ORNL/TM-2019/1366

Electrical Safety Practices Developed for Automotive Lithium-Ion Battery Dismantlement

Jonathan Harter
T.J. McIntyre
J.D. White

January 2020

Approved for public release. Distribution is unlimited.

OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE US DEPARTMENT OF ENERGY

ORNL/TM-2019/1366

Electrical and Electronics Systems Research Division

ELECTRICAL SAFETY PRACTICES DEVELOPED FOR AUTOMOTIVE LITHIUM ION BATTERY DISMANTLEMENT

Jonathan J. Harter
T.J. McIntyre
J.D. White

January 2020

Prepared by
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, TN 37831-6283
managed by
UT-BATTELLE, LLC
for the
US DEPARTMENT OF ENERGY
under contract DE-AC05-00OR22725

CONTENTS

LIST OF FIGURES v
LIST OF TABLES v
ABSTRACT 1
1. INTRODUCTION 1
2. LI-ION BATTERY ELECTRICAL SAFETY 2
   2.1 DIRECT HAZARDS 2
   2.2 SHOCK BOUNDARIES 3
      2.2.1 Prohibited Approach Boundary 4
      2.2.2 Restricted Approach Boundary 4
      2.2.3 Limited Approach Boundary 4
   2.3 ARC FLASH BOUNDARY 4
   2.4 HAZARD RISK CATEGORY 7
   2.5 PERSONAL PROTECTIVE EQUIPMENT 11
3. WORK INVOLVING ELECTRICAL HAZARDS 12
4. LITHIUM ION BATTERY HAZARDS AND CONTROLS 14
   4.1 LIB FAILURE MODES 15
      4.1.1 Non-Energetic Failure Mode 15
      4.1.2 Energetic Failure Mode 15
   4.2 LIB HAZARD CONTROLS 15
5. AUTOMOTIVE LITHIUM ION BATTERIES 16
   5.1 2013 FIRST-GENERATION CHEVROLET VOLT LIB PACK DISASSEMBLY 16
      5.1.1 355.2V Chevrolet Volt LIB Pack Disassembly 17
      5.1.2 92V Chevrolet Volt LIB Module Disassembly 20
      5.1.3 3.7V LG Chem NMC Pouch Cell Disassembly 22
6. SUMMARY 24
7. ACKNOWLEDGMENTS 24
8. REFERENCES 24
APPENDIX A. ORNL ENERGIZED ELECTRICAL WORK PERMIT (EEWP) A-1
APPENDIX B. ORNL HAZARD ANALYSIS **FOR** ELECTRICAL WORK B-1

LIST OF FIGURES

Figure 1. Approach boundaries from Article 130 NFPA70E. 4
Figure 2. Electrically insulated gloves (Class 0 Red 1,000 VAC/ 1,500 VDC) and leather outer. 11
Figure 3. HRC 2 Coveralls made of 100% flame-resistant Nomex IIIA 6-oz. fabric. 12
Figure 4. HRC (0-2/3) Salisbury Arc Flash 20 Cal Lift Front Hood with PrismShield. 12
Figure 5. Common electrical hazard signs and red arc-flash-boundary floor tape. 14
Figure 6. Common lithium ion battery forms (left to right: prismatic, pouch, cylindrical). 14
Figure 7. Midtronics EL-50332 EV/HEV battery service tool. 17
Figure 8. As-received Chevrolet Volt LIB pack before disassembly. 18
Figure 9. Chevrolet Volt pack disassembly. 20
Figure 10. Chevrolet Volt LIB pack internal diagram. 21
Figure 11. Disassembly of Module 5 to a cell. 22
Figure 12. Manual disassembly of a Chevrolet Volt pouch cell. 23

LIST OF TABLES

Table 1. Effect of current on human body. 3
Table 2. ORNL SBMS shock approach boundaries for alternating current (AC) systems. 6
Table 3. ORNL SBMS shock approach boundaries for direct current (DC) systems. 7
Table 4. One specific task-based arc flash hazard analysis for alternating current (AC) systems (see NFPA for other tasks; there are many). 8
Table 5. ORNL SBMS task-based arc flash hazard analysis for direct current (DC) systems. 9
Table 6. ORNL SBMS arc-rated protective clothing and PPE requirements per HRC. 10

ABSTRACT

ORNL is developing electrical safety practices for handling and disassembling automotive lithium ion batteries in a research environment. Online literature searches did not reveal any standard electrical safety practices for disassembling lithium ion battery stacks from automobiles. Until recently, there has been insufficient motivation to recycle or refurbish spent automotive lithium ion batteries due to limited volumes entering the secondary market. However, a growing volume of spent lithium ion batteries are beginning to collect in automobile salvage yards, recycling facilities, landfills, and other places due to a shortage of economically and environmentally viable end-of-life options. ORNL studied automotive battery pack, module, and cell dismantlement to understand the risks, hazards, and controls necessary to perform dismantlement safely and economically. Packs, modules, and cells were manually taken apart, while wearing appropriate personal protective equipment, with insulated hand tools. These dismantlement studies point out the hazards and risks associated with dismantling automotive lithium ion batteries and describe practices for controlling such hazards and risks while demonstrating the controls through a case study of a first-generation Chevrolet Volt battery pack.

1. INTRODUCTION

Lithium ion batteries (LIBs) are used extensively in electric vehicles (EVs), hybrid electric vehicles (HEVs), and extended range electric vehicles (EREVs). “Batteries are two or more electrochemical cells electrically interconnected in an appropriate series/parallel arrangement to provide the required operating voltage and current levels” [1]. LIB refers to an entire family of battery chemistries containing the lightweight element lithium, which offers higher energy density than most other batteries, higher cell voltage storage capability, and longer charge retention (5–10 years). They are a preferred battery for many portable electronic devices such as cell phones, laptops, headphones, smartwatches, and myriad other consumer products like power tools, lawn maintenance equipment and electric bicycles. Typical LIB cell voltage is between 3–4 volts.

LIBs are ideal sources of energy for transportation applications due to their high energy density, high voltage, low self-discharge rate, and lack of memory (e.g., decrease in capacity due to partially charging and discharging a battery). Increased energy density provides EVs with extended range and increased power. Consequently, these increases affect the safety of those working on EV LIBs. Fully charged LIB systems fall between several volts and several hundred volts. In addition to high voltage, short circuit current has been measured up to several thousand amps in large advanced battery systems. Systems with these properties are dangerous to work on and require certain personal protection equipment (PPE), work procedures, and work environments.

Low-voltage batteries are considered nonhazardous in most cases, but what if there are 96 batteries in series? A series circuit is an array of batteries connected by their positive and negative terminals (cathodes and anodes) so that the sum of each individual battery voltage is the battery series voltage. Therefore, the voltage of such a battery combination is 96 times the nominal voltage of a typical 3.7 VDC LIB (96 × 3.7 V = 355.2 VDC). This voltage is the same as the Chevrolet Volt automotive battery pack that will be discussed in greater detail later is this document. The nominal voltage of the system is beyond 100 VDC and according to ORNL electrical safety standards requires additional protection strategies. (See ORNL Standards-Based Management System subject area “Electrical Safety” at https://sbms.ornl.gov/sbms/SBMSearch/subjarea/elec/sa.cfm#HERE.)

Those who work on or near electrical equipment must be qualified to do so, as authorized by the institution authority having jurisdiction. A qualified person is one who “has skills and knowledge related to the construction and operation of the electrical equipment and installations and has received safety training to recognize and avoid the hazards involved" [2]. An additional precaution is needed for work on energized electrical systems. Live work, i.e., work on energized conductors, should be avoided whenever possible. However, automotive battery systems are always energized, unless they have been completely discharged, and do not provide any circuit protection or interruption such as circuit breakers in alternating current (AC) systems that stop the flow of electricity.

Life-after-first-use industries such as salvage yards, recyclers, and others may soon realize the need to process automotive LIB packs as the mobility market electrifies and batteries become one of the largest end-of-life products. Included in this document are electrical safety categories that are important to understand before proceeding with energized electrical work associated with automotive LIBs. First, direct and indirect hazards, shock and arc boundaries, hazard risk categories, and PPE will be covered. Second, procedures for filling out an energized electrical work permit and shock and arc flash hazard analyses will be discussed. Lastly, a Chevy Volt automotive LIB pack, case study, will be discussed in detail, including disassembly procedures of a fully charged pack, module, and cell.

This document is intended to guide work on or near energized automotive LIB systems, for the purpose of disassembly, and keep the worker and fellow workers safe by identifying the hazards and controls of low-voltage (<600 V) automotive LIB systems. Additionally, this document should not replace any official electrical safety resources but should supplement the work being conducted within the Critical Materials Institute at DOE's Ames Laboratory and other institutions where this work is being performed.

2. LI-ION BATTERY ELECTRICAL SAFETY

Electrical hazards may exist directly or indirectly. Accidental contact with energized conductors, electrocution, or internal/external burns are examples of direct contact. Alternatively, indirect contact is when a worker is affected by electrical system environments that may include smoke inhalation from fire, falling during evacuation, or tripping over cables that were not marked or covered. Indirect hazards may be controlled by establishing appropriate safety boundaries and a safe working environment.

Exposed battery terminals should always be covered with a protective cover or insulating barrier to prevent accidental contact. UL-rated electrical tape, original equipment manufacturer (OEM) protective covers, or electrical blankets are ideal controls for direct hazards.

2.1 DIRECT HAZARDS

Electric shock is one of the most common and well-known hazards associated with electricity. Electric shock occurs when a person completes a circuit, or becomes part of a circuit, and conducts electricity through their body. Voltage causes current to flow through conductors, and the amount of current (amperes) may be calculated using Ohms Law I (amperes) = V (volts) / R (ohms). The resistance of the body, under dry conditions, is approximately 1000 ohms [3]. Therefore, a 120 V outlet can conduct 0.120 amperes through dry skin. The biological effects of current passing through the body is shown in Table 1. An OSHA introduction to electrical safety module can be found here as an additional resource: https://www.osha.gov/sites/default/files/2018-12/fy07_sh-16610-07_01_pg-module_1.pdf.

Table 1. Effect of current on human body. [a]

Current (mA)	Effect on Human Body
1	Perception
5	Slight shock felt
6–25	Painful shock and loss of muscular control
9–30	“let go” limit or freezing current
50–150	Extreme pain, respiratory arrest, Severe muscle contractions, death possible
1,000–4,300	Ventricular fibrillation, nerve damage, death is likely
10,000+	Cardiac arrest, severe burns, high probability of death

[a] Adapted from W.B. Kouwenhoven, “Human Safety and Electric Shock,” *Electrical Safety Practices*, Monograph 112, Instrument Society of America, p. 93. (Papers delivered at the third presentation of the Electrical Safety Course in Wilmington, DE, November 1968.)

Electric shock prevention practices can protect yourself, fellow workers, and equipment. Creating an electrically safe work environment is essential when working with any electrical system. This may be done by eliminating power with a disconnect, unplugging the equipment, or removing a service disconnect plug, etc. Disconnection ensures that the system will not energize if the power is unintentionally turned on. Eliminating possible contact with exposed energized parts is another way of preventing electrocution and can be done by covering up conductors with an insulating material, wearing proper PPE, and establishing shock boundaries.

Automotive battery packs have several electrical safety features such as manual service disconnects, sealed plastic or metal covers, internal relays, and high-voltage indicators. If the battery pack is still in the car, a manual service disconnect plug may be accessed from inside the vehicle which disables the battery and electrically isolates the car. Battery covers protect the battery from punctures and scrapes and protect the worker from contacting internal conductors. High-voltage contacts such as fuses, cables, and disconnects are typically orange, indicating a high-voltage hazard.

2.2 SHOCK BOUNDARIES

Shock boundaries are a mandatory control intended to create distance between a person and an electrical source regardless of whether that person is working on the source or could potentially contact the source. Shock boundaries include prohibited, restricted, and limited approach boundaries (Figure 1). Each boundary serves a unique purpose and is differentiated by distance. Boundary distances are determined by the power source type (DC or AC), and the nominal voltage rating.

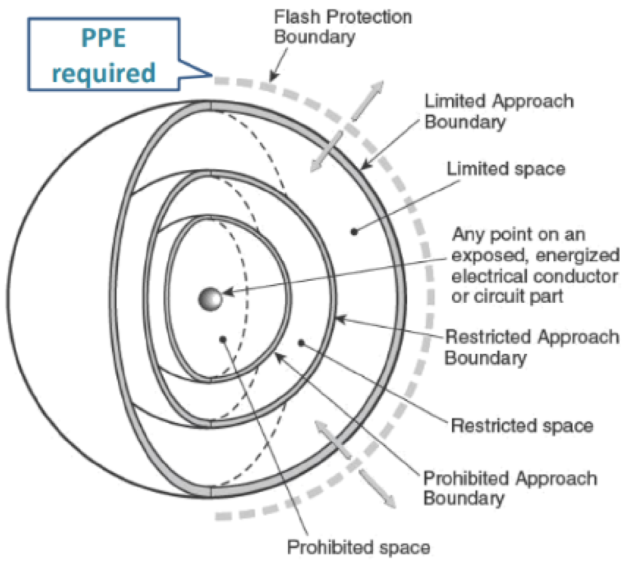


Figure 1. Approach boundaries from Article 130 NFPA70E ®. Reproduced with permission of NFPA from NFPA 70E®, Standard for Electrical Safety in the Workplace®, 2012 edition. Copyright© 2011, National Fire Protection Association. For a full copy of NFPA 70E®, please go to www.nfpa.org.

2.2.1 Prohibited Approach Boundary

Prohibited approach boundary (PAB) is nearest to the potential shock source and is equivalent to performing energized work. This boundary prohibits unqualified electrical workers from entering the space and requires insulated tools and appropriate PPE while within bounds. An Energized Electrical Work Permit (EEWP) is required when working within the PAB. An EEWP is a document that records specific tasks to be performed and the type of system that will be worked on. This document also lists the hazards and the minimum level of qualified electrical worker permitted to perform the work.

Note: An EEWP template is shown in Appendix A.

2.2.2 Restricted Approach Boundary

Restricted approach boundary (RAB) is second closest boundary to the potential shock source. This boundary is restricted to low-voltage-qualified electrical workers who are wearing appropriate PPE, using insulated tools, and are working under an EEWP.

2.2.3 Limited Approach Boundary

Limited approach boundary (LAB) is the furthest shock boundary from the potential shock source. This boundary limits unqualified personnel from entering unless escorted by a low-voltage-qualified worker. Insulated tools and an EEWP are required while working within the limited approach boundary.

2.3 ARC FLASH BOUNDARY

A supplemental boundary to be aware of is the arc flash boundary (AFB). An arc flash hazard is not exactly electric shock but is an ongoing plasma produced from current breaking down gas in a typically nonconductive medium such as air.

> An arc flash occurs during a fault, or short circuit condition, which passes through the arc gap. The arc flash can be initiated through accidental contact, equipment which is underrated for the available short circuit current, contamination or tracking over insulated surfaces, deterioration or corrosion of equipment and or parts, and other causes. An Arc Flash event can expel large amounts of deadly energy. The arc causes an ionization of the air, and arc flash temperatures can reach as high as 35,000 degrees Fahrenheit. This extreme temperature can set fire to clothing and severely burn human skin in fractions of a second at a significant distance from the event. The heat can also result in ignition of any nearby combustible materials. Arc Flash temperatures can also liquefy or vaporize metal parts in the vicinity of the event such as copper, aluminum conductors or steel equipment parts. This material rapidly expands in volume as it changes state from a solid to vapor, resulting in explosive pressure and acoustic energy. The pressure wave can knock workers off balance or off ladders and even throw them across the room against walls or other equipment. The sound blast can cause eardrums to rupture resulting in temporary or permanent hearing loss. Molten metal can be sprayed by the blast throughout the vicinity. Solid metal debris and other loose objects, such as tools, can be turned into deadly projectiles by the explosion. The bright flash from the event can also result in temporary or permanent blindness. All of these can result in equipment damage, personal injury, and possibly death [4].

An AFB surrounds the shock boundaries and is, therefore, the outermost safety boundary from the potential shock/arc source. Like shock boundaries, AFBs are determined by the power source type (DC or AC) and the nominal voltage rating. Additional protection is required when working within AFB. Tables 2 and 3 from the ORNL Standards-Based Management System (SBMS) are helpful for quickly identifying shock and arc boundaries. Shock and arc approach boundaries are also available in NFPA 70E, but these tables are standard. Every electrical system has shock boundaries but may or may not have an arc flash potential because of the nature of the system or voltage rating. Arc flash potentials are more common in high-voltage and poly-phase systems.

Table 2. ORNL SBMS shock approach boundaries for alternating current (AC) systems.

	Limited Approach Boundary		Restricted Approach Boundary	Prohibited Approach Boundary
Nominal System Voltage Range, Phase to Phase[a]	Exposed Movable Conductor[b]	Exposed Fixed Circuit Part	Includes Inadvertent Movement Adder	
<50V	Not specified	Not specified	Not specified	Not specified
50 V – 300 V	3.0 m (10 ft. 0 in.)	1.0 m (3 ft. 6 in.)	Avoid contact	Avoid contact
301 V – 750 V	3.0 m (10 ft. 0 in.)	1.0 m (3 ft. 6 in.)	0.3m (1 ft. 0 in.)	25 mm (0 ft. 1 in.)
751 V – 15 kV	3.0 m (10 ft. 0 in.)	1.5 m (5 ft. 0 in.)	0.7 m (2 ft. 2 in.)	0.2 m (0 ft. 7 in.)
15.1 kV – 36 kV	3.0 m (10 ft. 0 in.)	1.8 m (6 ft. 0 in.)	0.8 m (2 ft. 7 in.)	0.3 m (0 ft. 10 in.)
36.1 kV – 46 kV	3.0 m (10 ft. 0 in.)	2.5 m (8 ft. 0 in.)	0.8 m (2 ft. 9 in.)	0.4 m (1 ft. 5 in.)
46.1 kV – 72.5 kV	3.0 m (10 ft. 0 in.)	2.5 m (8 ft. 0 in.)	1.0 m (3 ft. 3 in.)	0.7 m (2 ft. 2in.)
72.6 kV – 121 kV	3.3 m (10 ft. 8 in.)	2.5 m (8 ft. 0 in.)	1.0 m (3 ft. 4 in.)	0.8 m (2 ft. 9 in.)
138 kV – 145 kV	3.4 m (11 ft. 0 in.)	3.0 m (10 ft. 0 in.)	1.2 m (3 ft. 10 in.)	1.0 m (3 ft. 4 in.)
161 kV – 169 kV	3.6 m (11 ft. 8 in.)	3.6 m (11 ft. 8 in.)	1.3 m (4 ft. 3 in.)	1.1 m (3 ft. 9 in.)
230 kV – 242 kV	4.0 m (13 ft. 0 in.)	4.0 m (13 ft. 0 in.)	1.7 m (5 ft. 8 in.)	1.6 m (5 ft. 2 in.)
345 kV – 362 kV	4.7 m (15 ft. 4 in.)	4.7 m (15 ft. 4 in.)	2.8 m (9 ft. 2 in.)	2.6 m (8 ft. 8 in.)
500 kV – 550 kV	5.8 m (19 ft. 0 in.)	5.8 m (19 ft. 0 in.)	3.6 m (11 ft. 10 in.)	3.5 m (11 ft. 4 in.)
765 kV – 800 kV	7.2 m (23 ft. 9 in.)	7.2 m (23 ft. 9 in.)	4.9 m (15 ft. 11 in.)	4.7 m (15 ft. 5 in.)

[a] For single-phase systems, select the range that is equal to the system's maximum phase-to-ground voltage multiplied by 1.732.

[b] This term describes a condition in which the distance between the conductor and a person is not under the control of the person. The term is normally applied to overhead line conductors supported by poles.

Table 3. ORNL SBMS shock approach boundaries for direct current (DC) systems.

	Limited Approach Boundary[a]		Restricted Approach Boundary[a]	Prohibited Approach Boundary
Nominal Potential Difference	Exposed Movable Conductor[b]	Exposed Fixed Circuit Part	Includes Inadvertent Movement Adder	
<100V	Not specified	Not specified	Not specified	Not specified
100 V – 300 V	3.0 m (10 ft. 0 in.)	1.0 m (3 ft. 6 in.)	Avoid contact	Avoid contact
301 V – 1 kV	3.0 m (10 ft. 0 in.)	1.0 m (3 ft. 6 in.)	0.3m (1 ft. 0 in.)	25 mm (0 ft. 1 in.)
1.1kV – 5 kV	3.0 m (10 ft. 0 in.)	1.5 m (5 ft. 0 in.)	0.5 m (1 ft. 5 in.)	0.1 m (0 ft. 4 in.)
5 kV – 15 kV	3.0 m (10 ft. 0 in.)	1.5 m (5 ft. 0 in.)	0.7 m (2 ft. 2 in.)	0.2 m (0 ft. 7 in.)
15.1 kV – 45 kV	3.0 m (10 ft. 0 in.)	2.5 m (8 ft. 0 in.)	0.8 m (2 ft. 9 in.)	0.4 m (1 ft. 5 in.)
45.1 kV – 75 kV	3.0 m (10 ft. 0 in.)	2.5 m (8 ft. 0 in.)	1.0 m (3 ft. 2 in.)	0.7 m (2 ft. 1 in.)
75.1 kV – 150 kV	3.3 m (10 ft. 8 in.)	3.0 m (10 ft. 0 in.)	1.2 m (4 ft. 0 in.)	1.0 m (3 ft. 2 in.)
150.1 kV – 250 kV	3.6 m (11 ft. 8 in.)	3.6 m (11 ft. 8 in.)	1.6 m (5 ft. 3 in.)	1.5 m (5 ft. 0 in.)
250.1 kV – 500 kV	6.0 m (20 ft. 0 in.)	6.0 m (20 ft. 0 in.)	3.5 m (11 ft. 6 in.)	3.3 m (10 ft. 10 in.)
500.1 kV – 800 kV	8.0 m (26 ft. 0 in.)	8.0 m (26 ft. 0 in.)	5.0 m (16 ft. 5 in.)	5.0 m (16 ft. 5 in.)

[a] All dimensions are distance from exposed energized electrical conductors or circuit parts to worker.

[b] This term describes a condition in which the distance between the conductor and a person is not under the control of the person. The term is normally applied to overhead line conductors supported by poles.

2.4 HAZARD RISK CATEGORY

Hazard Risk Category (HRC) defines the level of appropriate PPE and protective clothing that must be worn while working on or near an electrical source. Tables 4 and 5 from the SBMS contain a column designated for HRC that is determined by the system potential for shock and arc and is also dependent on the task being performed. Arc-rated protective clothing and PPE requirements per HRC are shown in Table 6. NFPA Table 130.7(C)(15)(a)(AC) and 130.7(C)(15)(b)(DC) include tasks performed on energized equipment, hazard/risk category, and whether rubber insulating gloves and insulated hand tools are required. NFPA Table 130.7(C)(16) lists the hazard/risk categories 0–4 and PPE requirements for each category.

Table 4. One specific task-based arc flash hazard analysis for alternating current (AC) systems (see NFPA for other tasks; there are many).

Tasks Performed on Energized Equipment	Hazard/Risk Category	Rubber Insulating Gloves	Insulated and Insulating Hand Tools
Panelboards or other equipment rated 240 V and below* Parameters: • Maximum of 25 kA short circuit current available; maximum of 0.03 sec (2 cycle) fault clearing time; minimum 18 in. working distance • Potential **arc flash boundary** with exposed energized conductors or circuit parts using above parameters: **19 in**.			
Perform infrared thermography and other non-contact inspections outside the restricted approach boundary	0	N	N
Circuit breaker (CB) or fused switch operation with covers on	0	N	N
CB or fused switch operation with covers off	0	N	N
Work on energized conductors and circuit parts, including voltage testings	1	Y	Y
Remove/install CBs or fused switches	1	Y	Y
Removal of bolted covers (to expose bare, energized electrical conductors and circuit parts)	1	N	N
Opening hinged covers (to expose bare, energized electrical conductors and circuit parts)	0	N	N
Work on energized electrical conductors and circuit parts of utilization equipment fed directly by a branch circuit of the panelboard	1	Y	Y

Table 5. ORNL SBMS task-based arc flash hazard analysis for direct current (DC) systems.

Tasks Performed on Energized Equipment	Hazard/Risk Category[a]	Rubber Insulating Gloves[b]	Insulated and Insulating Hand Tools
Storage batteries, direct-current switchboards and other direct-current supply sources ≥100 V ≤250 V Parameters: Voltage: 250 V Maximum arc duration and working distance: 2 sec @ 18 in.			
Work on energized electrical conductors and circuit parts, including voltage testing where arcing current is ≥1 kA and <4 kA Potential **arc flash boundary** using above parameters is 4 kA: **36 in.**	1	Y	Y
Work on energized electrical conductors and circuit parts, including voltage testing where arcing current is ≥4 kA and <7 kA Potential **arc flash boundary** using above parameters is 7 kA: **48 in.**	2	Y	Y
Work on energized electrical conductors and circuit parts, including voltage testing where arcing current is ≥7 kA and <15 kA Potential **arc flash boundary** using above parameters is 15 kA: **72 in.**	3	Y	Y
Storage batteries, direct-current switchboards and other direct-current supply sources ≥250 V ≤600 V Parameters: Voltage: 600 V Maximum arc duration and working distance: 2 sec @ 18 in.			
Work on energized electrical conductors and circuit parts, including voltage testing where arcing current is ≥1 kA and <1.5 kA Potential **arc flash boundary** using above parameters is 1.5 kA: **36 in.**	1	Y	Y
Work on energized electrical conductors and circuit parts, including voltage testing where arcing current is ≥1.5 kA and <3 kA Potential **arc flash boundary** using above parameters is 3 kA: **48 in.**	2	Y	Y
Work on energized electrical conductors and circuit parts, including voltage testing where arcing current is ≥3 kA and <7 kA Potential **arc flash boundary** using above parameters is 7 kA: **72 in.**	3	Y	Y
Work on energized electrical conductors and circuit parts, including voltage testing where arcing current is ≥7 kA and <10 kA Potential **arc flash boundary** using above parameters is 10 kA: **96 in.**	4	Y	Y

Y: Yes (required).

[a] If acid exposure is possible, the clothing is required to be protected from acid and arc rated to the hazard according to ASTM F 1891 or equivalent and evaluated by ASTM F 1296 for acid protection.

[b] In clean rooms or other electrical installations, that do not permit leather protectors for arc flash exposure, ASTM F 496 is required to be followed for use of rubber insulating gloves without leather protectors.

Table 6. ORNL SBMS arc-rated protective clothing and PPE requirements per HRC.

Hazard/Risk Category	ORNL PPE Category	Protective Clothing and PPE
0	A	**Arc-Rated Clothing, Minimum Arc Rating <1.2 cal/cm^2 [3]** **Protective Clothing, Nonmelting or Untreated Natural Fiber (i.e., untreated cotton, wool, rayon, or silk, or blends of these materials) with a Fabric Weight of at Least 4.5 oz/yd[2]** Shirt (long sleeve) Pants (long) **Protective Equipment** Safety glasses or safety goggles (SR) Hearing protection (ear canal inserts) Heavy duty leather gloves (AN)[1]
1 2	B	**Arc-Rated Clothing, Arc Rating of 1.2 cal/cm^2 to 8 cal/cm^2 [3]** Arc-rated long-sleeve shirt and pants or arc-rated coverall Arc-rated flash suit hood or arc-rated face shield[2] and arc-rated balaclava Arc-rated jacket, parka, rainwear, or hard hat liner (AN) **Protective Equipment** Hard hat Safety glasses or safety goggles (SR) Hearing protection (ear canal inserts) Heavy duty leather gloves[1] Leather work shoes
3 4	C	**Arc-Rated Clothing, Arc Rating of >8 cal/cm^2 to 40 cal/cm^2 [3]** Arc-rated long-sleeve shirt (AR) Arc-rated pants (AR) Arc-rated coverall (AR) Arc-rated flash suit jacket (AR) Arc-rated flash suit pants (AR) Arc-rated arc flash suit hood Arc-rated gloves[1] Arc-rated jacket, parka, rainwear, or hard hat liner (AN) **Protective Equipment** Hard hat Safety glasses or safety goggles (SR) Hearing protection (ear canal inserts) Leather work shoes
Dangerous	Dangerous	**Arc Rating of >40 cal/cm^2 [3]** Contact DESO or E-AHJ

AN: as needed (optional). AR: as required. SR: selection required.

[1]If rubber insulating gloves with leather protectors are required then additional leather or AR gloves are not required. The combination of rubber insulating gloves with leather protectors satisfies arc flash protection requirement.

[2]Face shields are to have wrap-around guarding to protect not only the face but also the forehead, ears, and neck, or, alternatively, an AR arc flash suit hood is required to be worn. Arc rating is defined as the arc thermal performance value (ATPV) or energy of break open threshold (E_{BT}).

[3]Arc rating is either ATPV or E_{BT}, whichever is the lower value.

Note: ORNL merges hazard/risk categories 1&2 and 3&4 to maximize protection and reduce injury risk. Non-ORNL workers may follow NFPA Table 130.7(C)(16), Protective Clothing and Personal Protective Equipment (PPE).

2.5 PERSONAL PROTECTIVE EQUIPMENT

"Personal protective equipment (PPE) refers to items typically worn by a worker to provide protection from recognized hazards. Depending on the job task to be performed, PPE for the electric power industry generally includes safety glasses, face shields, hard hats, safety shoes, insulating (rubber) gloves with leather protectors, insulating sleeves, and flame-resistant (FR) clothing. Additional PPE, such as fall protection equipment, respirators, chemical-resistant or cut-resistant gloves, and chaps, may be required, depending on the results of the hazard assessment required under 1910.132 or on additional '269' requirements (for example, when working with brush chippers, chain saws, or stump cutters)" [5]. Electrical PPE is specifically for protecting the person from electrical hazards. Listed below are categories of PPE and recommendations from ORNL Qualified Electrical Worker Safety Training.

- Foot Protection
  - Recommended foot protection includes heavy-duty leather work shoes that provide some arc flash protection.

- Hand Protection
  - Recommended hand protection consists of leather or flame-resistant gloves when arc flash protection is needed. Insulating rubber gloves are used for shock protection. Always wear rated gloves and make sure they are safe to use. At ORNL, gloves must be inspected prior to each use and properly stored. ORNL replaces gloves every 6 months and a rubber glove used without the leather protector may only be used one time, according to the ORNL guidelines (Figure 2).

Figure 2. Electrically insulated gloves (Class 0 Red 1,000 VAC/ 1,500 VDC) and leather outer. The minimum distance between protectors and rubber gloves for Class 0 = ½ in. (shown in right image).

- Arm Protection
  - Insulating rubber sleeves protect the shoulder, upper arm, and elbow from shock hazards.

- Body Protection (Figure 3)
  - Arc-rated coveralls are recommended; they provide a minimum protective factor of 1.2 calories/cm^2.
  - Natural fibers must be worn beyond HRC 0. Common natural fibers include cotton, wool, and silk.

Figure 3. HRC 2 Coveralls made of 100% flame-resistant Nomex IIIA 6-oz. fabric. Features 5.7 ATPV arc rating and meets NFPA 70E CAT 1.

- Head and Hearing
  - Head protection is provided by Class E (protects up to 20 kV) and G (protects up to 2.2kV) hard hats. Wear ear canal inserts whenever working within the AFB. Shields and balaclavas also provide protection from hazards (Figure 4).

Figure 4. HRC (0-2/3) Salisbury Arc Flash 20 Cal Lift Front Hood with PrismShield. Hard hat, balaclava, chin guard, and face shield in one; just add hearing protection.

3. WORK INVOLVING ELECTRICAL HAZARDS

Having covered the types of electrical hazards, controls, and PPE, a step-by-step approach to performing work involving electrical hazards will now be discussed. Article 130 of the NFPA covers work involving electrical hazards and may be used to establish safe electrical work conditions.

Note: Circuit parts and energized electrical conductors shall be put into an electrically safe work condition when a person is working within the limited approach boundary or interacting with equipment that does not have exposed conductors but where an arc flash hazard exists.

Step 1. Complete Energized Electrical Work Permit

Energized work is permitted; however, additional hazards or risks are introduced. Energized work above 50 V at ORNL requires an Energized Electrical Work Permit (EEWP). Elements of the EEWP include the following.

1) Description of the circuit and equipment to be worked on and their location.

2) Justification for why the work must be performed in an energized condition.

3) Description of safe work practices to be employed.

4) Results of the shock hazard analysis.
   a. Limited approach boundary
   b. Restricted approach boundary
   c. Prohibited approach boundary
   d. Necessary shock personal and other protective equipment to safely perform the assigned task

5) Result of the arc flash hazard analysis.
   a. Available incident energy or hazard/risk category
   b. Necessary PPE to safely perform the assigned task
   c. AFB

6) Means employed to restrict the access of unqualified persons from the work area.

7) Evidence of completion of a job briefing, including a discussion of any job-specific hazards.

8) Energized work approval (authorizing or responsible management, safety officer, or owner, etc.) signature(s).

Note: An example of an ORNL EEWP is provided in Appendix A.

Step 2. Perform Shock Hazard Analysis

A shock hazard analysis shall determine the voltage to which personnel will be exposed, the boundary requirements, and the PPE necessary to minimize the possibility of electric shock to personnel [2].

1) Determine nominal system voltage range phase to phase for AC systems or determine nominal potential difference for DC systems.

2) Look up Table 130.4(C)(a-b) of the NFPA and record limited approach boundary, restricted approach boundary, and prohibited approach boundary.

3) Determine the task(s) being performed on the electrical system.

4) Look up task(s) in Table 130.7(C)(a-b) to determine the HRC and if rubber insulating gloves and/or insulated and insulating hand tools are required.

5) Locate the determined HRC in Table 130.7(C)(16) for additional PPE requirements.

6) Tape, mark, or guard these approach boundaries for the safety of yourself and others.

7) Record boundaries in EEWP.

Step 3. Perform Arc Flash Hazard Analysis

The AFB for systems 50 V and greater shall be the distance at which the incident energy equals 5 J/cm^2 (1.2 calories/cm^2).

1) Determine the AFB by looking in task-based arc flash hazard analysis tables.

2) Obtain arc-rated clothing per HRC. Arc-rated clothing is rated in calories/cm^2. Be sure the material is arc rated and not just fire retardant.

3) Establish AFB with arc-flash-marked tape or a red marker indicating an AFB is present (Figure 5).

4) Record arc flash hazard analysis in EEWP.

Figure 5. Common electrical hazard signs and red arc-flash-boundary floor tape.

4. LITHIUM ION BATTERY HAZARDS AND CONTROLS

Lithium ion batteries are abundant in consumer products and are the most commonly used battery chemistry for electric automobile applications. A negative electrode (anode) and a positive electrode (cathode) provide access to the stored energy inside a LIB. A porous insulating separator made of polyethylene or polypropylene allows lithium ions to transfer between the anode and cathode. The Li ions move in and out of the solid electrolyte interface (SEI) by intercalation. The SEI consists of an electrolyte (ionic liquid or gel) containing the mobile Li-ions. LIBs come in many shapes, capacities, chemistries, and other characteristics demanded by electronics manufacturers. Some common types of LIB cells include cylindrical, prismatic, and pouch shown in Figure 6.

Figure 6. Common lithium ion battery forms (left to right: prismatic, pouch, cylindrical).

A major concern with LIBs is the challenge of preventing and/or controlling thermal runaway. LIBs are known to spontaneously self-heat and even ignite under certain conditions. Unique and unconventional control methods are required to suppress LIB fires due to the reactive nature of their constituents. "Since lithium ions are intercalated into host materials during charge or discharge, there is minimal free lithium metal within a lithium-ion cell, and thus, even if a cell does ignite due to external flame or thermo-mechanical impingement, or an internal fault, metal fire suppression techniques are not appropriate for controlling the fire" [6]. Determining the chemistry of a failing or burning battery on the spot is challenging, which makes extinguishing advanced battery fires problematic. However, preventing the thermal event from happening in the first place can be done with proper handling, use, and storage.

Note: ORNL safety officers and researchers have determined that the appropriate protocol is to isolate the failing battery from neighboring batteries in a ventilation exhaust hood, place it on a nonflammable surface, and allow energy dissipation if a thermal event were to occur. Personnel should close the hood completely, if reasonable, and stand clear. Some LIBs contain $LiPF_6$ electrolyte and can, under certain conditions, react with hydrogen from humidity and produce hydrogen fluoride gas. After the area is clear and safe to enter, battery materials such as cathode and anode foils and the pouch may be collected and recycled.

4.1 LIB FAILURE MODES

LIB operation and lifetime are dependent on the manufacturer's recommended storage temperature and voltage range. Most batteries contain safety mechanisms such as voltage and current control circuits to protect the battery from overcharging or over-discharging. However, failure to use an appropriate charger or a control circuit malfunction could result in overcharging or over-discharging, and dangerous charge/discharge rates. These are two of several causes for LIBs to degrade or self-heat. Regardless of how well LIBs are handled, stored, used, and so forth, they can and will fail in the two different modes described below.

4.1.1 Non-Energetic Failure Mode

Non-energetic failure is the most common mode for a battery to fail. LIBs lose capacity over time due to aging mechanisms such as increased internal resistance, separator breakdown, Li-ion trapping and electrolyte leakage. Eventually, these mechanisms will decrease the energy capacity of the cell so much that a charge can no longer be stored. These mechanisms occur slowly and, in most cases, do not produce enough heat to cause thermal runaway. The alternative failure mode is energetic release of energy commonly referred to as thermal runaway.

4.1.2 Energetic Failure Mode

Energetic failure, or thermal runaway, refers to rapid self-heating of a cell derived from the exothermic chemical reaction of the highly oxidizing positive electrode and the highly reducing negative electrode [3]. LIBs may experience energetic failure under many circumstances related to electrical abuse (overcharging or over-discharging), thermal abuse (exposure to heat), external short circuit (rapid release of electricity), and mechanical abuse such as punctures, drops, and shredding that cause the internal layers to come into contact and electrically short.

4.2 LIB HAZARD CONTROLS

Non-energetic failure modes are not easily controlled and occur by design, not by error. However, energetic failures can be prevented with proper handling, storage, and usage. LIBs should be stored at room temperature in a noncombustible container where the terminals will not contact conductive surfaces or other batteries and appropriate chargers should be used. Additionally, LIBs should be stored in reasonable quantities so that a thermal runaway could be easily contained and extinguished if an event occurs. Lithium ion batteries are susceptible to heat and therefore should not be placed near heaters, exhausts, or in direct sunlight for extended periods of time. Increasing internal cell temperature causes an increase in pressure (ideal gas law, $PV=nRT$) and may lead to gas venting and possible ignition. Using insulated tools prevents electrical shorts between terminals that may release enough energy to cause the battery to enter thermal runaway.

Uncontrolled failures may result from manufacturing defects that are unnoticeable until an event occurs. The innards of LIBs are several yards of rolled or folded active materials with very tight tolerances. Any deviation from manufacturer specifications could cause the cell to fail prematurely in either a non-energetic or energetic failure mode. Nonetheless, LIBs should be handled and stored in such a way that an unexpected failure can be suppressed and isolated before other batteries are affected.

5. AUTOMOTIVE LITHIUM ION BATTERIES

Most electric and hybrid electric vehicles are electrified by a several-hundred-pound, several-thousand-watt LIB pack that contains hundreds and even thousands of cells. Lithium ion–powered electric vehicles are manufactured in many makes/models and have been on the road since 2008, the first being the Tesla Roadster. In the United States only, over 350,000 plug-in-electric vehicles were sold in 2018 [7]. This was an increase of over 81% more than in 2017. These numbers are expected to grow across the United States and the world as battery technology becomes more affordable and practical for long-range travel.

A result of this large increase in EV production also means an increase in spent automotive batteries entering the recycling and scrapyard industries, so much so that LIB packs are being stockpiled due to limited options for second-life use and recycling. Only a few operations in the world are processing end-of-life LIBs, but these companies are limiting their value recovery by shredding, crushing, and burning the LIB feedstock.

ORNL is developing a technology that has capabilities beyond current industrial systems by taking advantage of automated robotic disassembly systems to rapidly separate and extract valuable materials from end-of-life LIBs for direct reuse and new battery manufacturing. This technology is currently at the research level and is being done manually until disassembly routines are identified. ORNL has prepared this report in conjunction with the Critical Materials Institute, who is at the forefront of replacing state-of-the-art recycling methods that are unfit for a sustainable future. Following the electrical safety guidelines stated previously, researchers at ORNL have developed a process for safely disassembling advanced automotive LIB stacks down to the sub-cell level (anode, cathode, separator).

5.1 2013 FIRST-GENERATION CHEVROLET VOLT LIB PACK DISASSEMBLY

General Motors produced two generations of the hybrid Chevrolet Volt from 2011–2019. Chevrolet's Bolt has succeeded the Volt and is a full electric vehicle that is expected to be produced over the next several years. Over 150,000 Volts have been sold in the United States since 2010 [8]. Therefore, approximately 43,200,000 LIB cells have been produced to meet this demand because each battery contains 288 cells. Additionally, each EV may use more than one battery over its lifetime, which implies there may be two to three times as many batteries manufactured. ORNL is working with a leading automotive core reclamation and reuse corporation in the United States to determine the availability of Volt and other automotive batteries to identify the value recovery opportunity and critical material supply chain impact.

The Generation-one (Gen-1) Chevrolet Volt was inspected and disassembled in 18 minutes and 16 seconds. A Midtronics EL-50332 battery discharging system (Figure 7) was used to collect information, such as the vin number, state of charge (SOC), and state of health and can also perform pack, section, and module discharging; section balancing; and pack and section de-powering. In the Gen-1 battery pack there are three sections consisting of nine modules (five in Section 1 and two in Sections 2 and 3). Each module contains a different number of cells that make up the voltage rating and energy capacity.

The EL-50332 is an advantageous tool for servicing a battery that is out of the car, allowing the battery interface cables to be placed directly on the pack, section, and module. Pack identification is a key element of the ORNL disassembly process. ID determines the disassembly routine, which differs for each make/model of battery. Communication and power cables were plugged into the battery interface in a few seconds. After powering up the EL-50332, one can work on the pack (or its three sections) in or out of the car and choose to charge, discharge, or balance. The Chevrolet Volt received for disassembly was at 30% SOC and in good condition. High-voltage and communication cables were disconnected, and the system was powered off. At this point the team determined the battery pack could be disassembled safely.

Figure 7. Midtronics EL-50332 EV/HEV battery service tool.

5.1.1 355.2V Chevrolet Volt LIB Pack Disassembly

Two ORNL qualified electrical workers wearing appropriate PPE removed the manual safety disconnect plug by hand. Next, exterior cover fasteners were removed using insulated tools, as shown in Figure 8, to lift off the protective plastic cover. A second inspection was performed upon removal of the cover to check for damage inside the pack that could not be seen with the cover on. The DC voltage was checked to validate that the Midtronics service tool measurements were correct. The battery pack was also checked for any signs of swelling, discoloration, and dents and scratches. Work would have stopped immediately if any serious mechanical damage had been present or if the battery showed signs of heating. After careful inspection, the QEWs began to eliminate high voltage in stages to keep reducing the voltage in halves by disconnecting bus bars and removing high-voltage cables until the sections were below 100V, a non-hazardous DC voltage. A wiring harness that connected the battery modules to voltage temperature measurement sensors (VTMS) was also removed. Coolant hoses were cut to free the three sections from each other, and the sections were extracted from the pack. This disassembly process is depicted in more detail as a series of 17 steps in Figure 9.

Note: Battery terminals should be covered with UL-rated electrical tape to prevent contact with people and other conductors.

Figure 8. As-received Chevrolet Volt LIB pack before disassembly. The insulated tool set used for dismantlement also shown.

1) Inspect pack for damage

2) Collect Barcode ID

3) Unpackage/ Remove Coolant (In, Out)

4) Remove Service Disconnect Plug

Service Disconnect Plug

5) Measure External Voltage with rated multi-meter

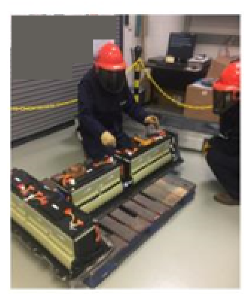
6) Remove (4) T30 fasteners surrounding service disconnect plug

7) Remove (47) 10mm cover screws

8) Remove (4) 13mm chassis fasteners

9) Remove Rear Chassis

10) Remove Cover



11) Measure Internal Voltages

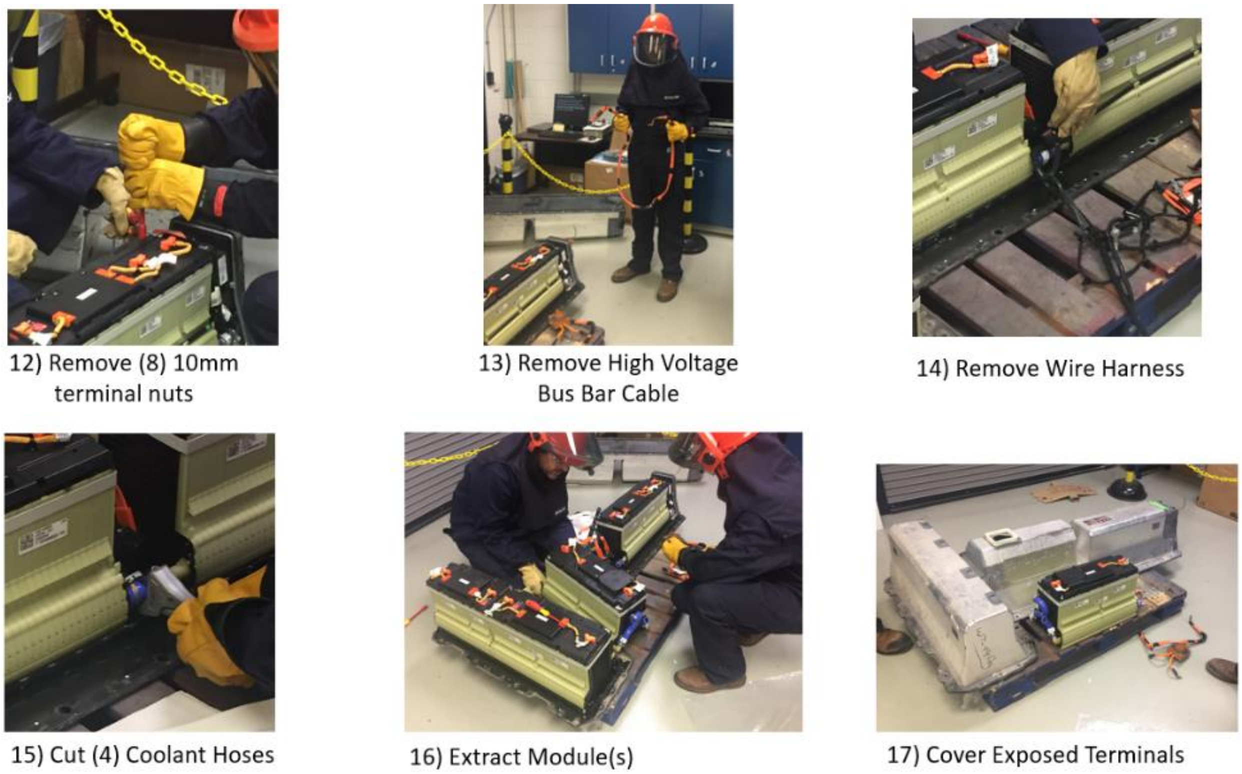


Figure 9. Chevrolet Volt pack disassembly.

5.1.2 92V Chevrolet Volt LIB Module Disassembly

The three sections of the Chevy Volt pack were separated into modules that collectively contain 288 cells (9 6series 3 parallel). A diagram of the Volt pack internals is provided in Figure 10. The modules were further separated by disconnecting the module bus bars shown in yellow (Figure 10), making disassembling the module not only simpler but also safer by dividing the voltage. Module 5 was disassembled to the cell level, as shown in Figure 11. The total disassembly process involved 28 steps, 11 module disassembly steps and 17 pack disassembly steps) and took less than 20 minutes using hand tools.

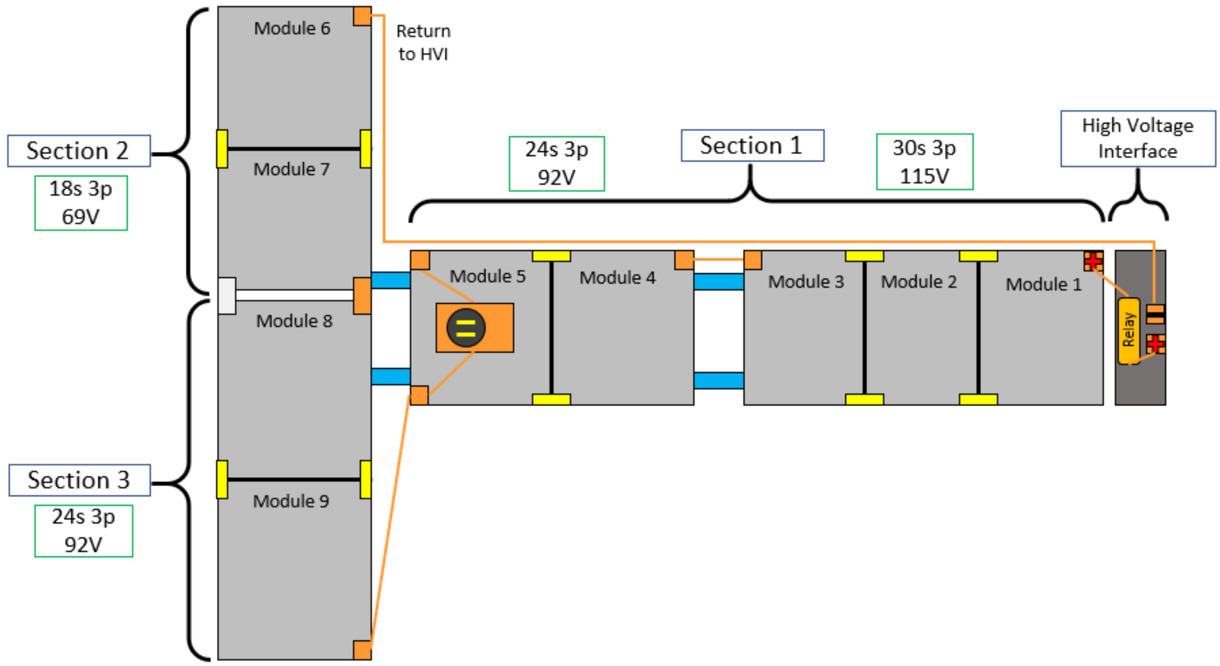


Figure 10. Chevrolet Volt LIB pack internal diagram. Orange lines indicate energized bus bars, yellow bars indicate module bus bars, and blue lines indicate coolant lines.

Figure 11. Disassembly of Module 5 to a cell.

5.1.3 3.7V LG Chem NMC Pouch Cell Disassembly

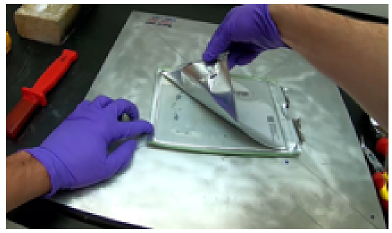
The Chevrolet Volt LIB pack contains 288 individual LG Chem nickel, manganese, and cobalt (NMC) pouch cells. Each cell weighs approximately 370 g and contains 16 anodes, 15 cathodes, and polyethylene separator sheets within a polymer laminate pouch. A cell was disassembled at 100% SOC and at 0% SOC inside a fire-resistant ventilated fume hood. Double layer Heavy-duty latex gloves were worn to protect from cuts and chemical contact. Shielded safety glasses and a lab coat were also worn to protect from debris that could blow out from the ventilated hood.

There is minimal shock hazard when using an insulated blade to cut around the edge of the pouch, as shown in step 1 of Figure 12. Contacting both tabs may result in an arc if the cell is sufficiently charged, but the voltage is well below a hazardous level (100V DC). Discharged cells lack the energy to create an arc and are disassembled using a process that includes an additional discharge step prior to disassembly. Anodes of fully charged cells may produce heat when removed from the cell and should be placed on a nonflammable surface until cool. Anode and cathode foils should also be separated after removal to prevent electrochemical reactions from occurring.

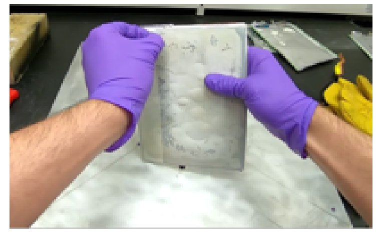
Steps 1–9 show the process of disassembling a fully charged LG Chem cell by hand to recover separated components. The cell was initially disassembled in 7.5 minutes. This study demonstrated that fully charged and discharged cells may be disassembled using the same process and tools with the same recovery rate and value.

Chevrolet Volt (LG Chem) NMC Cell Breakdown

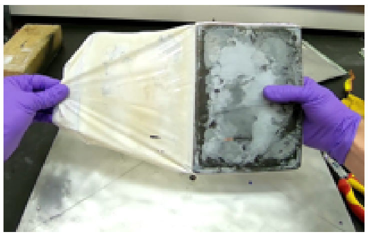
1) Cut around edge of pouch with insulated blade



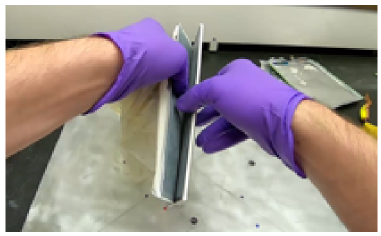
2) Peel back the flexible (foil-like) polymer laminate pouch



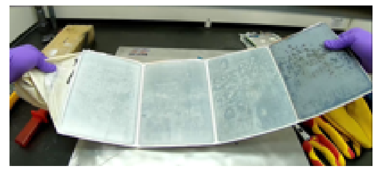
3) Peel separator material at seam to begin unfolding



4) Peel separator material and expose first layer of cell

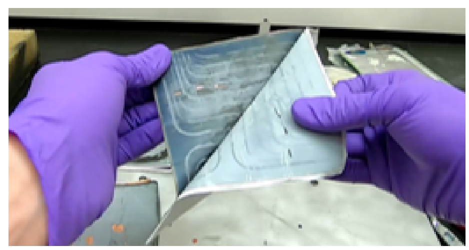


5) Further unfold cell

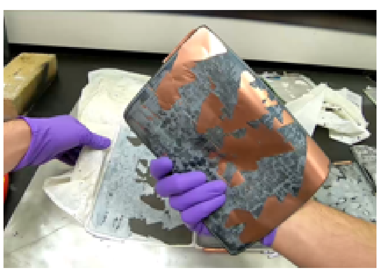


6) Completely unfold cell to look like this

7) Remove individual stacks of anode, separator, cathode, separator, anode

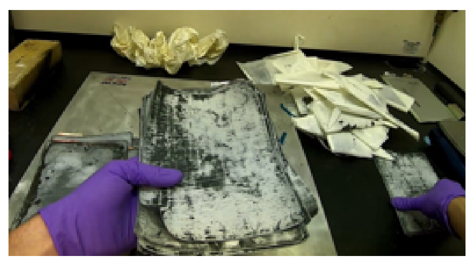


8) Peel separator away from anodes and cathodes



9) Remove individual terminal sheets and separate anodes and cathodes from one another.

Caution: Do NOT stack anodes together. The active material rapidly oxidizes and releases heat. Fire potential increases when several anodes are stacked together



Results

- Collected materials
  - 16 anodes, 127.8 g
  - 15 cathodes, 169.1 g
  - Polyethylene separator, 34.0 g
  - Polymer laminate pouch, 19.8 g
- Time
  - <10 minutes
- Tools
  - Insulated blade

Figure 12. Manual disassembly of a Chevrolet Volt pouch cell.

6. SUMMARY

ORNL has disassembled a fully charged Chevrolet Volt lithium ion battery (LIB) pack and demonstrated separation methods for packs, modules, and cells. The purpose of this disassembly study was to identify hazards, develop controls for such hazards, and demonstrate safe practices when dismantling LIBs. The information presented here was gathered by ORNL researchers, technicians, and safety officers and is intended to be used as a guide for working on or near automotive LIBs and should supplement the work being conducted within ORNL and the Critical Materials Institute. Additional resources include the most recent versions of NFPA 70E and the National Electrical Code (NEC). Electrical safety information and appendices apply to all automotive LIBs, not just the Gen 1 Chevrolet Volt covered in this report. ORNL will continue to disassemble automotive LIB packs to determine the scale of diversity among the top battery manufacturers who will play important roles in supplying the world with electrified vehicles in the years to come.

This is a living document. As more detailed processes and methods are developed, and automation technology is implemented, this "best practices" document will evolve. As different models and brands of Li-ion batteries are investigated, more detailed and precise recommendations will be included in this ORNL document.

7. ACKNOWLEDGMENTS

This research was supported by the Critical Materials Institute, an Energy Innovation Hub funded by the US Department of Energy, Office of Energy Efficiency and Renewable Energy, Advanced Manufacturing Office.

In addition, the authors appreciate the support and guidance provided by their Designated Electrical Safety Officer before and during battery dismantlement.

8. REFERENCES

[1] D. Linden, *Handbook of Batteries*, McGraw-Hill, 1995.

[2] National Fire Protection Association, *Standard for Electrical Safety in Workplace*, NFPA, 2012.

[3] P. Sutherland, "Principles of Electrical Safety," *Wiley Online Library*, 2015, onlinelibrary.wiley.com/doi/pdf/10.1002/9781118886397.

[4] GE, *The Basics of Arc Flash*. www.geindustrial.com/sites/geis/files/gallery/The-Basics-of-Arc-Flash-Article_GE_Industrial_Solutions_0.pdf.

[5] OSHA, "Personal Protective Equipment (PPE)." *Electric Power ETool: Personal Protective Equipment (PPE)*, www.osha.gov/SLTC/etools/electric_power/personal_protective_equipment.html.

[6] P. E. Mikolajczak, Celina et al., *Lithium-Ion Batteries Hazard and Use Assessment Final Report*, Nfpa.org, 2011.

[7] "USA Plug-in Sales for 2019 YTD October." *EV*, www.ev-volumes.com/country/usa/.

[8] "Chevrolet Volt Sales Numbers," *GM Authority*, https://gmauthority.com/blog/gm/chevrolet/volt/chevrolet-volt-sales-numbers/.

APPENDIX A. ORNL ENERGIZED ELECTRICAL WORK PERMIT (EEWP)

ENERGIZED ELECTRICAL WORK PERMIT (EEWP)

Complete this form in accordance with SBMS Procedure: Perform Electrical Work Requiring Energized Electrical Work Permit (EEWP).

Maintenance Work Package, MJR, Service Request, RSS or Work Order #: ______________________
Work Location (Bldg./Room or Area): ______________________
Equipment ID or System, as applicable: ______________________
Voltage / Circuit / Equipment or System information: ______________________
Circuit Isolation Point for Emergencies: ______________________

Description of Energized Components/Equipment and electrical work to be done: ______________________

Justification for Energized Work (Reasons why Components/Equipment cannot feasibly be deenergized or why overall risk will be significantly increased: ______________________

Minimum level of qualified electrical worker (select one):

- ☐ QEW Level 2 (≥50-240 VAC single phase only)
- ☐ QEW Level 3 (>240-600 VAC single phase and ALL three phase)
- ☐ QEW Level 4 (>600-13,800 VAC)
- ☐ QEW Level 5 (Lineman Electrician)

This form is ☐ **Job Specific** OR ☐ **Generic** which expires on ____________ (Maximum 1 year from approval date)

Shock Hazard Analysis & Approach Boundaries (Table 1[1] or 2[1])	**Arc Flash Analysis and Approach Boundary**
Limited Approach Boundary LAB (Non-QEW) (select one): _____ 42" (50-300 VAC) _____ 42" (301-750 VAC and 277 VAC single phase systems) _____ 60" (751-15,000 VAC) _____ Other: ________ inches Restricted Approach Boundary-RAB (QEW) (select one): _____ Avoid Contact (50-300 VAC) _____ 12" (301-750 VAC and 277 VAC single phase systems) _____ 26" (751- 15,000 VAC) _____ Other: ________ inches	Check method used and enter Arc Flash Boundary distance (select one): _____ Calculation (Attached) ____________ inches _____ Label on equipment ____________ inches _____ Table 3[1], Task-Based Activity Analysis (AC) ________ inches _____ Table 4[1], Task-Based Activity Analysis (DC) ________ inches

Hierarchy of Controls Methods (Check all that apply)

Elimation	☑ De-energized ☐ Lock/Tag/Verify
Substitution	☑ Reduce energy by replacing energy circuitry
Engineering Controls	☐ Guarding ☐ GFCI, LTV
Awarness	☐ Single/Posting ☐ Barricade, Nonconducting Barricade QWE Control at LAB, Task Leader/Supervisor present, Additional Lighting, Other ☐ Two Person Rule Safety Watch (>600V), Other
Administration Controls	☐ Written Procedure
PPE	☐ VR Tools ☐ VR Gloves, VR Sleeves, Dielectric Floor Mat, VR Insulating Blanket, Class E (20kV) Hard Hat , Class G (2200V) Hard Hat, ORNL PPE, VR Extended Lead M&TE

Arc-Rated (AR) ORNL PPE (Select the appropriate PPE from Table 5)

☐	A	Arc Rating <1.2 cal/cm^2, Long sleeve shirt and pants, Safety glasses or safety goggles, Hearing protection (ear canal inserts), Leather gloves
☐	B	Arc-Rating 1.2 ca/cm^2 to 8 cal/cm^2, Arc-rated long-sleeve shirt and pants or arc-rated coverall, arc-rated flash suit hood or arc-rated face shield and arc-rated balaclava, arc-rated jacket, parka, rainwear, or hard hat liner (AN), Hard hat, Safety glasses or safety goggles (SR), Hearing protection (ear canal inserts), Leather gloves and shoes
☐	C	Arc-Rating >8 ca/cm^2 to 40 cal/cm^2, Arc-rated long-sleeve shirt and pants or coverall (as required), arc-rated flash suit jacket, suit pants (AR), flash suit hood ; arc-rated gloves or rubber insulating gloves with protectors, arc-rated jacket, parks, rainwear, or hard hat liner (AN); Hard hat, Safety glasses or safety goggles (SR), Hearing protection (ear canal inserts), Leather work shoes
☐	D	H/RC 4: Arc Rating >40 cal/cm2 Contact DESO or E-AHJ

AN: as needed (optional). AR: as required. SR: selection required

[1]Tables 1-5 are located in: Hazard Analysis for Electrical Work exhibit in SBMS.

Task Demands	Individual Capabilities
☐ Time Pressure (in a hurry)	☐ Unfamiliarity with task/First time
☐ High Workload (memory requirements)	☐ Lack of Knowledge (mental model)
☐ Simultaneous, multiple tasks	☐ New technique not used before
☐ Repetitive actions, monotonous	☐ Imprecise communication habits
☐ Irrecoverable acts	☐ Lack of proficiency/inexperience
☐ Interpretation Requirement	☐ Indistinct problem-solving skills
☐ Unclear goals, roles & responsibilities	☐ "Hazardous" attitude for critical task
☐ Lack of or unclear standards	☐ Illness/Fatigue
Work Environment	**Human Nature**
☐ Distractions/Interruptions	☐ Stress (limits attention)
☐ Changes/Departures from routine	☐ Habit patterns
☐ Confusing displays or controls	☐ Assumptions (inaccurate mental picture)
☐ Workarounds/OOS instruments	☐ Complacency/Overconfidence
☐ Hidden system response	☐ Mindset ("tuned" to see)
☐ Unexpected equipment conditions	☐ Inaccurate risk perception (Pollyanna)
☐ Lack of alternative indication	☐ Mental shortcuts (biases)
☐ Personality conflicts	☐ Limited short-term memory

Human Performance Tools

1 Pre-job briefing
Identify hazards, assess risk and select and implement risk controls from a hierarchy of methods
2 Job site review
Increased situational awareness
3 Post-job review
Identify ways to improve and best practices
Peer check
4 Procedure use and adherence
Step-by-step procedure read, outcome understood
Circle the task to be performed, check off each task as it is completed
5 Self-check with verbalization
Stop, Think, Act, Review (STAR)
Verbalize intent before, during, and after each task
6 Three-way communication
Directives are repeated by receiver back to sender; receiver is acknowledged by sender
Use of the phonetic alphabet for clarity
7 Stop when unsure
Stop and obtain further direction when unable to follow a procedure or process step or if something unexpected occurs
Maintain a questioning attitude
8 Flagging and blocking
Identify (flag) equipment and controls that will be operated
Prevent access (block) equipment and controls that should not be operated

Additional Hazards and required PPE:

Hazard Analysis performed by:________________ **Badge No.:**________ **Date:**________
Note: Form preparer should be a qualified electrical worker.

APPENDIX B. ORNL HAZARD ANALYSIS FOR ELECTRICAL WORK

HAZARD ANALYSIS for ELECTRICAL WORK

Complete this form for electrical work activities performed per procedures listed under the Perform Electrical Work heading (except for work requiring an EEWP or work covered by 29 CFR 1910.269 Electric Power Generation, Transmission, and Distribution.)

Maintenance Work Package, MJR, Service Request, RSS or Work Order #: ____

Work Location (Bldg./Room or Area): ____

Equipment ID or System, as applicable: ____

Voltage / Circuit / Equipment or System information: ____

Circuit Isolation Point for Emergencies: ____

Description of electrical work to be done: (Select all tasks covered by this form)	Minimum level of electrical worker (select one):	Electrical Hazard Qualifications (select all that apply):
☐ Verify Zero Energy for LOTO ☐ Perform Inspection, Testing or Measurements ☐ Rack Breakers	☐ EW (<50 VAC) ☐ QEW Level 1 (≥50-240 VAC single phase only),outside RAB ☐ QEW Level 2 (≥50-240 VAC single phase only) ☐ QEW Level 3 (>240-600 VAC single phase and ALL three phase) ☐ QEW Level 4 (>600-13,800 VAC) ☐ QEW Level 5 (Lineman Electrician)	☐ Direct Current (DC) ☐ Batteries ☐ Capacitors ☐ Inductors

This form is ☐ **Job Specific** OR ☐ **Generic** which expires on ____ (Maximum 1 year from approval date)

Shock Hazard Analysis & Approach Boundaries (Table 1[1] or 2[1])	Arc Flash Analysis and Approach Boundary
Limited Approach Boundary LAB (Non-QEW) (select one): ☐ 42" (50-300 VAC) ☐ 42" (301-750 VAC and 277 VAC single phase systems) ☐ 60 " (751-15,000 VAC) ☐ DC: ____ inches Restricted Approach Boundary-RAB (QEW) (select one): ☐ Avoid Contact (50-300 VAC) ☐ 12" (301-750 VAC and 277 VAC single phase systems) ☐ 26" (751- 15,000 VAC) ☐ DC: ____ inches	Check method used and enter Arc Flash Boundary distance (select one): ☐ Calculation (Attached) ____ inches ☐ Label on equipment ____ inches ☐ Table 3[1], Task-Based Activity Analysis (AC) ____ inches ☐ Table 4[1], Task-Based Activity Analysis (DC) ____ inches ☐ No arc flash hazard (<240 VAC single phase system)

Hierarchy of Controls Methods (Check all that apply)	
Elimation	☐ De-energized ☐ Lock/Tag/Verify
Substitution	☐ Reduce energy by replacing energy circuitry
Engineering Controls	☐ Guarding ☐ GFCI, LTV
Awarness	☐ Single/Posting ☐ Barricade, Nonconducting Barricade QWE Control at LAB, Task Leader/Supervisor present, Additional Lighting, Other ☐ Two Person Rule Safety Watch (>600V), Other
Administration Controls	☐ Written Procedure
PPE	☐ VR Tools ☐ VR Gloves, VR Sleeves, Dielectric Floor Mat, VR Insulating Blanket, Class E (20kV) Hard Hat , Class G (2200V) Hard Hat, ORNL PPE, VR Extended Lead M&TE

Arc-Rated (AR) ORNL PPE (Select the appropriate PPE from Table 5)		
☐	A	Arc Rating <1.2 cal/cm², Long sleeve shirt and pants, Safety glasses or safety goggles, Hearing protection (ear canal inserts), Leather gloves
☐	B	Arc-Rating 1.2 cal/cm² to 8 cal/cm², Arc-rated long-sleeve shirt and pants or arc-rated coverall, arc-rated flash suit hood or arc-rated face shield and arc-rated balaclava, arc-rated jacket, parka, rainwear, or hard hat liner (AN), Hard hat, Safety glasses or safety goggles (SR), Hearing protection (ear canal inserts), Leather gloves and shoes
☐	C	Arc-Rating >8 cal/cm² to 40 cal/cm², Arc-rated long-sleeve shirt and pants or coverall (as required), arc-rated flash suit jacket, suit pants (AR), flash suit hood ; arc-rated gloves or rubber insulating gloves with protectors, arc-rated jacket, parks, rainwear, or hard hat liner (AN); Hard hat, Safety glasses or safety goggles (SR), Hearing protection (ear canal inserts), Leather work shoes
☐	D	H/RC 4: Arc Rating >40 cal/cm2 Contact DESO or E-AHJ

AN: as needed (optional). AR: as required. SR: selection required

[1]Tables 1-5 are located in: Hazard Analysis for Electrical Work exhibit in SBMS.

Task Demands	Individual Capabilities
☐ Time Pressure (in a hurry)	☐ Unfamiliarity with task/First time
☐ High Workload (memory requirements)	☐ Lack of Knowledge (mental model)
☐ Simultaneous, multiple tasks	☐ New technique not used before
☐ Repetitive actions, monotonous	☐ Imprecise communication habits
☐ Irrecoverable acts	☐ Lack of proficiency/inexperience
☐ Interpretation Requirement	☐ Indistinct problem-solving skills
☐ Unclear goals, roles & responsibilities	☐ "Hazardous" attitude for critical task
☐ Lack of or unclear standards	☐ Illness/Fatigue
Work Environment	**Human Nature**
☐ Distractions/Interruptions	☐ Stress (limits attention)
☐ Changes/Departures from routine	☐ Habit patterns
☐ Confusing displays or controls	☐ Assumptions (inaccurate mental picture)
☐ Workarounds/OOS instruments	☐ Complacency/Overconfidence
☐ Hidden system response	☐ Mindset ("tuned" to see)
☐ Unexpected equipment conditions	☐ Inaccurate risk perception (Pollyanna)
☐ Lack of alternative indication	☐ Mental shortcuts (biases)
☐ Personality conflicts	☐ Limited short-term memory

Human Performance Tools

1 Pre-job briefing
Identify hazards, assess risk and select and implement risk controls from a hierarchy of methods
2 Job site review
Increased situational awareness
3 Post-job review
Identify ways to improve and best practices
Peer check
4 Procedure use and adherence
Step-by-step procedure read, outcome understood
Circle the task to be performed, check off each task as it is completed
5 Self-check with verbalization
Stop, Think, Act, Review (STAR)
Verbalize intent before, during, and after each task
6 Three-way communication
Directives are repeated by receiver back to sender; receiver is acknowledged by sender
Use of the phonetic alphabet for clarity
7 Stop when unsure
Stop and obtain further direction when unable to follow a procedure or process step or if something unexpected occurs
Maintain a questioning attitude
8 Flagging and blocking
Identify (flag) equipment and controls that will be operated
Prevent access (block) equipment and controls that should not be operated

Additional Hazards and required PPE:

Hazard Analysis performed by:________________ **Badge No.:**________ **Date:**________
Note: Form preparer should be a qualified electrical worker.