Hazards of Electricity

ECE 492

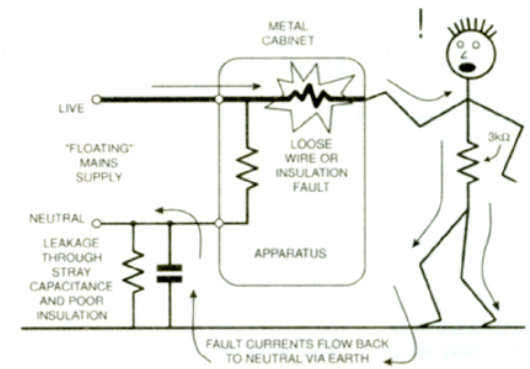
The Three Hazards

- Shock
- Arc
- Blast

Electric shock is physical stimulation and damage that occurs when electric current passes through the body.

An **arc flash** is the light and heat produced from an **electric arc** supplied with sufficient electrical energy to cause substantial damage, harm, fire, or injury.

Arc **blast** is a high pressure sound wave caused by the energy released by an electrical fault.



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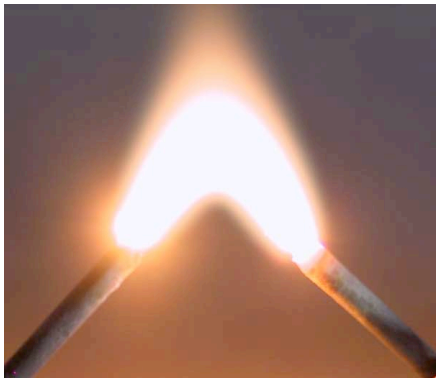
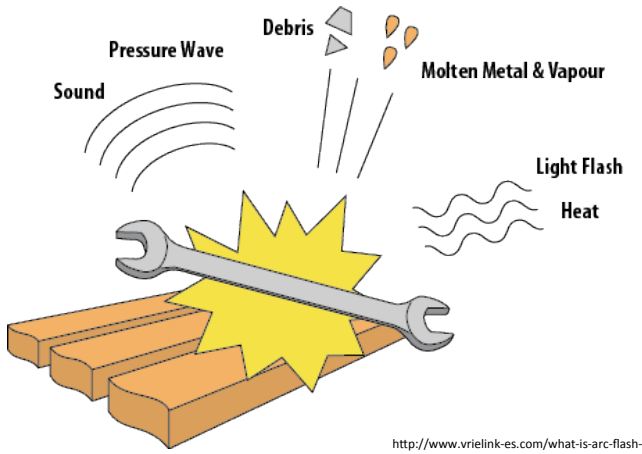


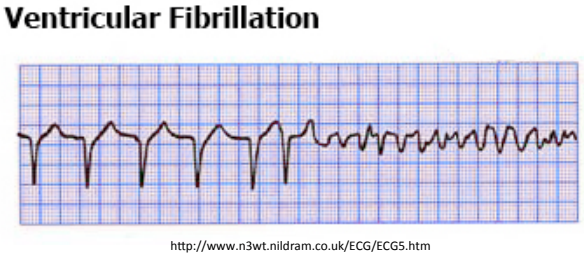
http://commons.wikimedia.org/wiki/File:Lichtbogen_3000_Volt.jpg#mediaviewer/File:Lichtbogen_3000_Volt.jpg



http://www.vrielink-es.com/what-is-arc-flash-hazard

Electric Shock

- Shock causes ventricular fibrillation (very rapid and irregular ventricular activation with no mechanical effect).



http://www.n3wt.nildram.co.uk/ECG/ECG5.htm

There's no documented case of a heart in fibrillation recovering unassisted. You will die unless someone uses an AED to restore sinus rhythm.

- Shock can contract the muscles involuntarily causing secondary injuries
- Shock can puncture cell walls – electroporation – suddenly reducing resistance.
- Significant currents can cause heating of tissue and internal burns

Current Divider

- *Electricity only takes the path of least resistance?*

NO

Electricity takes ALL paths. Current flows according to Ohms law, proportional to the voltage across the path, and inversely proportional to the resistance through the path.

Voltage Hazard

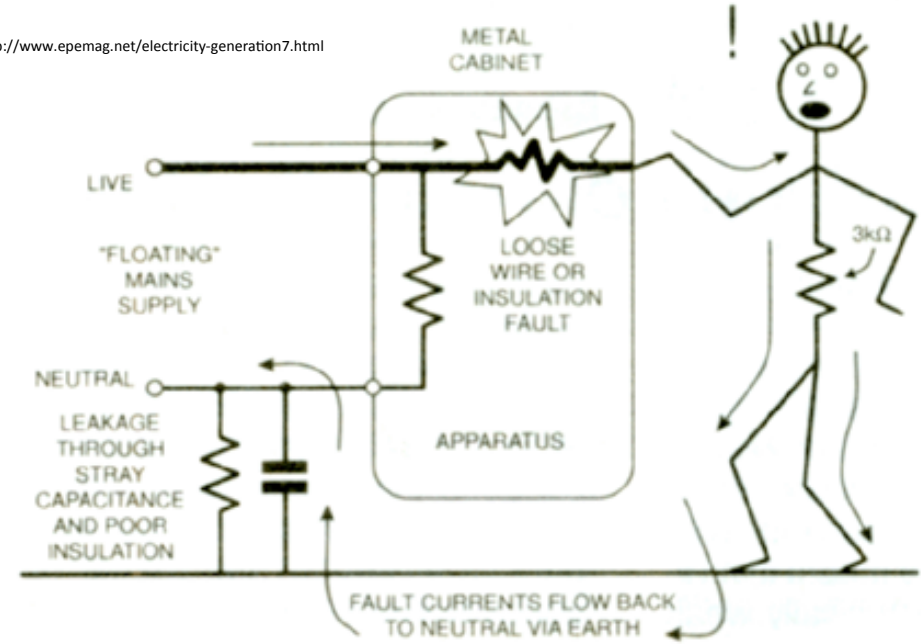
- *Voltage doesn't matter. It's the current that can kill you.*

NO

Current flows in proportion to the voltage across the path. The higher the voltage, the greater chance of a lethal current. Sufficient voltages can breakdown skin and suddenly reduce resistance.

Shock Circuit

http://www.epemag.net/electricity-generation7.html



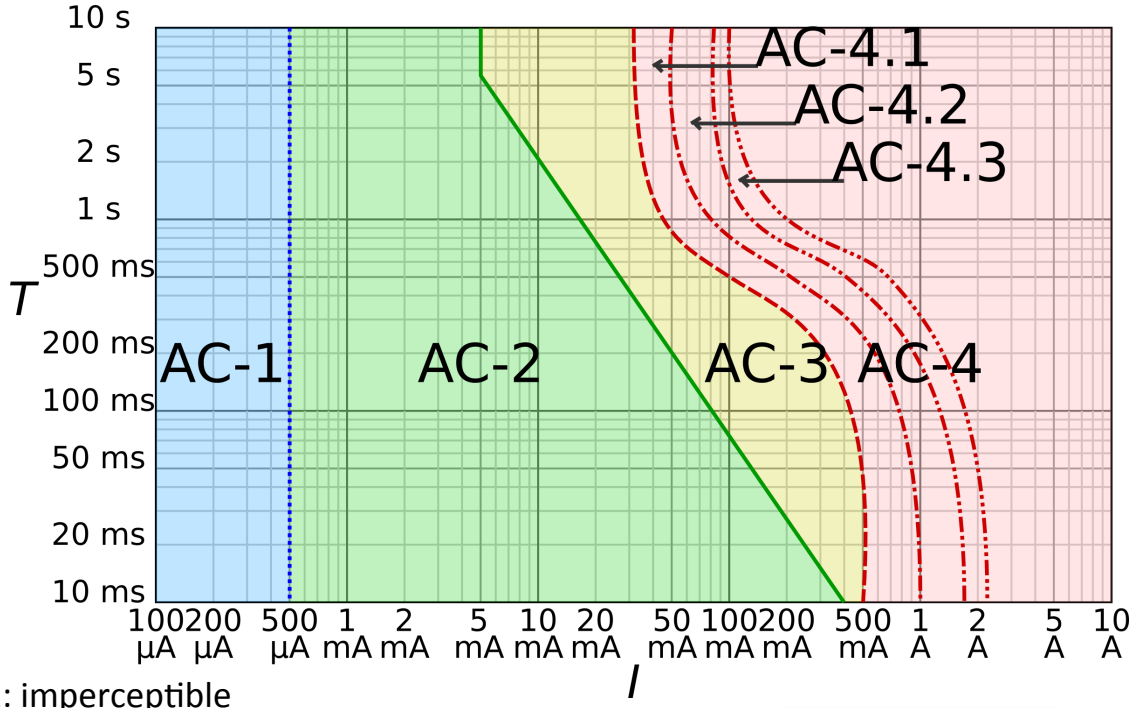
Ohm's Law
I=V/R

Situation	Wet Resistance	Dry Resistance
Finger touch	4 k – 15 kΩ	40 k - 1 MΩ
Hand holding a wire	3 – 6 kΩ	15 – 50 kΩ
Finger-thumb grasp	2 – 5 kΩ	10 – 30 kΩ
Hand around a drill handle	0.5 – 1.5 kΩ	1 – 3 kΩ
Hand immersed in water	200 – 750 Ω	--------
Foot immersed in water	100 – 300 Ω	--------

Cadick, John. *Electrical Safety Handbook*. 4th ed. New York: McGraw-Hill, 2012. Print.

Electric Shock Effects

AC current *I* of duration *T* passing from left hand to feet Per IEC publication 60479-1



AC-1: imperceptible
AC-2: perceptible but no muscle reaction
AC-3: muscle contraction with reversible effects
AC-4: possible irreversible effects
AC-4.1: up to 5% probability of ventricular fibrillation
AC-4.2: 5-50% probability of fibrillation
AC-4.3: over 50% probability of fibrillation

Can't let go

Assume 3.3K body resistance.

Is there a shock hazard from a

- 3.3V cell?
- 7 cell pack (23.1 V)?
- 92.4 V accumulator?

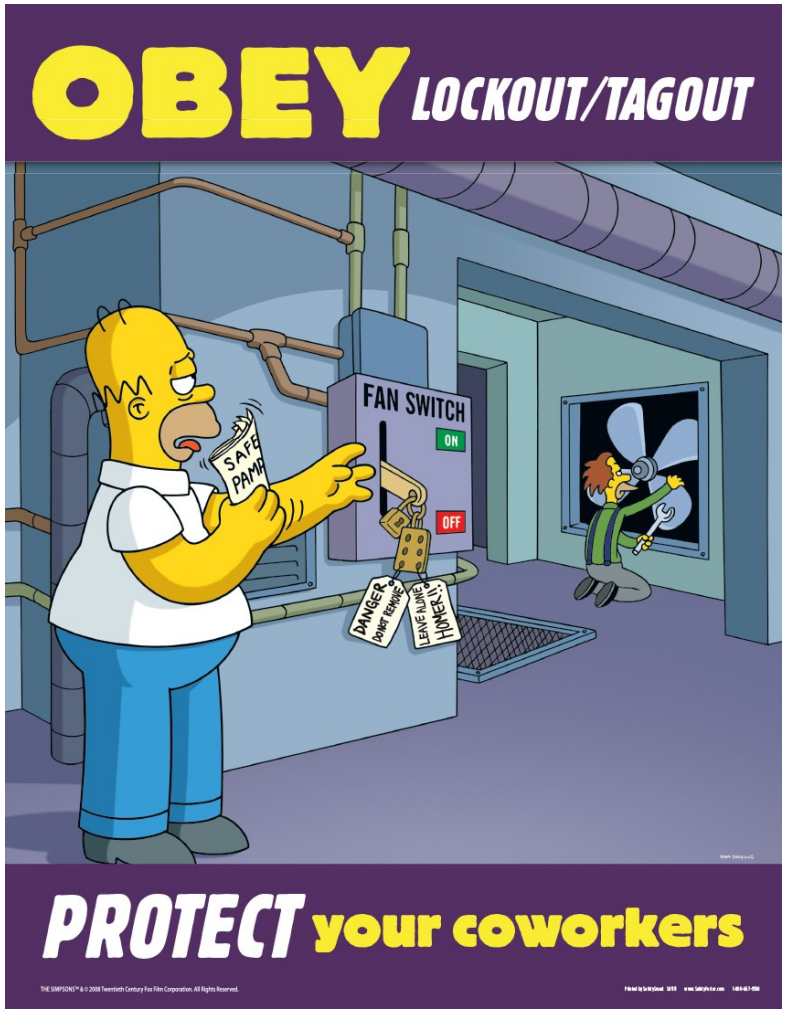
Protective Strategies against Shock

- Avoid Contact
- De-energize
- Lockout-Tagout
- Measurement

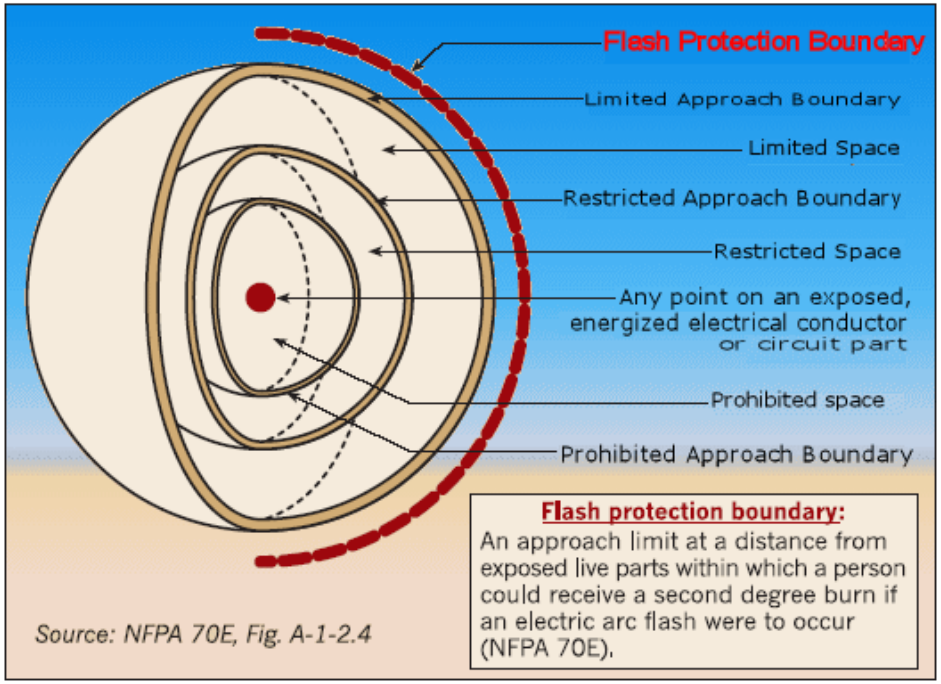
- Insulating Tools
- No conductive jewelry
- Insulating Gloves, Shoes, and other PPE
- Avoid synthetic (plastic) clothing

Lockout Tagout

- De-energize
- **Lockout-Tagout**
- Measurement



Shock Protection Boundaries



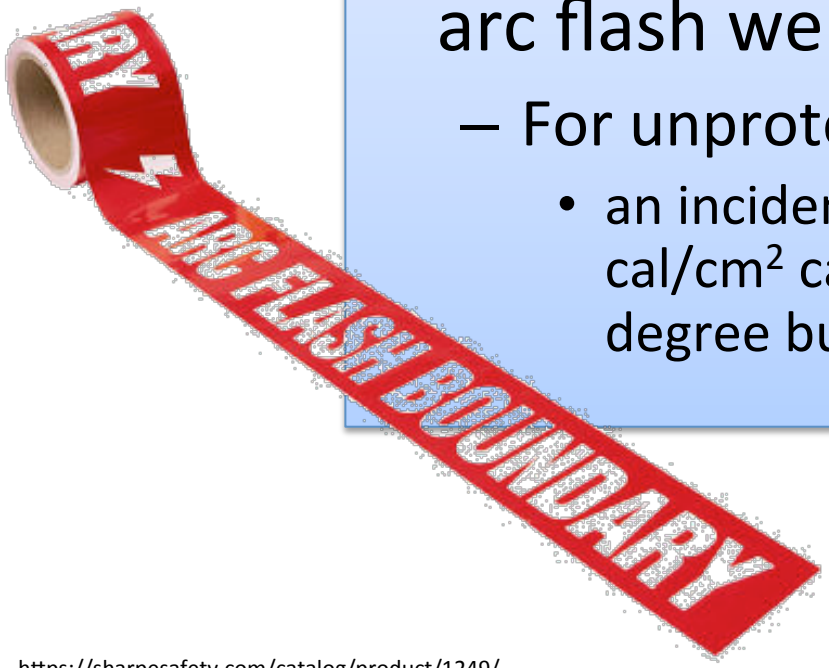
NFPA does not specify shock protection approach boundaries for DC systems under 100 volts. Nevertheless, setting up 1 meter approach boundaries is a good idea for many other reasons.

- Limited
  - Only qualified people
- Restricted
  - Insulation required
- Prohibited
  - Prohibited!

The limited approach boundary for fixed circuits with AC system of 50V – 300V (typical home wiring) is 1 meter.

Arc Flash Boundary

- Distance from prospective arc source within which a person could receive a **second degree burn** if an arc flash were to occur.
  - For unprotected skin
    - an incident energy level of 1.2 cal/cm^2 can cause a second degree burn.



https://sharpesafety.com/catalog/product/1249/

Burn. (2014, December 21). In *Wikipedia, The Free Encyclopedia*. Retrieved 18:44, February 3, 2015, from http://en.wikipedia.org/w/index.php?title=Burn&oldid=638998971

Burns

Type[10]	Layers involved	Appearance	Texture	Sensation	Healing Time	Prognosis	Example
Superficial (First degree)	Epidermis[5]	Red without blisters[10]	Dry	Painful[10]	5–10 days[10][11]	Heals well;[10] Repeated sunburns increase the risk of skin cancer later in life[12]	
Superficial partial thickness (Second degree)	Extends into superficial (papillary) dermis[10]	Redness with clear blister. Blanches with pressure.[10]	Moist[10]	Very painful[10]	less than 2–3 weeks[6][10]	Local infection/cellulitis but no scarring typically[6]	
Deep partial thickness (Second degree)	Extends into deep (reticular) dermis[10]	Yellow or white. Less blanching. May be blistering.[10]	Fairly dry[6]	Pressure and discomfort[6]	3–8 weeks[10]	Scarring, contractures (may require excision and skin grafting)[6]	
Full thickness (Third degree)	Extends through entire dermis[10]	Stiff and white/brown[10] No blanching[6]	Leathery[10]	Painless[10]	Prolonged (months) and incomplete[10]	Scarring, contractures, amputation (early excision recommended)[6]	
Fourth degree	Extends through entire skin, and into underlying fat, muscle and bone[10]	Black; charred with eschar	Dry	Painless	Requires excision[10]	Amputation, significant functional impairment and, in some cases, death.[10]	

Burn. (2014, December 21). In *Wikipedia, The Free Encyclopedia*. Retrieved 18:44, February 3, 2015, from http://en.wikipedia.org/w/index.php?title=Burn&oldid=638998971

DC Arc Flash Calculation

DC Arc: Unlike AC sources, DC sources do not have periodic current zeros that can give an arc a chance to extinguish.

- NFPA 70E – Annex D
  - D.8 Direct-Current Incident Energy Calculations
    - D.8.1.1 Maximum Power Method [2]

"This method is based on the concept that the maximum power possible in a DC arc will occur when the arcing voltage is one-half of the system voltage. Testing [3] has shown that this calculation is conservatively high in estimating the arc flash value. This method applies to DC systems rated up to 1000 VDC."

"A thorough theoretical review of DC arcing and energy was presented at the 2009 IEEE PCIC Conference [1].

1. "DC arc models and incident energy calculations," Ammerman, R.F.; Gammon, T.; Sen, P.K.; Nelson, J.P.; Petroleum and Chemical Industry Conference, 2009, Record of Conference Papers, 14-16 September 2009.
2. "Arc Flash Calculations for Exposures to DC Systems," Doan, D.R., IEEE IAS Electrical Safety Workshop, 2007, Record of Conference Papers, March 2007.
3. DC Arc Hazard Assessment Phase II Copyright Material Kinectrics Inc. Report No. K-012623-RA-0002-R00.

D.8.1.1 Maximum Power Method

$$I_{arc} = 0.5 \times I_{bf}$$

$$IE_m = \frac{0.01 \times V_{sys} \times I_{arc} \times T_{arc}}{D^2}$$

Where:

I_{arc} = arcing current, amperes
I_{bf} = bolted flash current, amperes
IE_m = incident arc flash energy, cal / cm^2
V_{sys} = system voltage, volts
T_{arc} = arcing time, sec
D = working distance, cm

Arc Current and Duration

- For each cell
  - V_{oc} = 3.3V,
  - R_{th} = 0.002 Ω
    - Therefore Isc = 1650 A
    - I_{arc} = 825 A

- Duration of Arc
    - A 60 amp-hour cell sustains 825 A current for 262 seconds (4.4 min)
    - Per EV4.7.2 manual disconnect should be possible within 10 seconds
    - Some authors report it difficult to sustain an arc for more than 2 seconds
    - At 825 A, the installed A3T200 fuse will blow in 0.08 seconds

Arc Hazard Distance

- Solve D.8.1.1 equation for distance

$$D = \frac{1}{10}\sqrt{\frac{V_{sys}\, I_{arc}\, T_{arc}}{IE_m}}$$

		Arc Hazard Boundary (meters)		
		Cell Discharge (sec)	Manual Disconnect (sec)	Blow Fuse (sec)
Number of Cells	*System Voltage (v)*	*262*	*10*	*0.08*
1	3.3	0.771	0.073	0.002
7	23.1	2.040	0.118	0.003
14	46.2	2.885	0.141	0.003
21	69.3	3.533	0.156	0.003
28	92.4	4.080	0.167	0.003

Conclusions

- If the fuse blows within its rated time (0.08 s), arc flash hazard exists for skin in direct contact with arc (< 3 mm)
- For 10 seconds of exposure during manual disconnect (assuming the arc is sustained and victim is “snagged” or otherwise can’t move away), the Flash Hazard Boundary is less than 6 inches
- For full discharge exposure (unconscious victim, self sustaining arc) the Flash Boundary can extend to 4 meters

Protective Strategies for Arc

- Distance
- Energy Absorbing Clothing
- Face Shield and Gloves

Synthetic fiber can melt and stick to skin. Natural fibers such as cotton and wool tend to provide better protection. Arc flash rated clothing is best.

http://www.thinknsa.com/

Personal Protective Equipment (PPE)

Hazard/Risk Category 0	Untreated natural fiber Shirt (long sleeve) Pants (long) Safety glasses Hearing protection Heavy duty leather gloves (as needed)	
Hazard/Risk Category 4 cal/cm² 1	Arc-rated long-sleeve shirt Arc-rated pants or overall Arc-rated face shield with hard hat Safety glasses Hearing protection Leather & voltage rated gloves (as needed) Leather work shoes	
Hazard/Risk Category 8 cal/cm² 2	Arc-rated long-sleeve shirt Arc-rated pants or overall Arc-rated face shield & balaclava or Arc flash suit with hard hat Safety glasses, Hearing protection Leather & voltage rated gloves (as needed) Leather work shoes	
Hazard/Risk Category 25 cal/cm² 3	Arc-rated long-sleeve jacket Arc-rated pants Arc-rated flash hood with hard hat Safety glasses, Hearing protection Leather & voltage rated gloves (as needed) Leather work shoes	
Hazard/Risk Category 40 cal/cm² 4	Arc-rated long-sleeve jacket Arc-rated pants Arc-rated flash hood with hard hat Safety glasses, Hearing protection Leather & voltage rated gloves (as needed) Leather work shoes	

For more detailed information or other options, please refer to NFPA 70E 2012 Edition

http://powerhawke.com/our-solutions/electrical-safety/arc-flash/ppe/

How can we improve our **Product Images**?

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Item # **11V625**

Mfr. Model # **FRK007 DNY REG XLG** UNSPSC # **46181508**

Catalog Page # **2323**

Catalog Group # **D5647**

Shipping Weight **2.7 lbs.**

Country of Origin **Mexico** | *Country of Origin is subject to change.*

Technical Specs

Item	**Flame-Resistant Hooded Sweatshirt**
Color	**Navy**
Size	**XL**
Fits Chest Size	**46 to 48"**
Sleeve Length	**35"**
Fabric Weight	**14 oz.**

Material	**58% Cotton/35% Modacrylic/7% Polyester**
Closure Type	**Zipper**
Number of Pockets	**2**
ATPV Rating	**33.6 cal/cm2**
Hazard Risk Category (HRC)	**3**
Standards	**NFPA 70E**

Blast

There is no PPE effective against blast

Summit Entertainment's The Hurt Locker (2009), promotional photo

General Safety Rules

- Follow all posted lab safety rules.
- Students may NEVER work on energized circuits over 30 volts.
- Students may NEVER enter the Dyno room when the dynamometer is energized, even if it is not spinning.

The latest revision of the LFEV safety plan is on the 2015 web site. All students should be familiar with it.

http://sites.lafayette.edu/ece492-sp15/files/2015/02/SafetyPlan.pdf

Pack Safety Rules

- No“loose” uncovered cells or open energized packs can be left unattended anywhere.
- All work on open cells and packs must occur within the safety zone.
- During open pack work (>1 cell), a safety watch person must continuously observe from outside the safety zone.
- Wear safety glasses when working with open packs and cells. Safety watch also wears safety glasses.
- Secure packs and cells when work is complete.