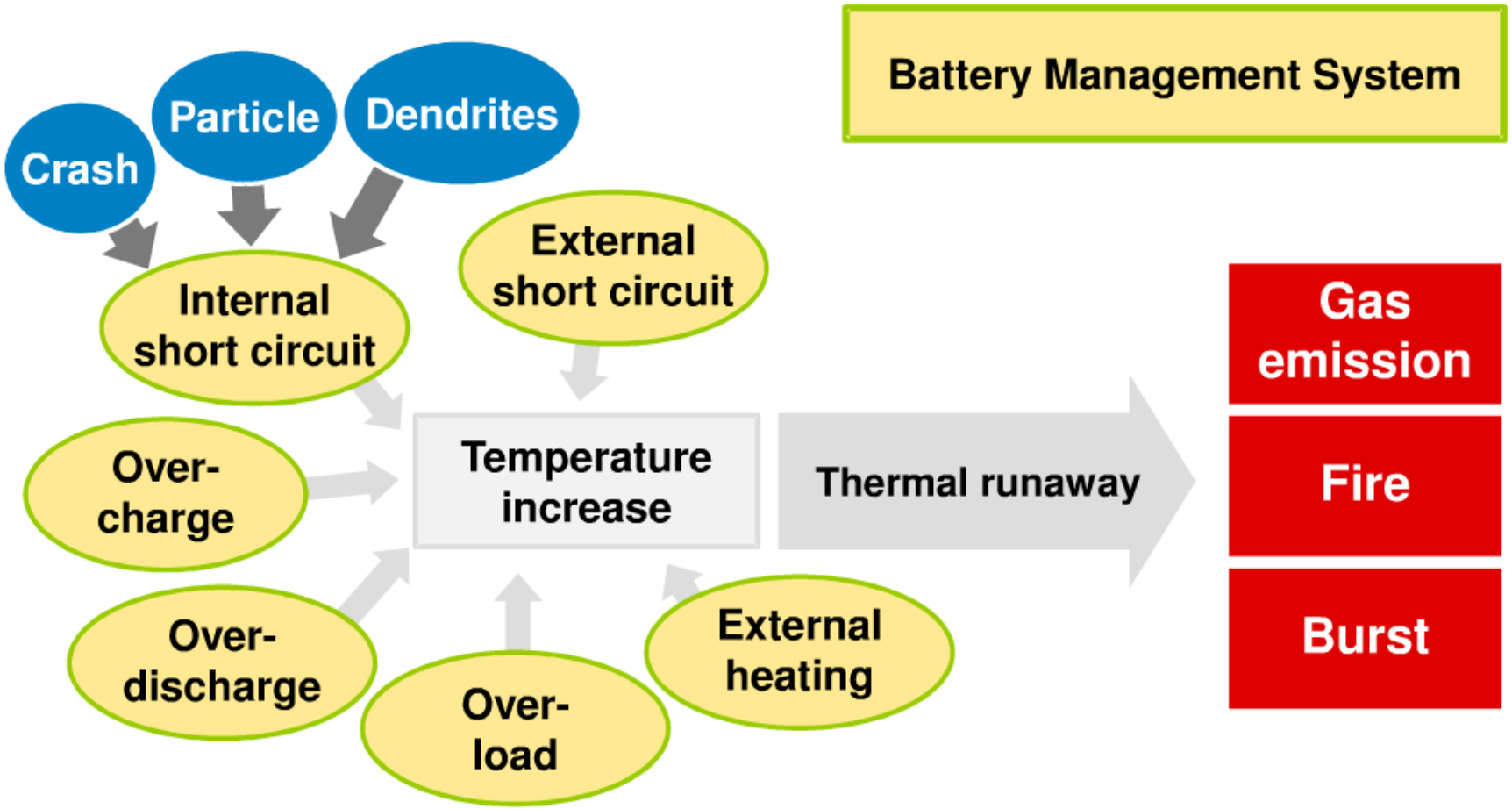
- The selection of safe and productive secondary lithium ion batteries is important for mining applications
- The selection of NMC chemistry gives safe operations, high performance and high energy capacity.

Lithium batteries

Battery failure mechanism



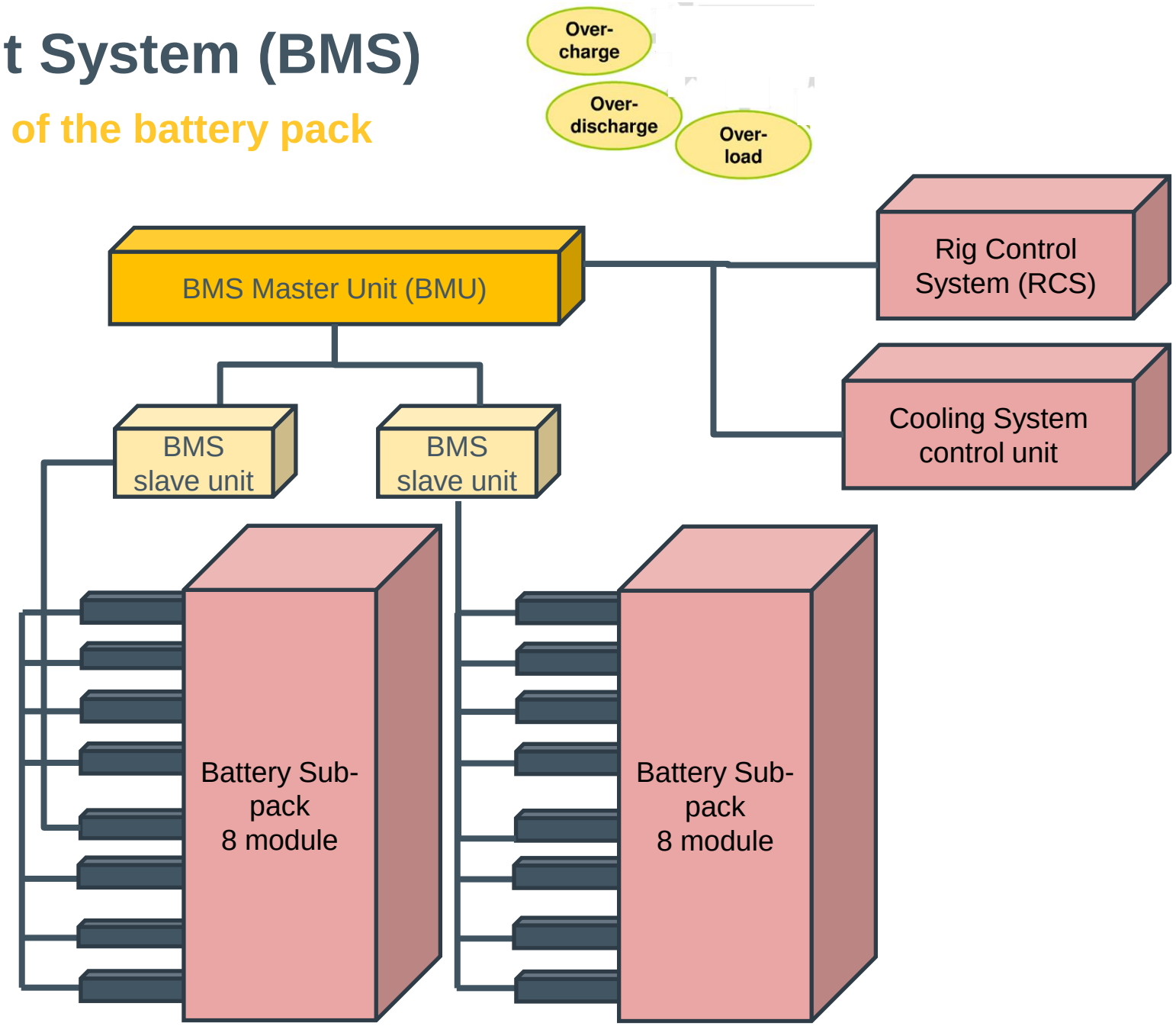
Battery Management System (BMS)

The brain and nerve system of the battery pack

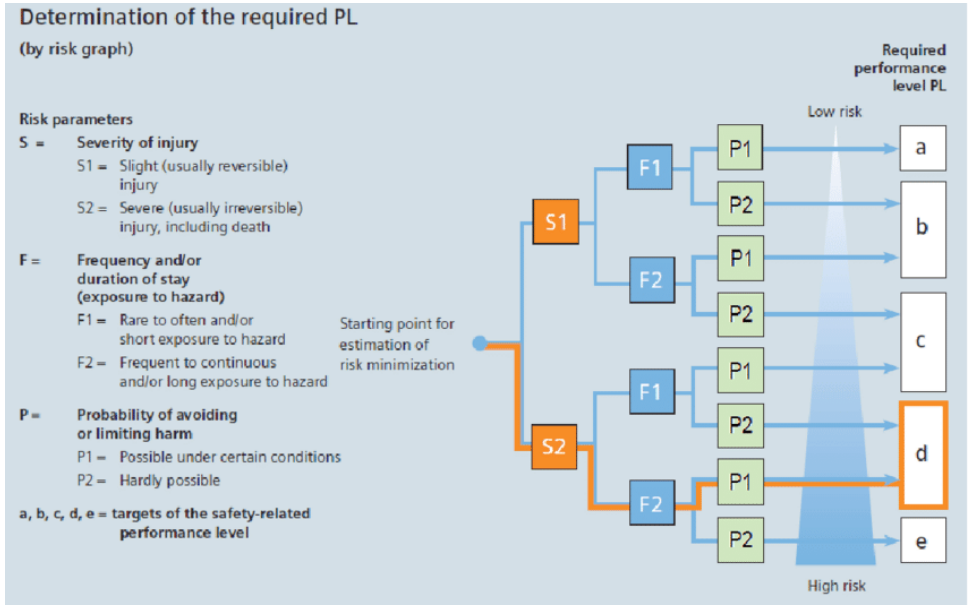
The BMS is an advanced control system that keeps the battery in a safe operation condition.

The BMS monitors:

- **Voltage**
- **Current**
- **Temperature**
- **Other electrical safety functions**



Performance level (PL) assesment according to ISO 13849-1



Performance Level (PL)	Probability of Dangerous Failure per Hour (PFHd) 1/h
a	$\geq 10^{-5}$ and $<10^{-4}$ ⟨0.001% to 0.01%⟩
b	$\geq 3 \times 10^{-6}$ and $<10^{-5}$ ⟨0.0003% to 0.001%⟩
c	$\geq 10^{-6}$ and $<3 \times 10^{-6}$ ⟨0.0001% to 0.0003%⟩
d	$\geq 10^{-7}$ and $<10^{-6}$ ⟨0.00001% to 0.0001%⟩
e	$\geq 10^{-8}$ and $<10^{-7}$ ⟨0.000001% to 0.00001%⟩

- Functional Safety = risk reduction of safety function failure by proper design and self-diagnostics
- Higher Performance Level (PL) implies a longer Mean Time To Dangerous Failure ($MTTF_D$).
- Many manufacturers target a level of PL-C
  - Does not guarantee safety in case of single faults.
  - Dangerous failure detection coverage of 60-90%
- **The Northvolt BMS is designed towards PL-D (SIL 2)** for the fundamental cell monitoring functions
  - Provides safety even in case of single faults in the system.
  - Dangerous failure detection coverage of 90-99%

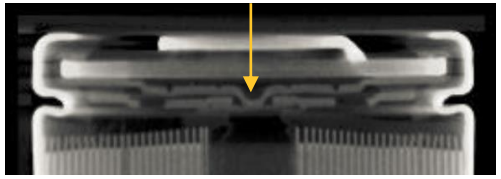
Fuses

Fuses breaks the current when the contactors cannot

External short circuit

Fuses on all system levels:

- Pack Fuses
- Sub-pack fuses
- Wirebond fuses on each cell in the module.
- The current Interrupt Disc inside cell breaks current in case of pressure build up.
- 24 volt control system has fuses.



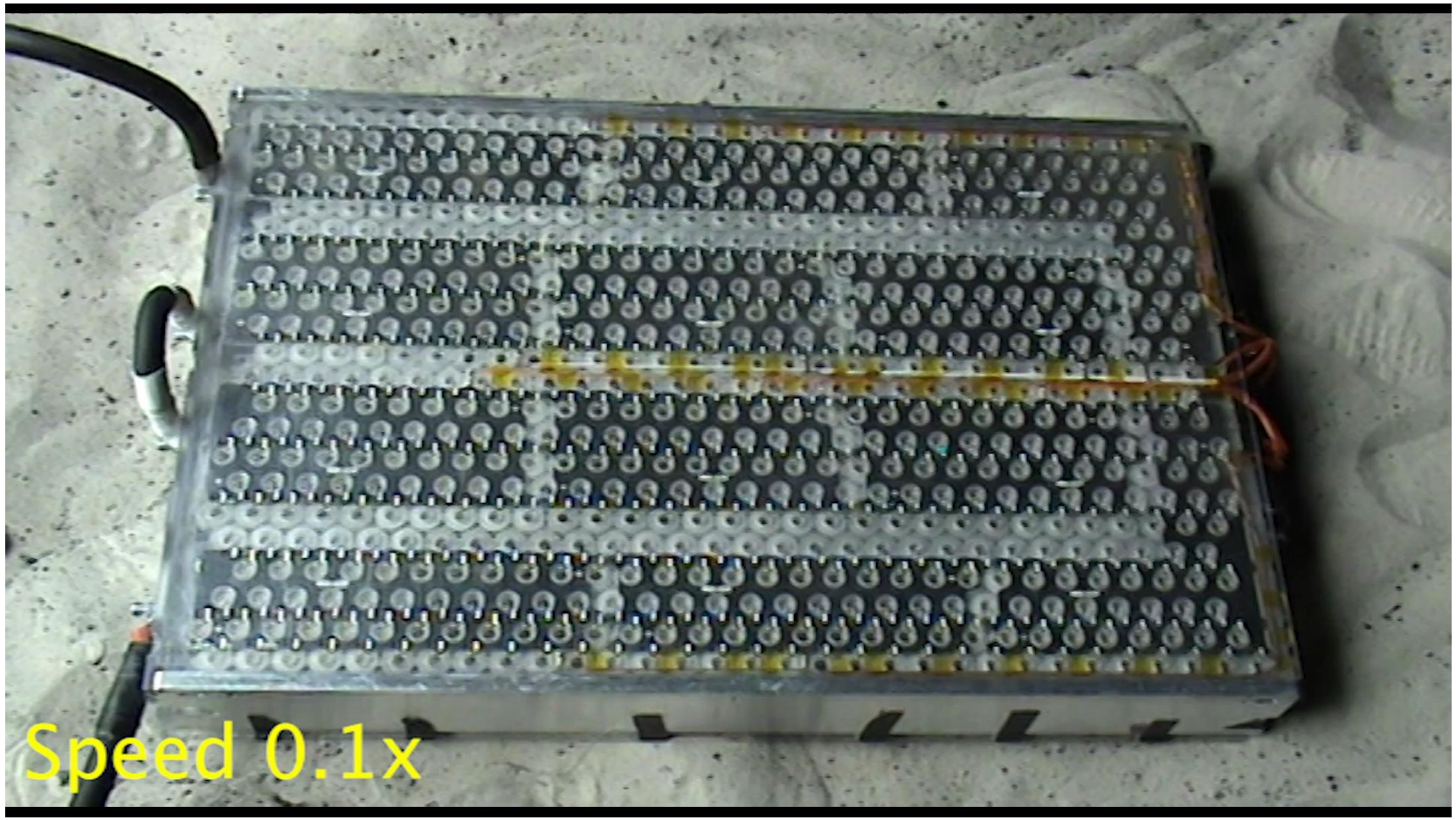
Current interrupted if pressure builds up

Cells connected via wirebonds

Sub-pack and pack fuses

Safety

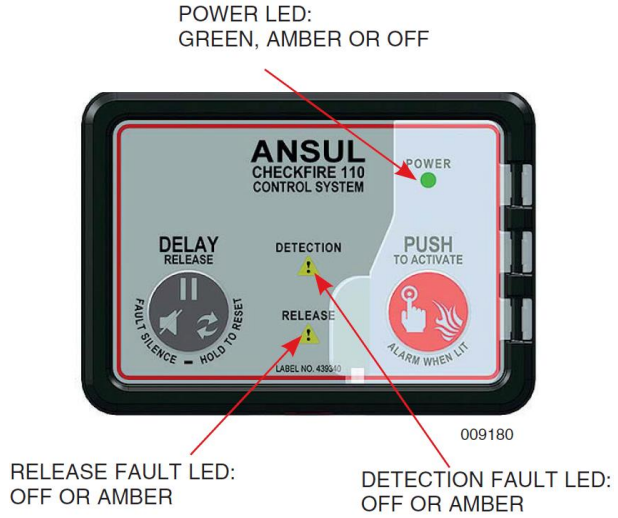
Short circuit test on complete module



- The wirebonds act as fuses during external short circuits

Safety

External heating



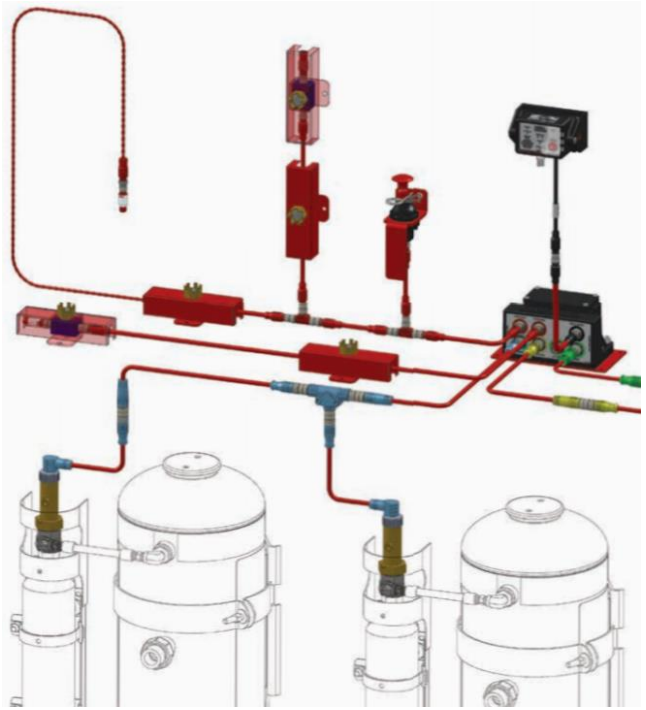
- **Firefighting Equipment for the machine**

➢ Hand Held Fire Extinguisher

➢ ANSUL manually activated fire suppression system, must be activated manually if there is fire.
When triggered, the following occurs:

- ✓ Extinguishing starts
- ✓ The motors are switched off
- ✓ The parking brake is applied
- ✓ Emergency stop circuit broken

➢ ANSUL Checkfire automatically activated fire suppression system

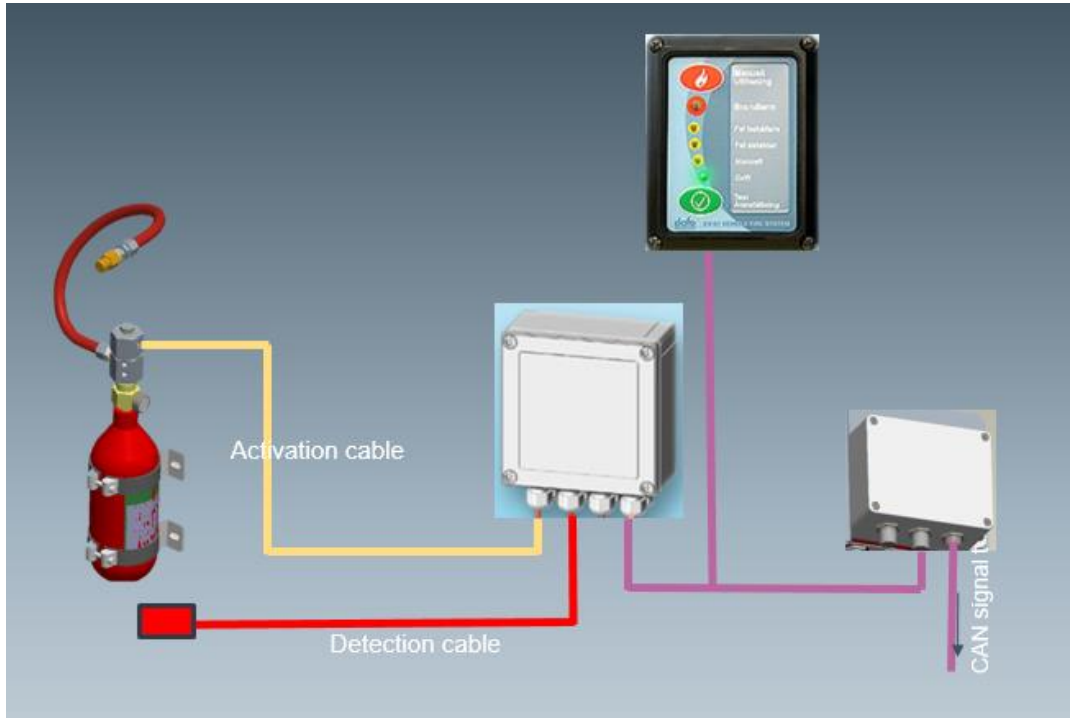


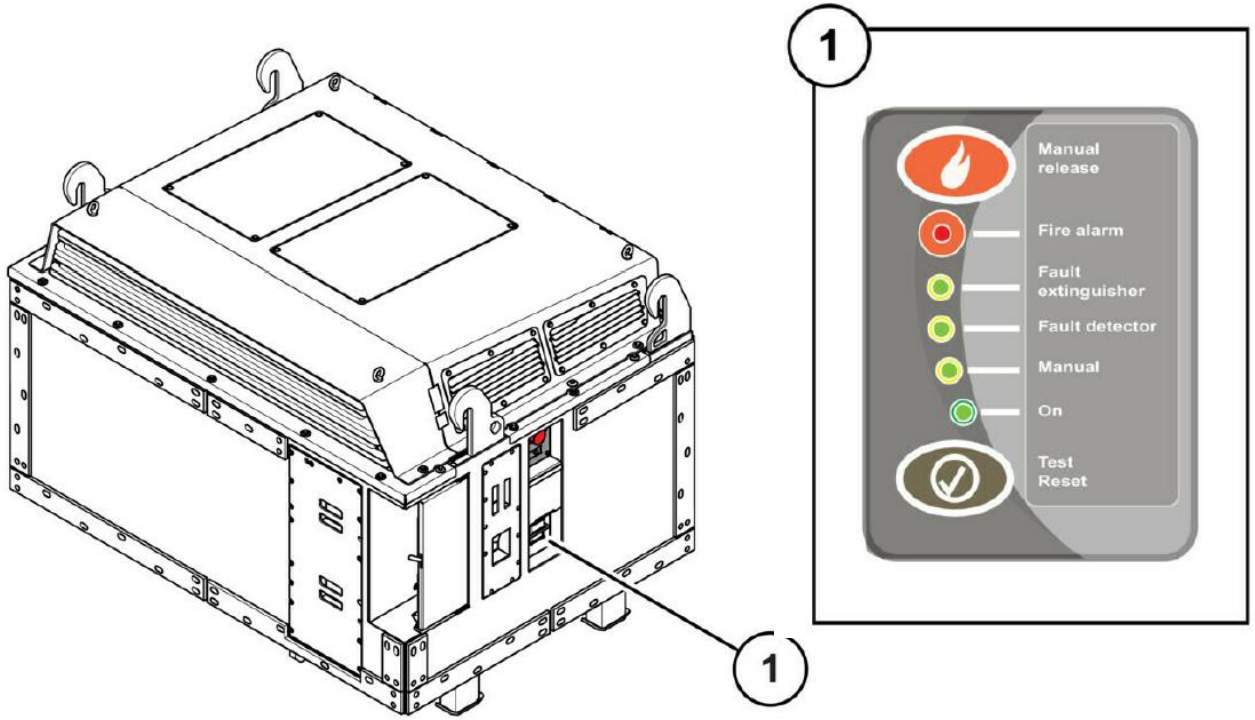
Safety

External heating

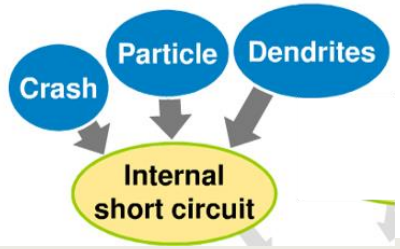
Fire Suppression System for the Main Battery

- Stand alone system that detects and **extinguishes fire only on the main battery system (VCB) and does not activate the fire suppression system for the machine**. System has its own extinguisher tank inside the Battery Pack and uses gas as a suppression medium.
- The system triggers automatically when fire is detected in the main battery system and also send a warning signal to the RCS. System can also be activated manually.





Safety Precautions - Mechanical Part



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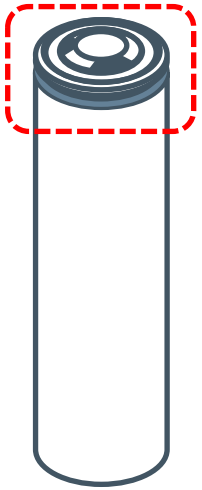
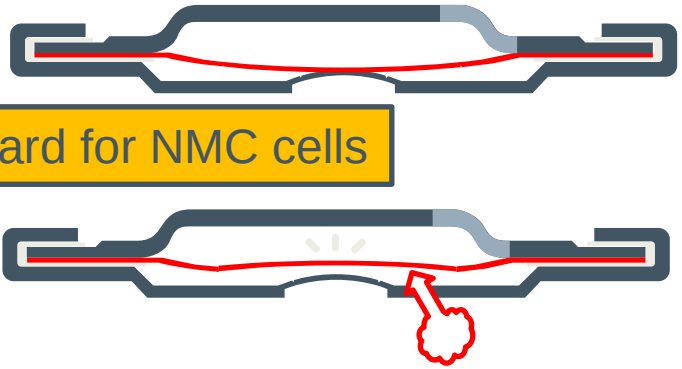
CID

+ “Current Interrupt Device” will work with high internal pressure due to gas production
+ The operating condition is optimized by Northvolt's design



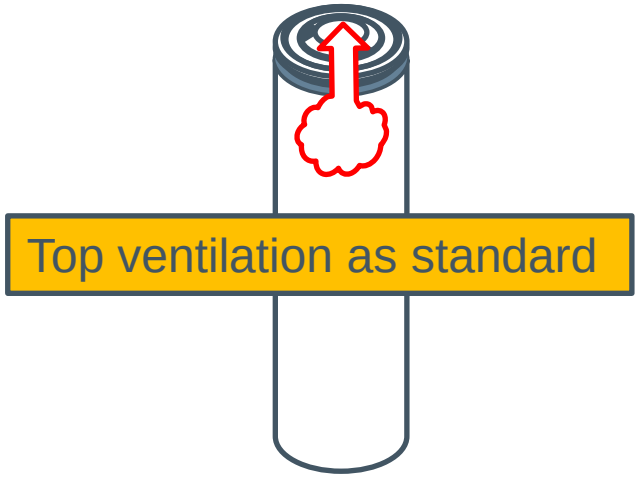
Cross sectional view of cylindrical cell top



CID operation with internal gas

Ventilation Direction Control

+ The direction of gas ventilation can be adjusted based on module and pack design



Ventilation with internal gas

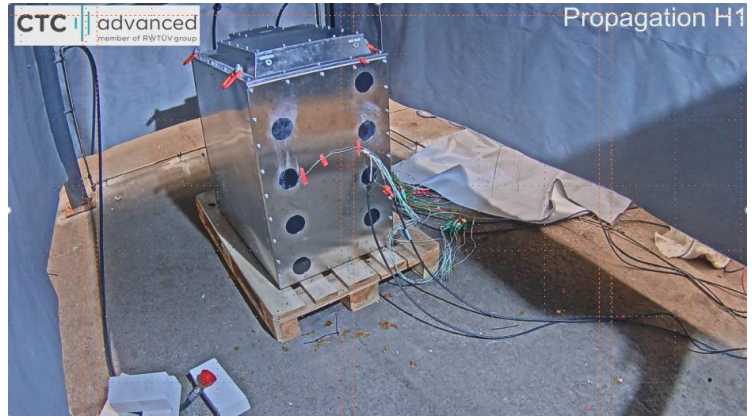
Bottom view of cylindrical cell

Flat type

Ventilated type

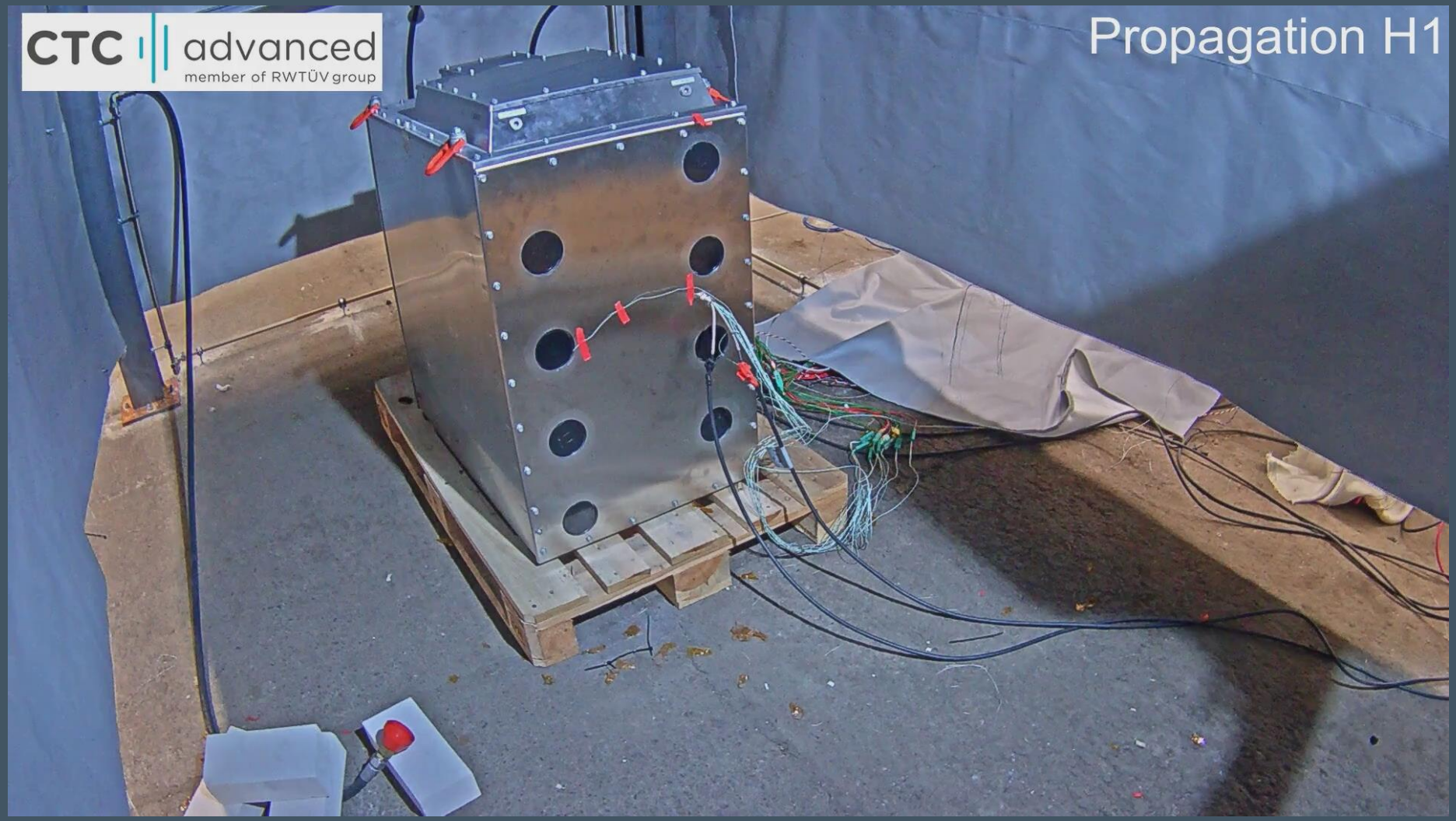
Northvolt Voltpack Core - Thermal runaway testing

- Northvolt Voltpack is validated to withstand single cell thermal runaway without propagation.
- Northvolt has passed thermal propagation testing according to requirements:
  - IEC/EN 62619 (Safety requirements for secondary lithium cells and batteries, for use in industrial applications), Test 7.3.3
  - UL2580 (Batteries for use in electric vehicles), Test 43 Internal Fire Exposure Test
- Pass criteria:
  - No external fire from the battery system or no battery case rupture
- **Additionally succeeded - No propagation between cells within a module**
- Thermal runaway initiation method:
  - Heating by heater, resistive heating method
  - Minimally invasive to the module design
- Test done with three modules stacked inside the Voltpack
  - Module cooling channels filled with water coolant (UL requirement)
  - Test done with 25degC start temperature
  - No active external safety functions such as fire extinguishing system or ventilation



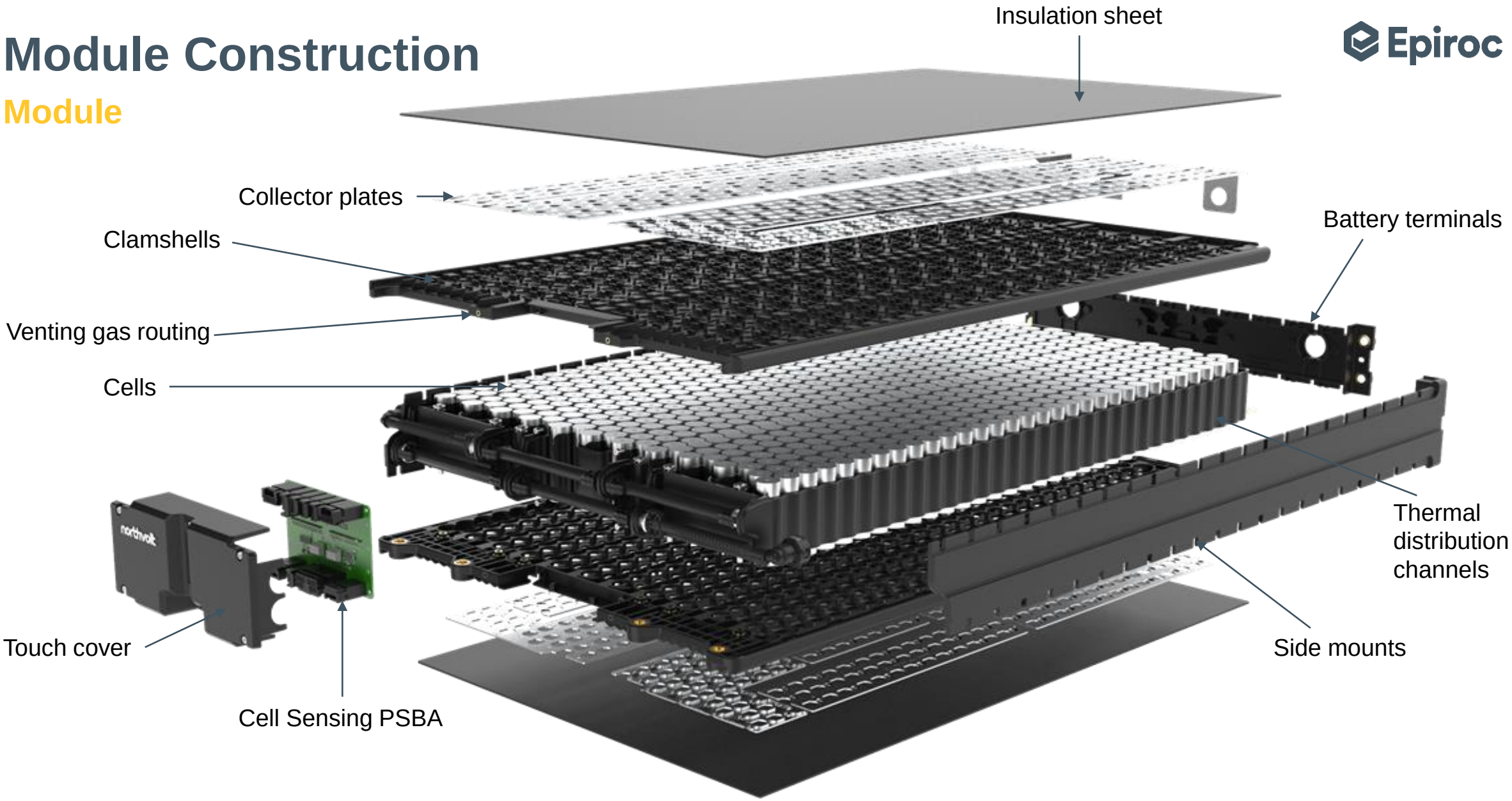
Thermal runaway

Tested in a safe environment



Module Construction

Module

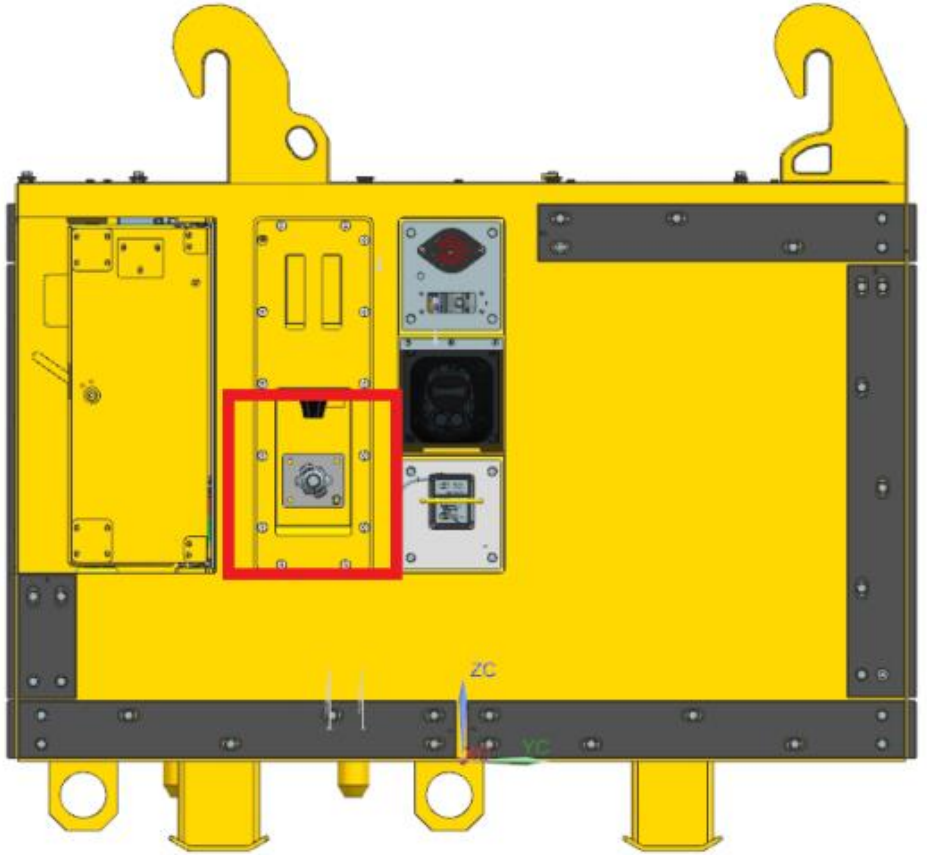


Safety

Flooding of the Battery Pack

Batteries are equipped with a “quick connect” hose coupler outside the main case.

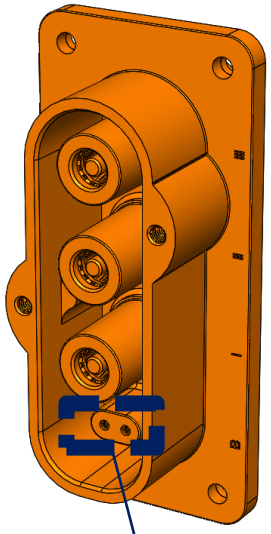
Inside the main case, water is routed directly into each individual subpack.



High Voltage Interlock Loop (HVIL)

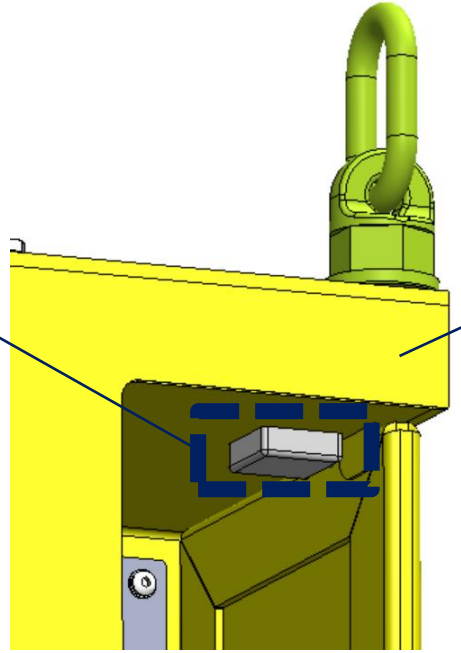
Contactors open when dangerous voltage is accessible

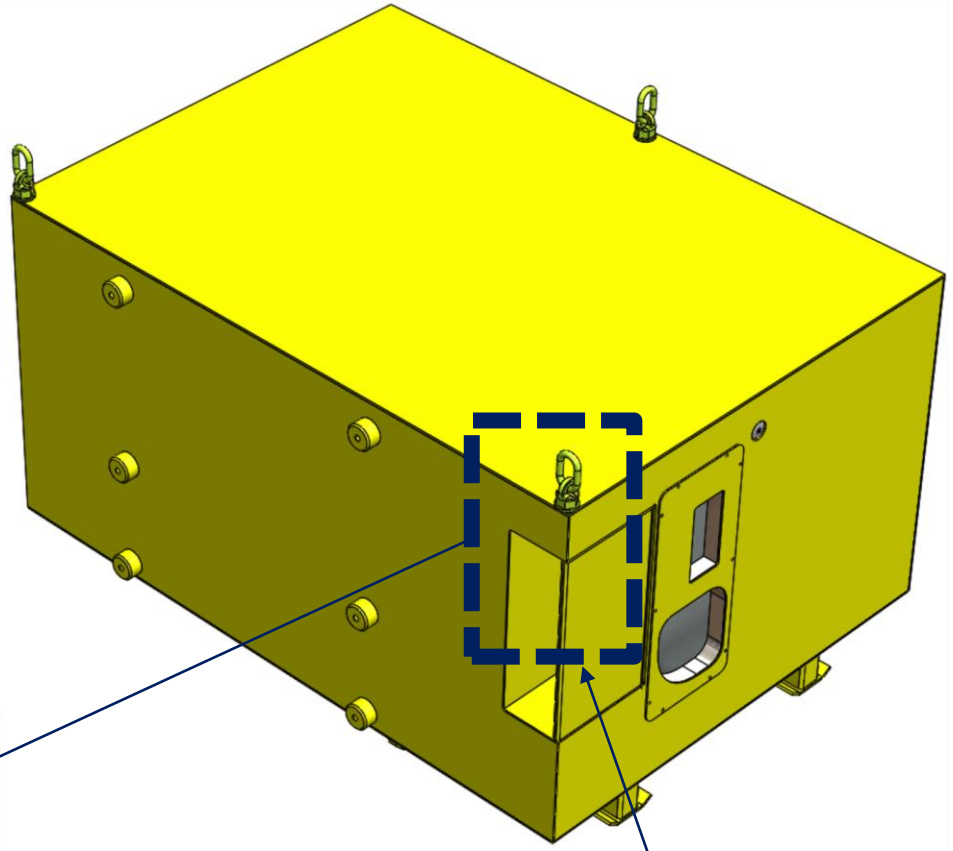
- HVIL is an electric control loop
- Contactors open if the loop is broken.
- Switches that opens the HVIL are located at all interface hatches and panels (see image, and next slide).
- 800 volt contacts also have built in HVIL
- 800 volt contacts are finger proof



HVIL on connections

This switch is pressed out when the hatch is opened, thereby opening the HVIL.





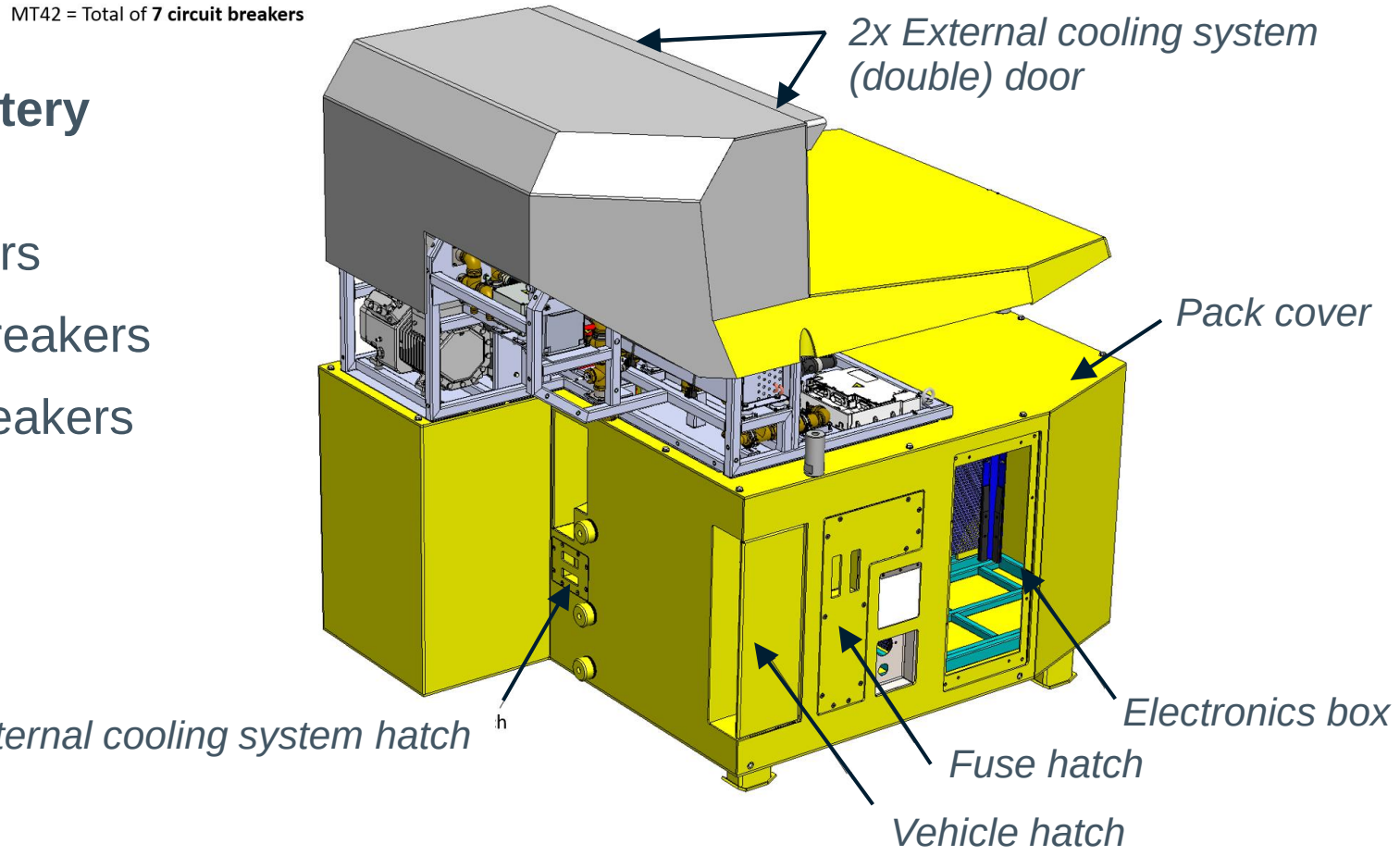
Vehicle Interface Hatch

Hot zones protected by HVIL

Contactors open when dangerous voltage is accessible

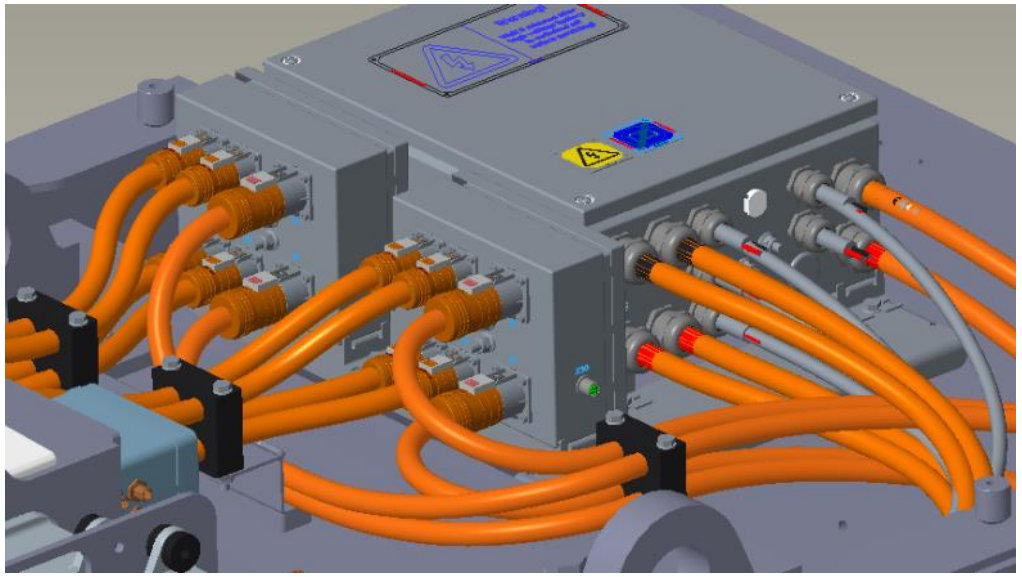
Number of HVIL in the different battery packs:

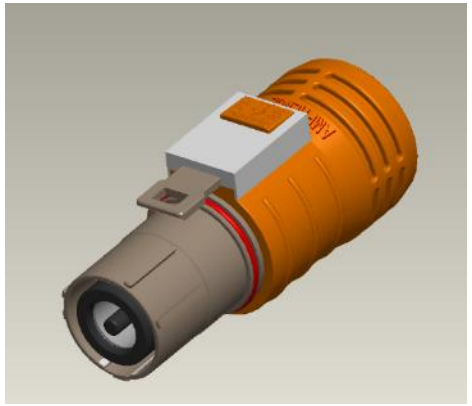
- **MLE Carrier:** 3 HVIL circuit breakers
- **Scooptram ST14:** 6 HVIL circuit breakers
- **Minetruck MT42:** 7 HVIL circuit breakers (highlighted in the image)

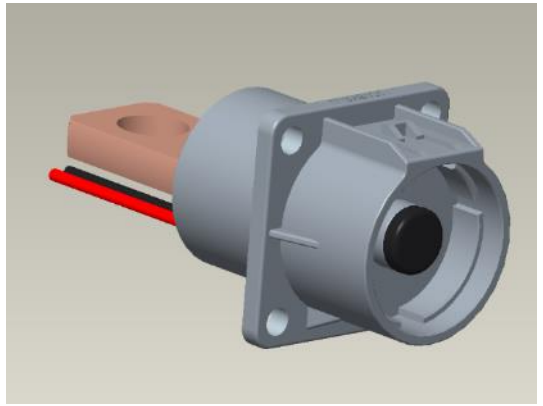


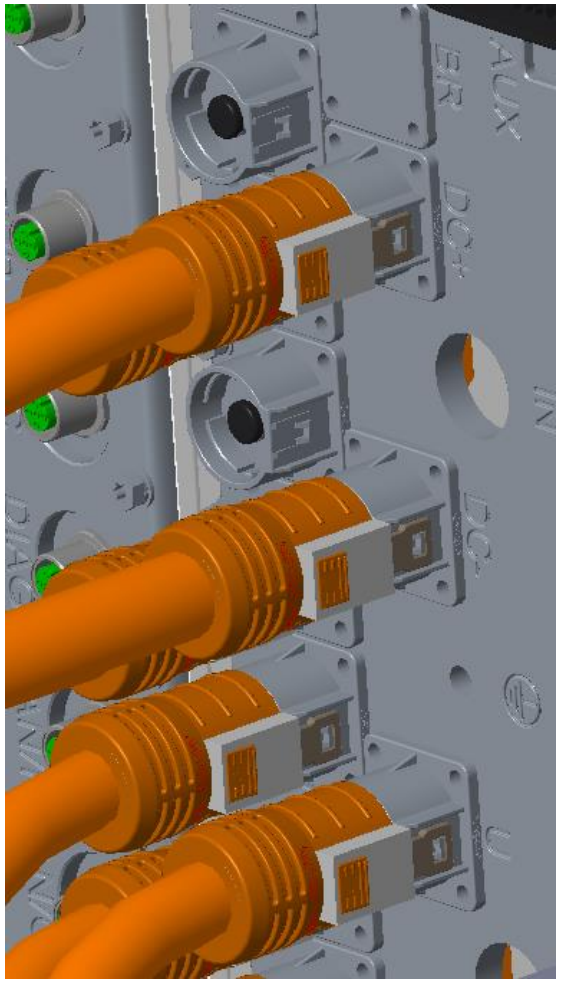
Overview of the HVIL protection in the MT42 battery pack

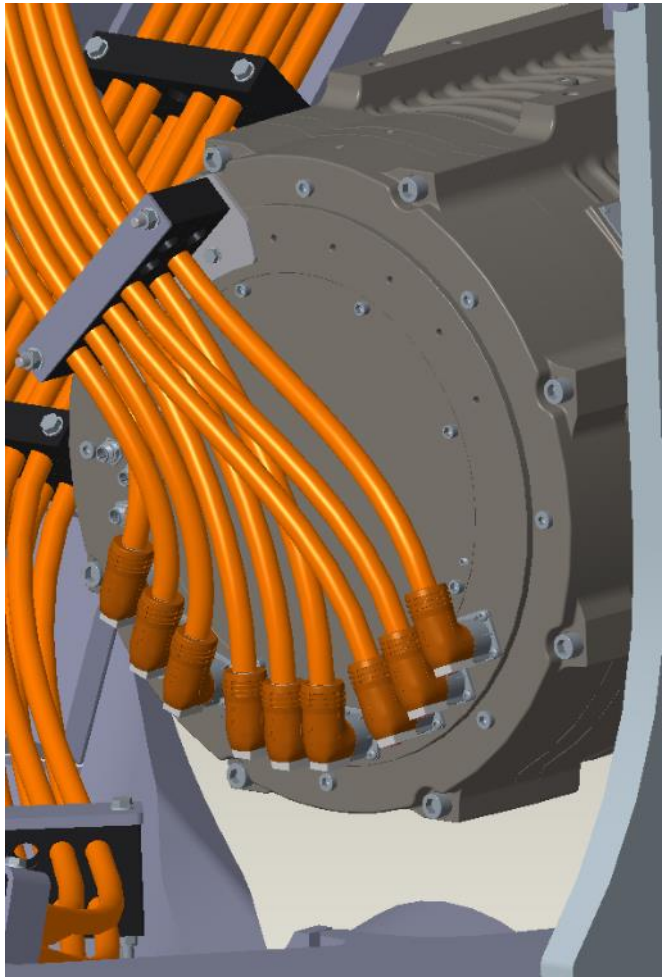
Amphenol power connectors











Contactors

- The 800 volt connections on sub-pack and pack have contactors.
- The contactors open in potentially unsafe scenarios.
- Examples of when contactors opens are:
  - Ground fault.
  - HVIL broken (next page).
  - Operation outside specified voltage, current, or temp. region.

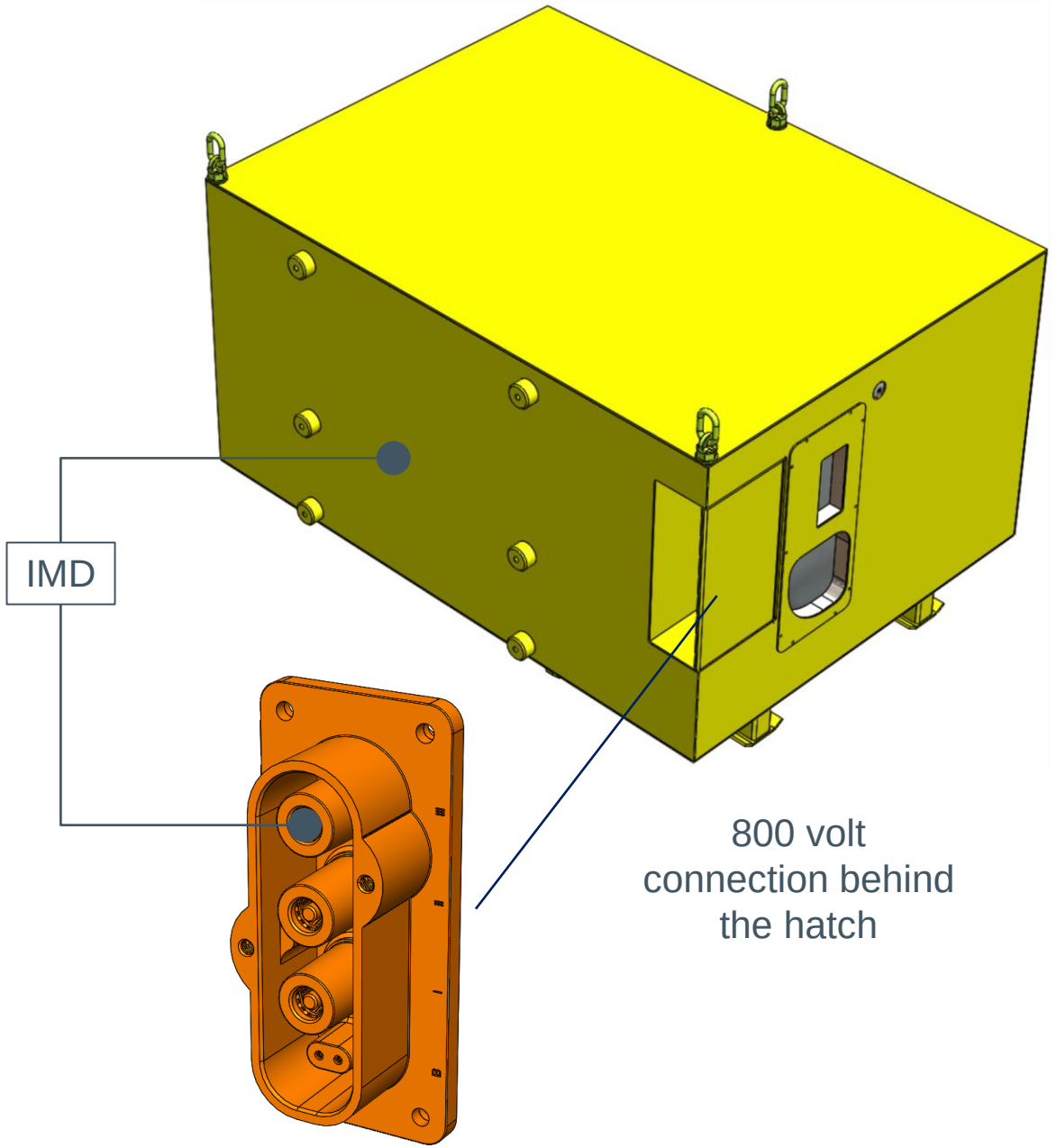
Sub-pack contactor

Pack contactor

Isolation Monitoring Device (IMD)

Protection from ground faults

- The Isolation Monitoring Device (IMD) detects the resistance between:
  - Plus (+) and chassis
  - Minus (-) and chassis
- Ground fault is detected by a low resistance.
- In case of ground fault the contactors opens and operators and service personal are protected from dangerous voltages.



Active Discharge

Protection from Residual Voltage

- Machine safety system that after the battery power supply voltage (VCB) has been cut off (manually, automatically or accidentally), discharges the remaining voltage of the dc-bus through a circuit that includes a resistance and relays directly connected to the battery (VCA) of the equipment.

A complete safety system

Safety isn’t only cell deep

- Built-in thermal management system
- Integrated battery management system
- High machine visibility and maneuverability
- Integrated monitoring and fail safes
- Rugged crash-safe design

Cell certifications and standards

Rigorously tested to international standards

IEC 62619	UL1642	UN38.3
External short circuit	Short circuit, @ RT and @60 °C	Altitude simulation
Impact	Abnormal charging	Thermal test
Drop	Forced discharge	Vibration
Thermal abuse	Crush	Shock
Overcharge	Impact	External short circuit
Forced discharge	Shock	Impact/crush
Internal short circuit	Vibration	Forced discharge
	Heating	
	Temperature cycling	
	Low pressure (altitude simulation)	

The charging interface

Socket and cable, Scooptram ST14, Minetruck MT42 and MLE Carrier

Charging interface features:

- Charging socket and charging cable are finger proofed
- The socket and cable are energized only when connected
- Charging socket is protected by a temperature sensor monitored by the BMS
- Charing cannot be initiated if the vehicle is still running
- During charging the cooling system will be activated

Connectivity

Information

Field data analysis

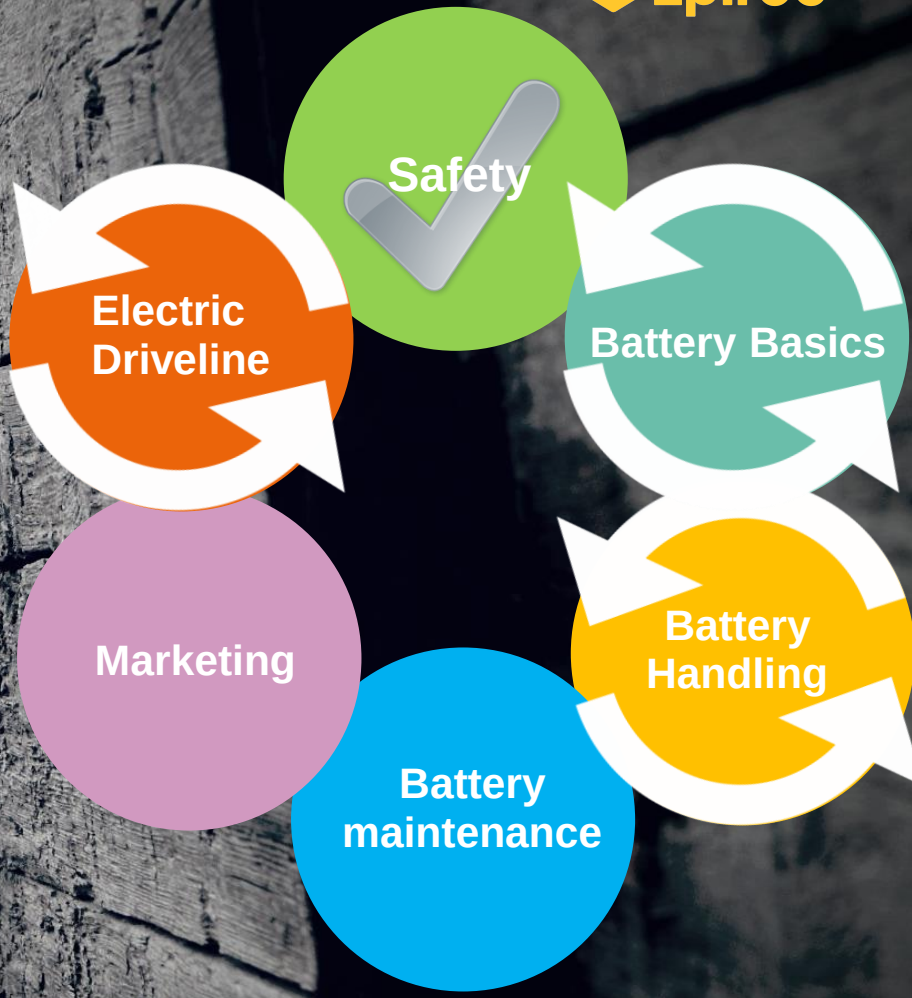
- Close to 600 000 kWh of battery usage
- Predominantly mix of drill rigs and ST14
- Equivalent of 10 000 hours of EV operation

- Zero battery fire
- Zero accident
- Zero incident
- Zero near miss
- Zero lost loss time injury

Battery Training Matrix

Epiroc

Prototype Verification	Other R&D	Control System	Mechanic design	Electric design	PC Specialist	PC Analytic	CC Specialist	CC Technician	Machine operator	Storage	Shipping	Production	CC Storage	CC Transport	Sales	
●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	Battery Basics
●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	Safety
●	●	●	●	●	●	●	●	●	●	●	●	●	○	○	○	Handling
●	●	●	●	●	●	●	●	●	○	●	○	●	●	○	○	Maintenance
●	○	●	○	●	●	●	●	●	○	○	○	○	○	○	○	Electrical Driveline
○	○	○	○	○	●	●	●	○	○	○	○	○	○	○	●	Marketing
●	●	●	●	●	●	○	○	○	○	○	○	○	○	○	○	GMG Guideline



●	●	●	●	●	○	○	○	○	○	○	○	○	○	○	○	Design for electrical safety
●	●	●	●	●	○	○	○	○	○	○	○	○	○	○	○	Electrical safety for workshop Personell

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and commitment drives us to keep moving forward.
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to succeed today and the technology to lead tomorrow.

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