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SAFE MAINTENANCE OF HIGH VOLTAGE ELECTRICAL VEHICLES

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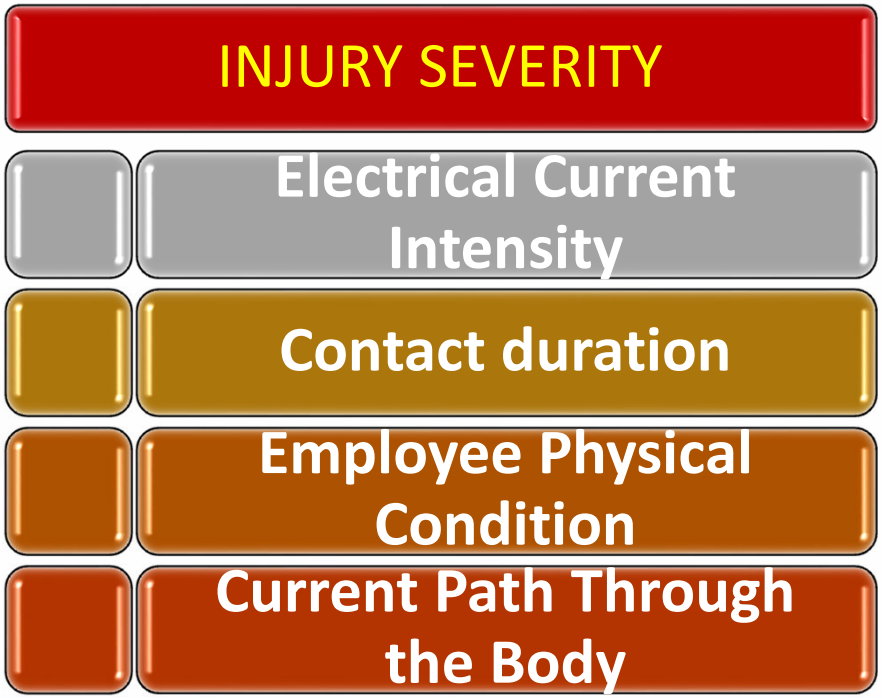
ELECTRICAL HAZARDS

ELECTRIC SHOCK

- **Bodily stimulation when electrical energy flows through the human tissue**
- **It occurs when there is contact with a live conductor, since the human body usually has the lowest resistance**



ELECTRICAL HAZARDS

ARC FLASH INJURY

- **Shockwave exposure**
  - **overheated (>15.000°C) air plasma → BURNS**
  - **instant (1/100 – 1/1000 sec) → INJURY**
- **It occurs due to a short circuit between two live conductors too close in proximity, when a fault current is created to bridge the gap from one conductor to the other through ionization of the surrounding air**

INJURY SEVERITY

- Duration of power disruption / outage
- Distance from the arc
- Temperature of the ionized air
- Sufficient clothing insulation

INDIRECT / SECONDARY NATURE ELECTRICAL HAZARDS

Electric Shock → **Loss of consciousness** → **Loss of Muscular Control** → **Fall** → **Injury**

Arc Flash → **Injury** → **Loss of Muscular Control** → **Fall** → **Additional Injury**

Arc Blast → **Injury** → **Flash/ Blast** → **Fire/ Explosion** → **Additional Injury**

WORKING IN EXPLOSIVE AREAS

OHM'S LAW

$$I = \frac{V}{R}$$

$$I_{BODY} = \frac{V_{CONTACT}}{R_{BODY}}$$

I = Electric Current flowing through a conductor

V = Voltage across the conductor

R = Resistance of the conductor

I = Electric Current flowing through a human body

V = Voltage measured across the human body (touch potential)

R = Body Resistance

OHM'S LAW

$$I_{BODY} = \frac{V_{CONTACT}}{R_{BODY}}$$

I = Electric Current flowing through a human body

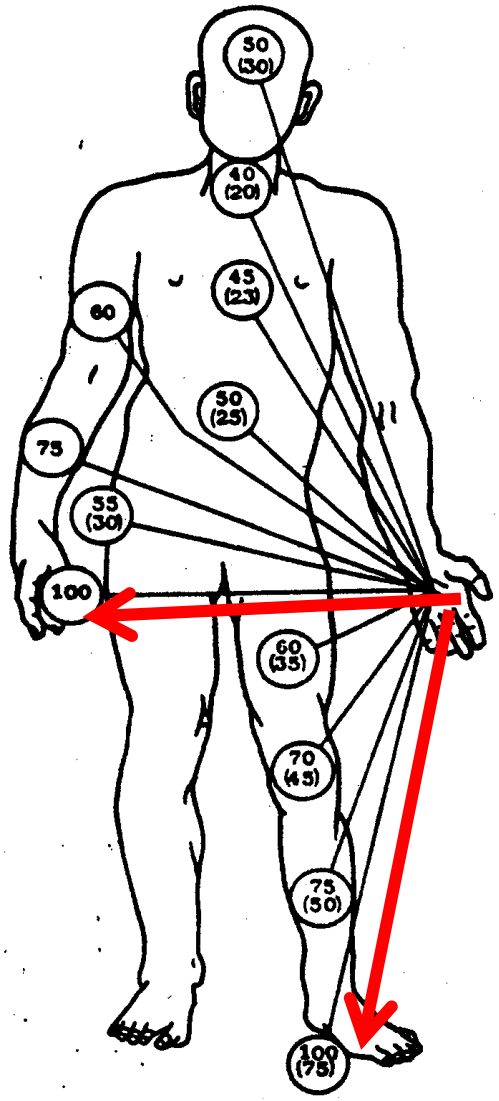
V = Voltage measured across the human body (touch potential)

R = Body Resistance

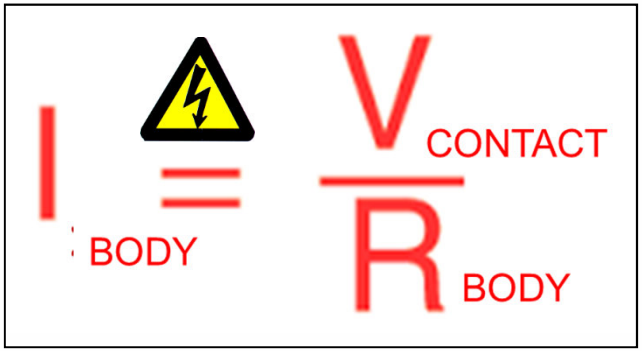
- EV battery pole voltage → 400 – 800 V
- Traction battery energy → 24 – 100 kWh
- Considering a 4-hour battery autonomy (full power operation) → Traction Battery Power P → 6 – 25 kW → 6.000 – 25.000 W
- $P=V*I_{max}$ → I_{max} =(P/V) → 10-60 A.

BODY RESISTANCE DEPENDING ON THE PATH OF THE CURRENT

- Human Body Resistance → 1.000 – 100.000 Ω
- Electric current flow → skin breakdown → 2.000 Ω
- The resistance decreases depending on the path the electric current follows through the body, as shown in the opposite graph, depicting the resistance percentages between the hand and different parts of the human body
- The path from hand-to-hand or from hand-to-foot corresponds to 100% of the body's resistance
- The values in brackets, correspond to the current flow from both hands together to the corresponding parts of the body shown.

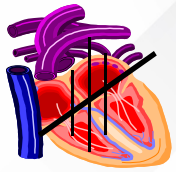
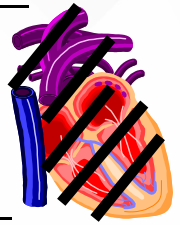
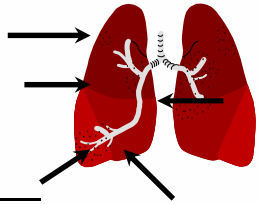
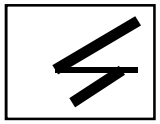
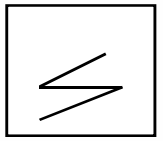


LEAKAGE CURRENT THROUGH THE HUMAN BODY



400/ 800 V	2000 Ω (dry skin)	200/ 400 mA
400/ 800 V	200 Ω (moist /wet skin)	2000/ 4000 mA

EFFECTS OF DC ELECTRIC SHOCK ON THE HUMAN HEALTH

500mA	CARDIAC ARREST 
300 mA	VENTRICULAR FIBRILLATION 
90 mA	RESPIRATORY PARALYSIS 
5.2-62 mA	MUSCLE CONTRACTIONS 
2 mA	SLIGHT TINGLING SENSATION 

'Barrier' means the part providing protection against direct contact to the live parts from any direction of access.

'Direct contact' means the contact of persons with live parts.

'Indirect contact' means the contact of persons with exposed conductive parts.

'Enclosure' means the part enclosing the internal units and providing protection against direct contact from any direction of access.

'High Voltage' means the classification of an electric component or circuit, if its' working voltage is > 60 V and ≤ 1 500 V DC or > 30 V and ≤ 1 000 V AC root mean square (rms).

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

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

'Protection degree' means the protection provided by a barrier/enclosure related to the contact with live parts by a test probe, such as a test finger (IPXXB) or a test wire (IPXXD), as defined in Annex 3.

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

Figure 1 - Marking of high voltage equipment

The symbol shown in Figure 1 shall appear on or near the RESS. The symbol background shall be yellow, the bordering and the arrow shall be black.

Cables for high voltage buses which are not located within enclosures shall be identified by having an outer covering with the color orange.

Places for containing open type traction battery that may produce hydrogen gas shall be provided with a ventilation fan or a ventilation duct to prevent the accumulation of hydrogen gas.

a) electrolyte leakage

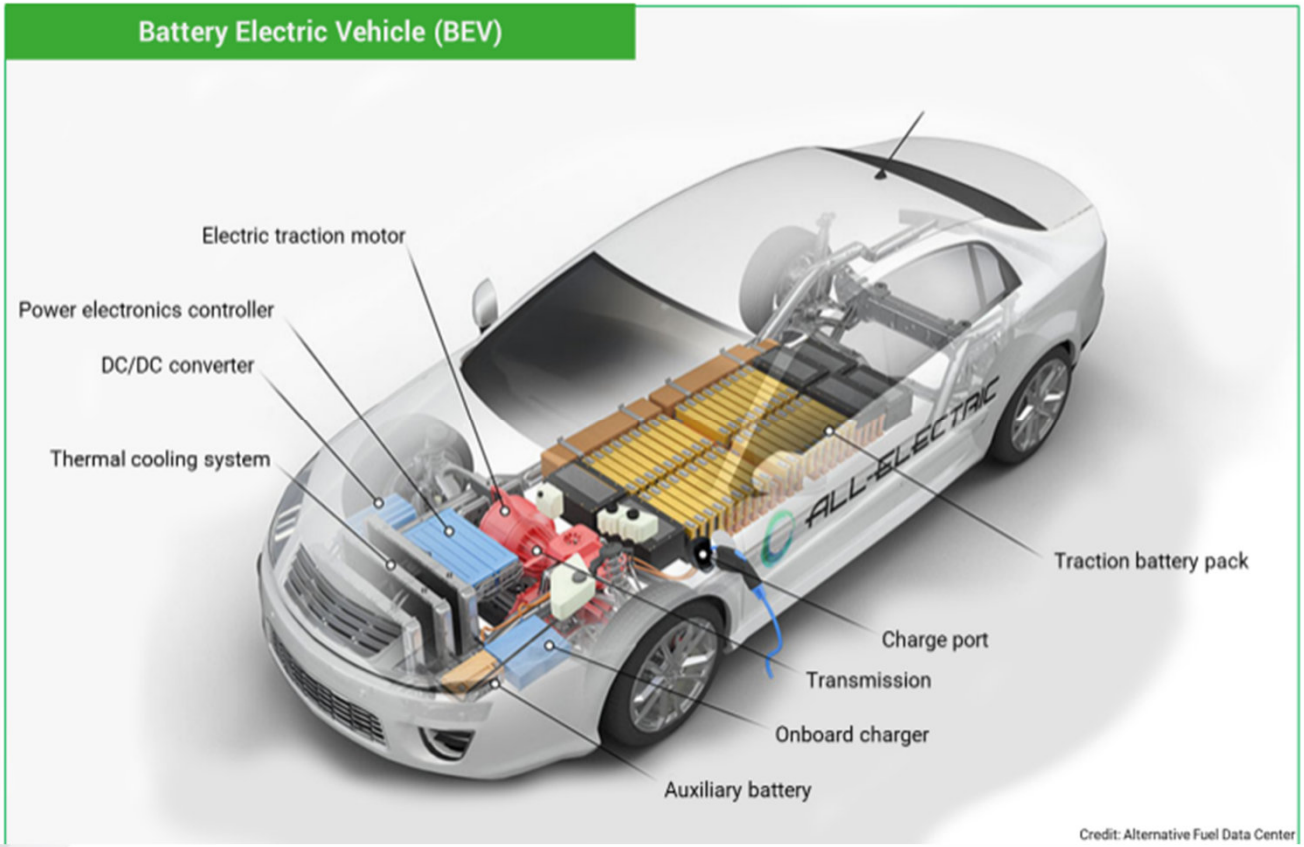
b) power failure (appears only on high voltage RESS)

c) fire

d) explosion

HIGH VOLTAGE (HV) ELECTRIC VEHICLES

a. **<u>Battery Electric Vehicles (BEVs)</u>,** run entirely on electricity only and are moved by one or more electric motors powered by rechargeable batteries.

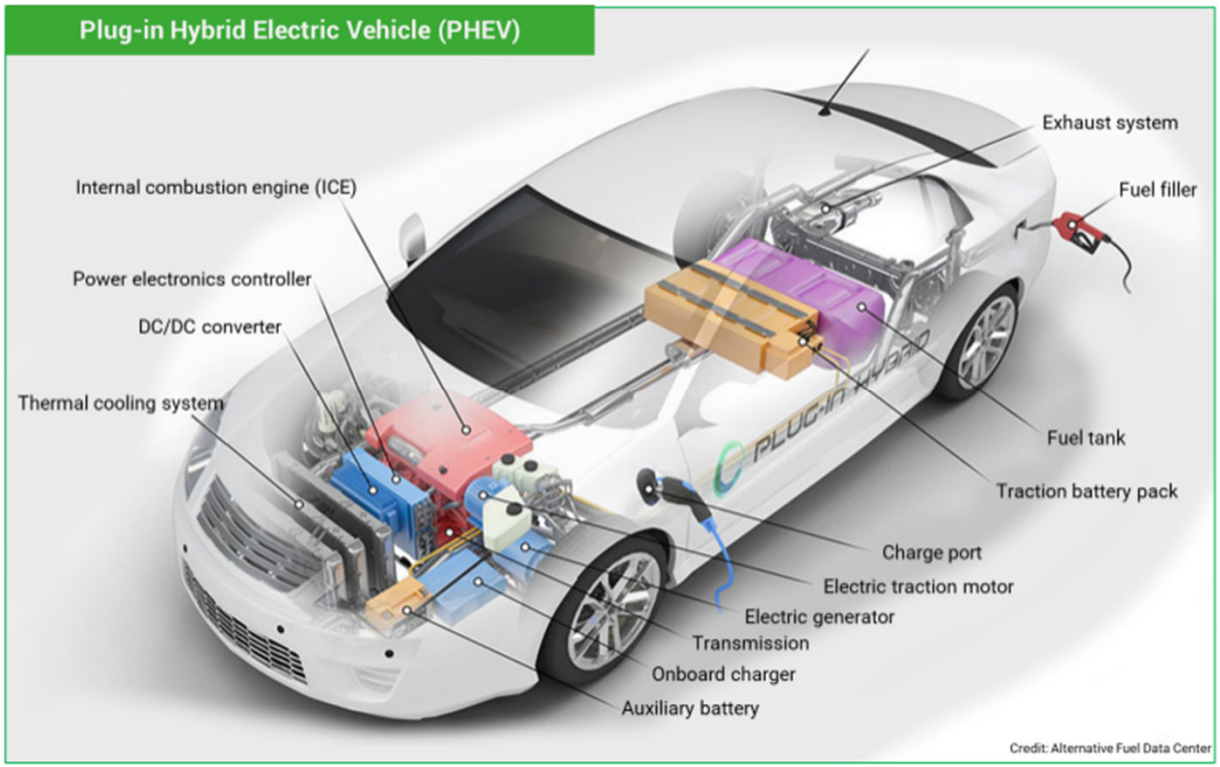


HIGH VOLTAGE (HV) ELECTRIC VEHICLES

b. <u>Extended Range Electric Vehicles (EREVs</u>), are battery electric vehicles with a combustion engine used purely as a generator and as such, there is no connection between the engine and the drivetrain. The vehicle is powered entirely by the electric motor(s) and is run on electricity only, as is the case with BEV–type electric vehicles.

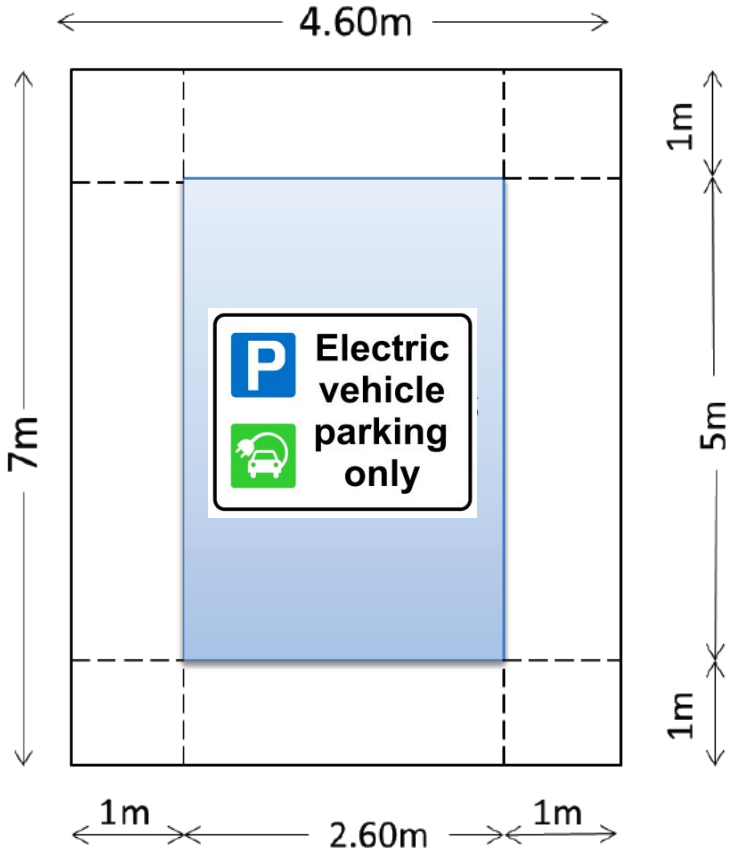
HIGH VOLTAGE (HV) ELECTRIC VEHICLES

c. <u>Hybrid Electric Vehicles (HEVs)</u> that use both an internal combustion engine and an electric motor, **<u>as well as Plug-in-Hybrid (PHEVs) Vehicles</u>**, that use batteries to power an electric motor and incorporate an internal combustion engine that can recharge the batteries.



VEHICLE REPAIR SHOPS / SAFETY REQUIREMENTS

- Quarantine Area → vehicle pre-check and defective HV vehicle parking area (Figure)
- In a restricted and secured indoor or outdoor area → battery and/ or vehicle check
- Alternatively, subcontracting a Road Assistance Company that provides corresponding specifications area.



VEHICLE REPAIR SHOPS/ SAFETY REQUIREMENTS

- Drivers' Reception & Waiting Area
- Sanitation areas
- Office areas
- Indoor area → only for routine maintenance work
  - MAINTENANCE AREA
  - BATTERY STORAGE AREA
- Demarcation with safety signs for the technical personnel repair & vehicle safety
  - Floor marking
  - Signage
  - Safety Cones/ Poles
- Public Road Access
- Urban Planning Permit and Conformance with Building Fire Safety Regulations.

VEHICLE REPAIR SHOPS/ SAFETY REQUIREMENTS

- Indicative layout of a HV electric vehicle repair area

https://www.powerandcables.com/product/product-category/electrical-vehicle-ev-safety-kits/

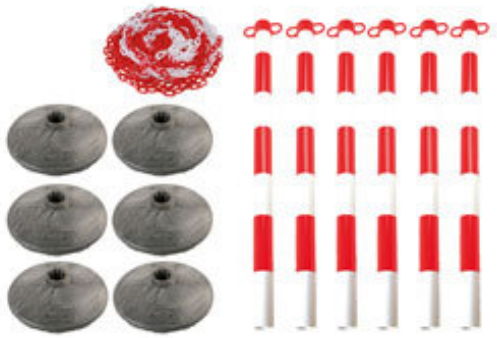
VEHICLE RERAIR SHOPS/ INDICATIVE SAFETY SIGNAGE

- Repair Shop (entrance area) & Repair Shop Indoor Area

- Vehicle Repair Area

- Traction Battery Storage Area

VEHICLE REPAIR SHOP AREAS/ INDOOR MAINTENANCE REPAIR AREA ISOLATION FOR EACH INDIVIDUAL VEHICLE



https://www.lasertools.co.uk/article/Hybrid-and-Battery-Electric-Vehicle-Workshop-Safety

BATTERY STORAGE AREAS

- Flammable/ Dangerous Goods Cabinets

- Drum Spill Containment Pallets

BATTERY STORAGE AREAS

- Ventilation
  - Hydrogen emission measurements
  - Installation of an ATEX Ventilation System (i.e. with explosion-proof specifications)
  - All electrical installations in the area must comply with ATEX Requirements
- Smooth and acid-proof flooring
- Insulated pipework and controlled drainage
- Acid spill containment, absorption and disposal materials.

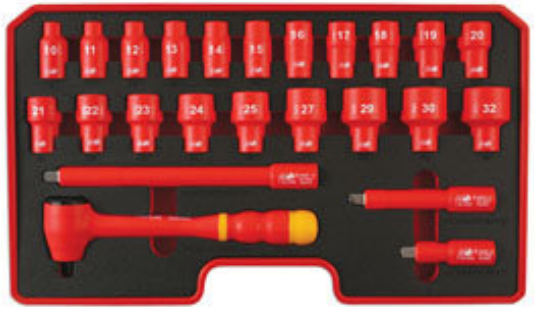
SPECIAL EQUIPMENT FOR EACH TECHNICIAN

- Insulated tools for HV electric vehicle maintenance

  https://www.lasertools.co.uk/products/Hybrid--Electric-Vehicles/Insulated-Tools





MAINTENANCE & TESTING HVEV TECHNICIAN

- «Level 1 HV E-Vehicle Technician»
  - is the technician that, under the guidance of a Level 2 HVEV Technician, performs basic vehicle maintenance tasks, not related to the high-voltage system. They are familiar with the general structure of the high-voltage system and its associated hazards.
- «Level 2 HV E-Vehicle Technician»,
  - is the technician that knows and checks the power supply interruption in high-voltage systems, preventing accidental activation during maintenance. The Level 2 HVEV Technician knows how to remove and reinstall the battery on a HVEV, undertakes the battery repair or the recycling procedure and has the knowledge and ability to safely restart the HVE-system. They are responsible for every task carried out on high-voltage systems and may perform tasks whether or not the HVE-Systems are under voltage or not.
- In each EV repair shop, a Level 2 HV EV Technician is appointed as the person responsible for the safe and proper execution of maintenance works on HV electric vehicles.

SPECIAL Lockout/ Tagout (LOTO) EQUIPMENT

- Lockout, deactivation and immobilization of HV Vehicle power supply system
  - Deactivation of the electrical energy sources from the power switch
  - Personal padlock for the power switch (single or through hasps) → personal padlock for each technician
  - Placement of Lockout Tags → personal tag for each technician
  - LOTO equipment storage in specific LOTO stations or cabinets
  - Steering Wheel Warning Signs
  - Connector Covers.

PERSONAL PROTECTIVE EQUIPMENT/ LEVEL 1 & 2 EV TECHNICIANS

- Electrically Insulated Safety Boots
- 1000V Electrician Gloves
- Insulating Aprons
- Masks/ Respirators
- Face Shields & Goggles/ glasses.

PERSONAL PROTECTIVE EQUIPMENT/ LEVEL 2 EV TECHNICIAN

- Thermal Imaging Camera to locate HV EV traction battery overheating before starting any maintenance work
- Critical traction battery State-of-Health (SOH)
  - Overheating
  - Leakage
  - Emissions
  - Deformation
  - Other unidentifiable failures.

LEVEL 1 & 2 TECHNICIAN DUTIES

- Vehicle Reception by the Level 2 EV Technician
- Infrared camera battery check
- Placing a "suitable or unsuitable for use" sign over the vehicle
- Instructions to the Level 1 Technician by the Level 2 Technician
- Placing a red warning sign on the vehicle windshield
- Placing a yellow safety sign on top of the vehicle
- Level 1 Technician maintenance work under supervision of Level 2 Technician.

LEVEL 1 & 2 HV VEHICLE TECHNICIANS' OCCUPATIONAL HAZARDS

- Electrical shock (electrocution) due to contact with live elements above 25V AC or 60V DC
- Electrical shock due to contact with transient voltage elements
- Arc-Flash explosion shock wave and high temperature exposure due to battery and pole failure
- Exposure to battery acid electrolyte fumes due to spillage
- Fire due to hydrogen emissions' ignition during open battery charging
- Fire caused by Li-Ion batteries' ignition of lithium
- Injury due to unexpected vehicle movement, caused by magnetic forces of the vehicle electric motors
- Musculoskeletal disorders due to heavy load lifting
- Exposure to hazardous electromagnetic fields that may affect pacemakers.

SAFETY MEASURES TO PREVENT ACCIDENTS

- Risk information from the electrolyte Safety Data Sheet
- Meticulous Area Housekeeping
- Safety equipment availability
- Premises' and vehicles' safety signage
- Regular supervision of Level 1 Technician by Level 2 Technician
- Implementation of a LOTO system, i.e. switching off the power supply, placing individual keyed padlocks on the power isolation switches and personal warning tags, removing the electrical supply plugs and vehicle keys, releasing residual energy in intermediate circuits, placing an insulating cover.

SAFETY MEASURES TO PREVENT ACCIDENTS

- Development of a Risk Assessment Study by the Safety Practitioner in collaboration with the Level 2 EV Technician
- Development of safety procedures and guidelines regarding the EV maintenance and repair work
- Development of an "Evacuation and Emergency Plan in case of serious and imminent danger" as well as of an "Evacuation Procedure in case of serious personnel injury"
- A list of the people responsible for the implementation of the corresponding procedures must be clearly posted in every individual area of the E-vehicle repair shop building.

FIRE SAFETY RISKS

- In case of (Li-Ion) lithium battery ignition, toxic hydrogen fluoride vapors, nitrogen oxides, carbon monoxide, ammonia, chlorine, hydrogen sulphide, cyanide fumes etc. as well as high levels of heat, are released
- The ONLY effective fire-extinguishing means is water but in quantities available exclusively to the Fire Brigade
- The Vehicle Manufacturers recommend observing the incident at a distance of at least 10m, without any intervention
- The vehicle will be exposed to high temperatures and will be completely destroyed.

FIRE SAFETY RISKS

- Extinguishing medium → Water → coolant and toxic fume suppressant
- After vehicle extinguishment → monitor battery temperature by a thermal imaging camera → until <70°C (up to 24 hrs) → remove/ transport the vehicle in special containers
- Alternative fire extinguishing means → vehicle blankets but approved by the Fire Safety Authorities ?
- https://www.youtu.be/ZfDEZPODj8
- https://www.youtube.com/watch?v=8n5Wf7TlGrU&ab_channel=BrockArcher
- Hence, further research is needed.

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