Protection from Electric Shock and Arc Flash

Journeyman Technical Information Paper 2

About 50 electrical workers are killed in construction every year in the U.S. by electric current and many more are injured. Over half of the deaths are from working on energized ("live") electric circuits without proper protection – often when it was not necessary to work "live." At least one-third of the electrocutions occur at low voltage, under 600 volts. **This paper discusses precautions for electricians, but does not cover electric utility work.**

Electric hazards

Electricity-related hazards include electric shock and burns, arc-flash burns, arc-blast impacts, and falls.

- **Electric shock and burns.** An electric shock occurs when electric current passes through your body. This can happen when you touch an energized part. If the electric current passes across the chest or head, you can be killed. At high voltages, severe burns can result.
- **Arc-flash burns.** An electric arc flash can occur if a conductive object gets too close to a high-amp current source or by equipment failure (for instance, while opening or closing disconnects). The arc can heat the air to temperatures as high as 35,000° F, and vaporize metal in the equipment. The arc flash can cause severe skin burns by direct heat exposure and by igniting clothing.
- **Arc-blast impacts.** The heating of the air and vaporization of metal creates a pressure wave that can damage hearing and cause memory loss (from concussion) and other injuries. Flying metal parts are also a hazard.
- **Falls.** Electric shocks and arc blasts can cause falls, especially from ladders or unguarded scaffolding.

Electric Safety Principles

Plan every job. Decide on your approach and step-by-step procedures. Write down first-time procedures. Discuss hazards and procedures in a job briefing with your supervisor and other workers before starting a job. Your employer should already have or develop a permit system for working on live circuits, if a circuit must be worked live.

- **Identify the hazards.** Do a job hazard analysis (*see* fig. 1). Identify steps that could create electric shock or arc-flash hazards.
- **Minimize the hazards.** De-energize the equipment or insulate or isolate exposed live parts so you cannot contact them. If this is impossible, get proper personal protective equipment (PPE) and tools.
- **Anticipate problems**. If it can go wrong, it might. Make sure you have the right PPE and tools for the worst-case scenario.
- **Get training**. Make sure you and everyone working with you is a qualified person with appropriate training for the job.*

To De-Energize or Not to De-Energize

One of the most important decisions in planning an electric task is whether to de-energize. Whenever possible, live parts to which you might be exposed should be put into an **electrically safe work condition**, unless your employer can demonstrate that de-energizing creates more or worse hazards, or is not practical because of equipment design or operational limitations.

You might need to work live to avoid interrupting life-support systems, de-activating emergency alarm systems, or shutting down ventilation equipment for hazardous locations, for instance. And de-energizing would not be practical during testing of live electric circuits or work on circuits that are part of a continuous process that cannot be completely shut down.

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* OSHA defines an electrical-qualified person as "one familiar with the construction and operation of the equipment and the hazards involved."

De-Energizing

An Electrically Safe Work Condition

The most important principle of electric safety is, **assume electric circuits are energized unless you make sure they are not**. Test every circuit and conductor every time you work on them. The National Fire Protection Association lists six steps to ensure conditions for electrically safe work.**

- Identify all sources of power to the equipment.
- Interrupt the load current, then open the disconnecting devices for each power source.
- Where possible, visually verify that blades of disconnecting devices are fully open or that drawout-type circuit breakers are fully withdrawn.
- Apply lockout/tagout devices in accordance with a formal, written policy.
- Test each phase conductor or circuit part with an adequately rated voltage detector to verify that the equipment is de-energized. Check the voltage detector before and after each test to be sure it is working.
- Properly ground all possible sources of induced voltage and stored electric energy (such as, capacitors) before touching. If conductors or circuit parts that are being de-energized could contact other exposed conductors or circuit parts, apply ground-connecting devices rated for the available fault current.

The process of de-energizing is "live" work and can result in an arc flash due to equipment failure. When de-energizing, follow the procedures described below in "Working On or Near Live Circuits."

Lockout/tagout program

Your employer should establish a written lockout/tagout program and train employees in the program. The program should cover planning for locating and labeling energy sources, identifying employees at risk, how and by whom the equipment is de-energized, releasing of stored energy, verifying that the circuit is de-energized and can't be restarted, voltage testing, grounding requirements, shift changes, coordination with other jobs in progress, a procedure for keeping track of all involved personnel, applying and removing lockout/tagout devices, return to service, and temporary re-energizing for testing/positioning. Lockout/tagout procedures should be developed for each machine or piece of equipment that will require servicing.

Lockout/tagout application. Each person who could be exposed to electric energy must be involved in the lockout/tagout process.

- After de-energizing, each employee at risk should apply an individual lockout/tagout device to each source of electric energy. Pushbuttons or selector switches cannot be used as the only way to de-energize.
- A lockout device is a key or combination lock with a tag that can be attached to a disconnecting device to prevent the re-energizing of the equipment being worked on without removal of the lock. The lockout device should have a way of identifying whose lock it is. Individual lockout devices with your name and picture on them are preferred. You must be the only person who has the key or combination for a lockout device you install, and you should be the only person to remove the lock after all work has been completed.
- A tagout device is a tag and a way to attach it that can withstand at least 50 pounds of force. Tagout devices should be used alone only when it is not possible to install a lockout device.
- The tag used in conjunction with a lockout or tagout device must have a label prohibiting unauthorized operation of the disconnecting means or unauthorized removal of the device.
- Before beginning work, you must verify through testing that all energy sources have been de-energized.
- Electric lockout/tagout procedures should be coordinated with all other site procedures for controlling exposure to electric energy and other types of energy sources.

Individual qualified-employee control procedure. For minor servicing, maintenance, inspection, and so on, on plug-connected equipment, work may be done without attaching lockout/tagout devices if the plug is next to where you are working and is always easy to see, and you do not ever leave the equipment alone.

Complex lockout/tagout procedures. Special procedures are needed when there is more than one energy source, crew, craft, location, employer, way to disconnect, or lockout/tagout procedure – or work that lasts beyond one shift. In any of these cases, one qualified person should be in charge of the lockout/tagout procedure with full responsibility for

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entirety.
ensuring all energy sources are under lockout/tagout and to account for all people on the job. There should be a written plan addressing the specific details and naming the person in charge.

Removal of lockout/tagout devices. Lockout and tagout devices should be removed only by the person installing them. If work is not completed when the shift changes, workers arriving on shift should apply their locks before departing workers remove their locks.

Return to service. Once work is completed and lockout/tagout devices removed, tests and visual inspection must confirm that all tools, mechanical restraints, electric jumpers, shorts, and grounds have been removed. Only then is it safe to re-energize and return to service. Employees responsible for operating the equipment and needed to safely re-energize it should be out of the danger zone before equipment is re-energized.

Temporary release. If the job requiring lockout/tagout is interrupted for testing or positioning equipment, follow the same steps as in return to service (above).

Working On or Near Live Circuits

Working on live circuits means actually touching energized parts. Working near live circuits means working close enough to energized parts to pose a risk even though you make be working on de-energized parts. Common tasks where you need to work on or near live circuits include:

- Taking voltage measurements
- Opening and closing disconnects and breakers
- Racking breakers on and off the bus
- Removing panels and dead fronts
- Opening electric equipment doors for inspection.

There should be standard written procedures and training for these common tasks. For instance, when opening and closing disconnects, use the **left-hand rule** when possible (stand to the right side of the equipment and operate the disconnect with your left hand). For other situations where you might need to work on or near live circuits, your employer should institute a written live work permit system which must be authorized by a qualified supervisor.

Live-work permit system

A live work permit should, at a minimum, contain this information:

- A description of the circuit and equipment to be worked on and location
- The date and time covered by the permit
- Why live work will be done
- Results of shock hazard analysis and determination of shock protection boundaries
- Results of flash hazard analysis and determination of flash protection boundary
- PPE to be worn and description of safe work practices to be used
- Who will do the work and how unqualified persons will be kept away
- Evidence of completion of job briefing, including description of job-specific hazards.

Approach distances to exposed live parts

The National Fire Protection Association defines three approach distances for shock hazards and one for arc flash.***

Electric shock *(see* table 1).

- The **limited approach boundary** is the closest distance an unqualified person can approach, unless accompanied by a qualified person.
- The **restricted approach boundary** is the closest distance to exposed live parts a qualified person can approach without proper PPE and tools. Inside this boundary, accidental movement can put a part of your body or conductive tools in contact with live parts or inside the prohibited approach boundary. To cross the restricted approach boundary, the qualified person must:
  (a) Have a documented plan that is approved by the manager responsible for the safety plan.
  (b) Use PPE suitable for working near exposed live parts and rated for the voltage and energy level involved.

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(c) Be certain that no part of the body enters the prohibited space.

(d) Minimize the risk from unintended movement, by keeping as much of the body as possible out of the restricted space; body parts in the restricted space should be protected.

- The **prohibited approach boundary** is the minimum approach distance to exposed live parts to prevent flashover or arcing. Approaching any closer is comparable to making direct contact with a live part. To cross the prohibited approach boundary, the qualified person must:
  (a) Have specified training to work on exposed live parts.
  (b) Have a documented plan with proper written work procedures and justifying the need to work that close.
  (c) Do a written risk analysis.
  (d) Have (b) and (c) approved by the manager responsible for the safety plan.
  (e) Use PPE appropriate for working near exposed live parts and rated for the voltage and energy level involved.

Arc flash. The **flash protection boundary** is the distance at which PPE is needed to prevent incurable burns (2nd degree or worse) if an arc flash occurs. (You still can get 1st or 2nd degree burns.) For systems of 600 volts and less, the flash protection boundary is 4 feet, based on an available bolted fault current of 50 kA (kiloamps) and a clearing time of 6 cycles (0.1 seconds) for the circuit breaker to act, or any combination of fault currents and clearing times not exceeding 300 kA cycles. For other fault currents and clearing times, *see* NFPA 70E.

Remember, when you have de-energized the parts you are going to work on, but are still inside the flash protection boundary for nearby live exposed parts: If the parts cannot be de-energized, you must use barriers such as insulated blankets to protect against accidental contact or you must wear proper PPE.

Proper Personal Protective Equipment

When working on or around live circuits, be sure to wear the right PPE to protect against electric shock and arc flash. Never wear clothing made from synthetic materials, such as acetate, nylon, polyester, or rayon – alone or combined with cotton. Such clothing is dangerous because it can burn and melt into your skin.

The type of PPE worn depends on the type of electric work being done (*see* table 2).

Once the hazard/risk category has been identified, check requirements for clothing and other PPE when working on or near energized equipment within the flash protection boundary (*see* tables 3 and 4). These PPE requirements protect against electric shock and incurable arc-flash burns. They do not protect against physical injuries from arc blasts.

The **minimum** PPE required would be an untreated natural fiber long-sleeve shirt and long pants with safety glasses with side shields (hazard/risk category 0).

For more information, call your local union, the Center to Protect Workers' Rights (CPWR) (301-578-8500 or **www.cpwr.com**), the National Institute for Occupational Safety and Health (1-800-35-NIOSH or **www.cdc.gov/niosh**), or OSHA (1-800-321-OSHA or **www.osha.gov**) – or go to **www.elcosh.org.**

 CPWR is a research, development, and training arm of the Building and Construction Trades Dept. (BCTD), AFL-CIO: CPWR, Suite 1000, 8484 Georgia Avenue, Silver Spring, MD 20910. (Edward C. Sullivan is president of the BCTD and CPWR and Joseph Maloney is secretary-treasurer.) Production of this technical information paper was supported by grant CCU317202 from the National Institute for Occupational Safety and Health, NIOSH. The contents are solely the responsibility of the Center to Protect Workers' Rights and do not necessarily represent the official views of NIOSH.

Table 1. Approach boundaries to live parts for shock prevention

	Limited approach boundary			
Nominal system voltage range, phase to phase	Exposed movable conductor	Exposed fixed-circuit part	Restricted approach boundary (allowing for accidental movement)	Prohibited approach boundary
0 to 50 volts	Not specified	Not specified	Not specified	Not specified
51 to 300 volts	10 ft. 0 in.	3 ft. 6 in.	Avoid contact	Avoid contact
301 to 750 volts	10 ft. 0 in.	3 ft. 6 in.	1 ft. 0 in.	0 ft. 1 in.
751 to 15,000 volts	10 ft. 0 in.	5 ft. 0 in.	2 ft. 2 in.	0 ft. 7 in.

Source: From a portion of table 2-1.3.4, Approach Boundaries to Live Parts for Shock Protection (NFPA 70E *Standard for Electrical Safety Requirements for Employee Workplaces, 2000 edition*). Tables are reprinted with permission. Copyright ©2000 National Fire Protection Association, Quincy, MA 02269. This reprinted material is not the complete and official position of the National

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Table 2. Hazard risk category classification (within flash protection boundary)

For low-voltage tasks (600 volts and below), this table applies only when there is an available short-circuit capacity of 25 kA or less, and when the fault clearing time is 0.03 seconds (2 cycles) or less. For 600-volt-class motor control centers, a short-circuit current capacity of 65 kA or less and fault-clearing time of 0.33 seconds (20 cycles) is allowed. For 600-volt-class switchgear, you need a short-circuit current capacity of 65 kA or less and fault-clearing time of 1 second (60 cycles). For tasks not covered in this table and tasks involving equipment with larger short-circuit current capacities or longer fault-clearing times, a qualified person must conduct a flash hazard analysis (*see* section 2-1.3.3, Part II, NFPA 70E).

	Hazard/risk category	Voltage-rated Gloves	Voltage-rated Tools
Opening Doors and Covers			
Opening hinged covers (to expose bare, energized parts)			
240 volts or less	0	N	N
600-volt-class motor control centers	1	N	N
600-volt-class lighting or small power transformers	1	N	N
600-volt-class switchgear (with power circuit breakers or fused switches) 2	N	N	
NEMA E2 (fused contactor) motor starters, 2.3 kV through 7.2 kV	3	N	N
1 kV and over (metal clad switchgear)	3	N	N
1 kV and above metal clad load interrupter switches, fused or unfused	3	N	N
Removing bolted covers (to expose bare, energized parts)			
240 volts or less	1	N	N
600-volt-class motor control centers or transformers	2*	N	N
600-volt-class lighting or small power transformers	2*	N	N
600-volt-class switchgear (with power circuit breakers or fused switches) 3	N	N	
NEMA E2 (fused contactor) motor starters, 2.3 kV through 7.2 kV	4	N	N
1 kV and above (metal clad switchgear)	4	N	N
1 kV and above metal clad load interrupter switches, fused or unfused	4	N	N
Opening transformer compartments for metal clad switchgear 1 kV and above	4	N	N
Installing, Removing or Operating Circuit Breakers (CBs), Fused Switches, Motor Starters or Fused Contactors			
Installing or removing circuit breakers or fused switches, 240 volts or less	1	Y	Y
Inserting or removing (racking) CBs from cubicles, doors closed			
600-volt-class switchgear (with power circuit breakers or fused switches)	2	N	N
NEMA E2 (fused contactor) motor starters, 2.3 kV through 7.2 kV	2	N	N
1 kV and above metal clad switchgear	2	N	N
Inserting or removing (racking) CBs or starters from cubicles, doors open			
600-volt-class switchgear (with power circuit breakers or fused switches)	3	N	N
NEMA E2 (fused contactor) Motor Starters, 2.3 kV through 7.2 kV	3	N	N
1 kV and above metal clad switchgear	4	N	N
Operating circuit breaker (CB), fused switch, motor starter or fused contactor, covers on/doors closed			
240 volts or less	0	N	N
>240-<600 volt panelboards/switchboards (molded case or insulated case CBs)	0	N	N
600 volt class motor control centers 0	N	N	
600 volt class switchgear (with power circuit breakers or fused switches)	0	N	N
NEMA E2 (fused contactor) motor starters, 2.3 kV through 7.2 kV	0	N	N
1 kV and above (metal clad switchgear)	2	N	N
1 kV and above metal clad load interrupter switches, fused or unfused	2	N	N
Operating circuit breaker, fused switch, motor starter or fused contactor, covers off/doors open			
240 volts or less	0	N	N
>240-<600 volt panelboards/switchboards (molded case or insulated case CBs)	1	N	N
600 volt class motor control centers 1	N	N	
600 volt class switchgear (with power circuit breakers or fused switches)	1	N	N
NEMA E2 (fused contactor) motor starters, 2.3 kV through 7.2 kV	2*	N	N
1 kV and above (metal clad switchgear)	4	N	N

(continued on page 6)

Table 2. Hazard risk category classification (within flash protection boundary) *(continued)*

	Hazard/risk category	Voltage-rated	
		Gloves	Tools
Working on Energized Parts			
Working on energized parts, voltage testing, applying safety grounds			
240 volts or less	1	Y	Y
>240-<600 volt panelboards/switchboards (molded case or insulated case CBs)	2*	Y	Y
600-volt-class motor control centers	2*	Y	Y
600-volt-class switchgear (with power circuit breakers or fused switches)	2*	Y	Y
600-volt-class lighting or small power transformers	2*	Y	Y
600-volt-class revenue meters	2*	Y	Y
NEMA E2 (fused contactor) motor starters, 2.3 kV through 7.2 kV	3	Y	Y
1 kV and above metal clad switchgear	4	Y	Y
1 kV and above metal clad load interrupter switches, fused or unfused	4	Y	Y
Working on control circuits with exposed energized parts, 120 volts or below			
600-volt-class motor control centers	0	Y	Y
600-volt-class switchgear (with power circuit breakers or fused switches	0	Y	Y
NEMA E2 (fused contactor) motor starters, 2.3 kV through 7.2 kV	0	Y	Y
1 kV and above metal clad switchgear	2	Y	Y
Working on control circuits with exposed energized parts, over 120 volts			
600-volt-class Motor Control Centers	2*	Y	Y
600-volt-class switchgear (with power circuit breakers or fused switches)	2*	Y	Y
NEMA E2 (fused contactor) motor starters, 2.3 kV through 7.2 kV	3	Y	Y
1 kV and above metal clad switchgear	4	Y	Y
Other Tasks			
Reading panel meters while operating meter switches	0	N	N
Metal clad load interrupter switches, fused or unfused, 1 kV and above			
Outdoor disconnect switch operation (hookstick operated)	3	Y	Y
Outdoor disconnect switch operation (gang-operated, from grade)	2	N	N
Insulated cable examination, in open area	2	Y	N
Insulated cable examination, in manhole or other confined space	4	Y	N
Removing/installing other equipment			
Starter "buckets" for 600-volt-class motor control centers	3	Y	N
600-volt-class revenue meters	2*	Y	N
Covers or cable troughs for 600-volt-class revenue meters	1	N	N

2* = A double-layer switching hood and hearing protection are required, in addition to the other hazard/risk category 2 requirements of table 3-3.9.2 of Part II of NFPA 70E. *See* tables 3 and 4.

kV = kilovolt

Note: Applying safety grounds after voltage testing does not require voltage-rated tools. Voltage-rated gloves or tools are rated and tested for the maximum line-to-line voltage on which work will be done. The hazard/risk category may be reduced by one number for low-voltage equipment listed here where the short-circuit current available is less than 15 kA (less than 25 kA for 600-volt-class switchgear).

Source: Adapted from table 3-3.9.1, Hazard Risk Category Classifications (*NFPA 70E Standard for Electrical Safety Requirements for Employee Workplaces, 2000 edition*). Tables are reprinted with permission. Copyright ©2000 National Fire Protection Association, Quincy, MA 02269. This reprinted material is not the complete and official position of the National Fire Protection Association on the referenced subject, which is represented only by the standard in its entirety.

Table 3. Simplified, two-category, flame-resistant clothing system

Applicable tasks	Clothing requirement
All hazard/risk category 1 and 2 tasks listed in table 2 On systems operating at less than 1000 volts, these tasks include work on all equipment *except* • Insertion/removal of low-voltage motor starter "buckets" • Insertion/removal of power circuit breakers with the switchgear doors open • Removal of bolted covers from switchgear. On systems operating at 1000 volts or more, tasks also include the operation, insertion, or removal of switching devices *with equipment enclosure doors closed.*	**Everyday work clothing** Flame-resistant long-sleeve shirt (minimum ATPV of 5) worn over an untreated cotton T-shirt with FR pants (minimum ATPV of 8) *Or* FR coveralls (minimum ATPV of 5) worn over an untreated cotton T-shirt (or an untreated natural-fiber long-sleeve shirt) with untreated natural-fiber pants.
All hazard/risk category 3 and 4 tasks listed in table 2 On systems operating at 1000 volts or more, these tasks include work on energized parts of all equipment. On systems of less than 1000 volts, tasks include insertion or removal of low-voltage motor-start motor control center "buckets," insertion or removal of power circuit breakers with the switchgear enclosure doors open, and removal of bolted covers from switchgear.	**Electric "switching" clothing** Double-layer FR flash jacket and FR bib overalls worn over either FR coveralls (minimum ATPV of 5) or FR long-sleeve shirt and FR pants (minimum ATPV of 5) worn over untreated natural-fiber long-sleeve shirt and pants worn over an untreated cotton T-shirt *Or* Insulated FR coveralls (minimum ATPV of 25, independent of other layers) worn over untreated natural-fiber long-sleeve shirt with untreated cotton blue jeans ("regular weight," minimum 12 oz./sq. yd. fabric weight), worn over an untreated cotton T-shirt.

FR - flame resistant.

ATPV - arc thermal performance exposure value of the clothing in calories/cm^2.

Source: Based on Table F-1 in appendix F of NFPA 70E, *Electrical Safety Requirements for Employee Workplaces,* 2000.

Table 4. Flame-resistant protective clothing and equipment

Flame-resistant protective clothing and equipment	Protective systems for hazard/risk category (4 = most hazardous)			
Hazard/risk category number	**1**	**2**	**3**	**4**
Flash suit jacket (2-layer)				X
Flash suit pants (2-layer)				X
Head protection				
Hardhat	X	X	X	X
Flame-resistant hardhat liner			X	X
Eye protection (safety glasses + side shields or safety goggles)	X	X	X	X
Face protection (double-layer switching hood)		2* tasks	X	X
Hearing protection (ear canal inserts)		2* tasks	X	X
Leather gloves or voltage-rated gloves with leather protectors	As needed	X	X	X
Leather work shoes	As needed	X	X	X

Source: Based on personal protective equipment requirements of table 3-3.9.2 of NFPA 70E, *Electrical Safety Requirements for Employee Workplaces*.

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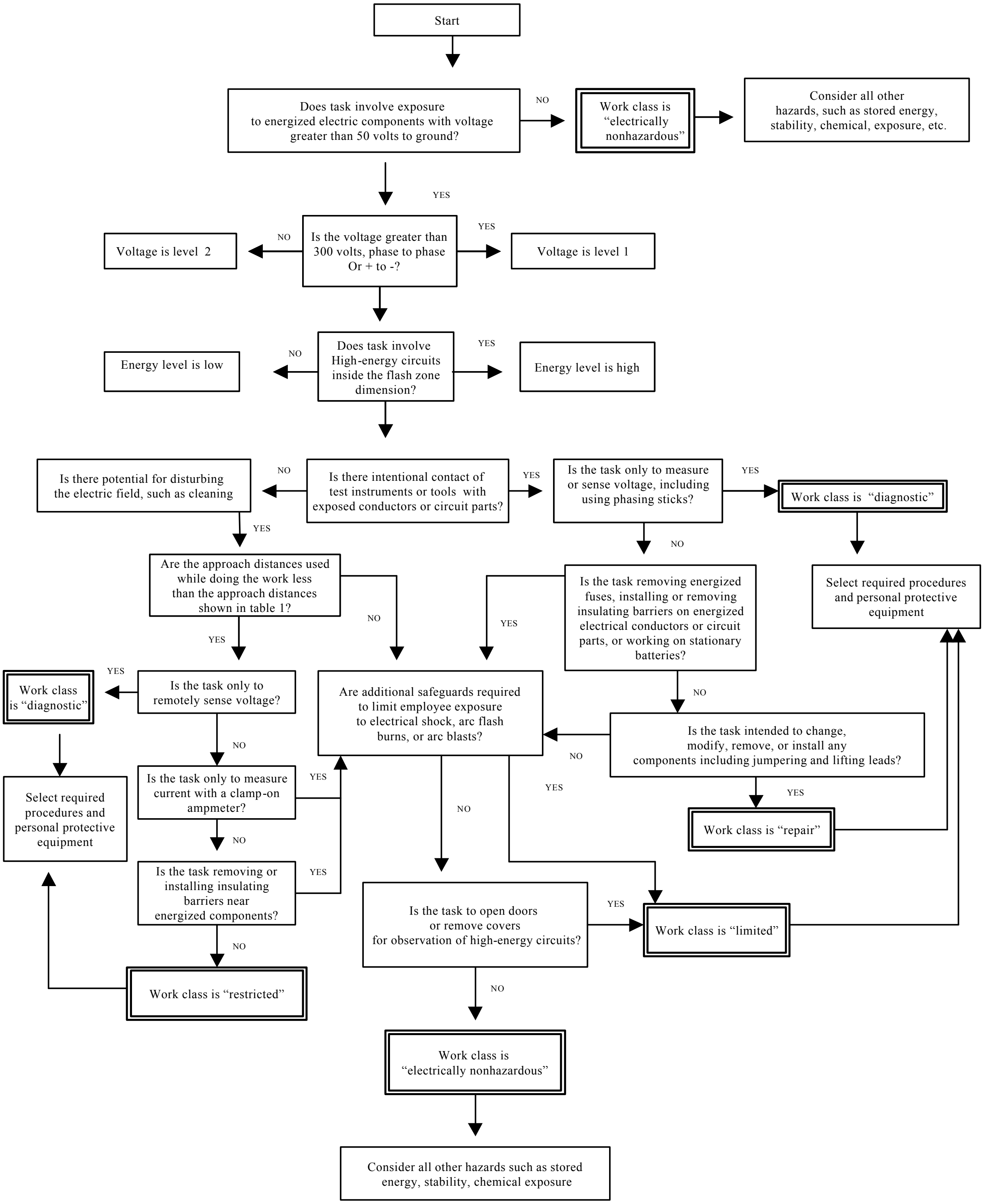
Figure 1. Hazard / risk analysis flow



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