SEMI S21-1103
SAFETY GUIDELINE FOR WORKER PROTECTION

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1 Purpose

1.1 This safety guideline identifies preferred methods for the protection of persons from safety and health hazards as they perform work on or around semiconductor manufacturing equipment.

2 Scope

2.1 This guideline describes methods for protection against hazards that workers may encounter in the work area, such as hazardous energies, physical hazards, or hazardous chemicals.

2.2 This guideline is intended to recommend considerations for protecting all persons that work on or around semiconductor equipment.

2.3 This guideline applies to equipment suppliers and users of equipment, including activities related to semiconductor manufacturing, and equipment and process development activities.

2.4 This guideline includes the following sections:

1 Purpose

2 Scope

3 Limitations

4 Referenced Standards

5 Terminology

6 General Worker Safety

7 Chemical Hazards

8 Control of Hazardous Energy

9 EEW at Hazardous Voltage or Energy Levels

10 Radiation-Producing Equipment

11 Physical Hazards

12 Personal Protective Equipment

13 Emergency Preparation and Managing Abnormal Situations

NOTICE: This safety guideline does not purport to address all of the safety issues associated with its use. It is the responsibility of the users of this safety guideline to establish appropriate safety and health practices and determine the applicability of regulatory or other limitations prior to use.

3 Limitations

3.1 This guideline is intended to be used by the equipment suppliers and users in consideration of worker protection. This guideline is not intended to be all-inclusive or used to verify conformance to any regulatory requirements.

3.2 Equipment design criteria are outside the scope of this document.

4 Referenced Standards

4.1 *SEMI Standards*

SEMI F34 — Guide for Liquid Chemical Pipe Labeling

SEMI S2 — Environmental, Health, and Safety Guidelines for Semiconductor Manufacturing Equipment

SEMI S8 — Safety Guidelines for Ergonomics Engineering of Semiconductor Manufacturing Equipment

SEMI S13 — Safety Guideline for Operation and Maintenance Manuals Used with Semiconductor Manufacturing Equipment

SEMI S19 — Safety Guideline for Training of Semiconductor Manufacturing Equipment Installation, Maintenance and Service Personnel

4.2 *ANSI Standards*[1]

ANSI B 11.21 — Machine Tools - Machine Tools Using Lasers for Processing Materials - Safety Requirements for Design, Construction, Care, and Use

ANSI Z136.1 — Safe Use of Lasers

ANSI/NFPA 70E Standard for Electrical Safety Requirements for Employee Workplaces 2000 Edition

1 American National Standards Institute, New York Office: 11 West 42nd Street, New York, NY 10036, USA. Telephone: 212.642.4900; Fax: 212.398.0023 Website: www.ansi.org

4.3 *European Directives*[2]

89/686/EEC — Personal Protective Equipment Directive

4.4 *European Standards*[3]

EN207 — Personal Eye-Protection - Filters and Eye-Protection Against Laser Radiation

EN208 — Personal Eye-Protection - Eye-Protectors for Adjustment Work on Lasers and Laser Systems (Laser Adjustment Eye-Protectors)

4.5 *JIS Standards*[4]

JIS C 6802 — Safety of Laser Products

4.6 *OSHA Standards*[5]

29 CFR 1910.147 — The Control of Hazardous Energy (lockout/tagout)

29 CFR 1910.1200 — Hazard Communication

NOTICE: Unless otherwise indicated, all documents cited shall be the latest published versions.

5 Terminology

5.1 *Abbreviations and Acronyms*

5.1.1 *CPR* — cardiopulmonary resuscitation

5.1.2 *EEW* — energized electrical work – Also known as Working On Energized Electrical Circuitry.

5.1.3 *EMO* — Emergency Off

5.1.4 *ERT* — Emergency Response Team

5.1.5 *MSDS* — Material Safety Data Sheet

5.1.6 *PPE* — Personal Protective Equipment

5.2 *Definitions*

5.2.1 *confined space* — a space that: (1) is large enough and so configured that an employee can bodily enter and perform assigned work; and (2) has limited or restricted means for entry or exit (e.g., chambers, space in enclosures are spaces that may have limited means of entry.); and (3) is not designed for continuous employee occupancy.

5.2.2 *e-diagnostic* — electronic access to equipment for the purpose of diagnosing problems from a distance (e.g., via dial-up, network connection, or wireless communication means).

5.2.3 *electrical PPE* — personal protective equipment specially designed to provide protection from electrical arc, shock or other effect that could cause injury to a person touching an electrical circuit or causing an electrical fault.

5.2.4 *emergency* — a sudden, serious event or situation, such as earthquake, explosion, fire, or release of hazardous energy or chemicals.

5.2.5 *emergency response team* — a team who is responsible for responding to emergencies.

5.2.6 *employer* — entity that directly supervises employees.

5.2.7 *energized electrical work* — work performed on energized equipment or systems containing hazardous voltages.

5.2.8 *facility operator* — entity that controls activities at the site.

5.2.9 *facility owner* — the actual owner of the property that may not be the actual operator of the facility.

5.2.10 *hazardous energy* — any energy that can potentially result in serious injury, illness, or death.

NOTE 1: Hazardous energies include electrical (e.g., capacitors, batteries), chemical, thermal/cryogenic, stored pressure (e.g., pressurized containers), suspended weight, stored mechanical (e.g., springs), generated pressure (e.g., hydraulics and pneumatics), and other sources that may lead to the risk of injury.

5.2.11 *operator* — a person who interacts with the equipment only to the degree necessary for the equipment to perform its intended function. [SEMI S2]

5.2.12 *hazardous voltage* — voltages greater than 30 volts rms, 42.4 volts peak, 60 volts DC [SEMI S2].

NOTE 2: To avoid confusion between hazardous voltage and non-hazardous electrical energy, see definition for non-hazardous electrical energy.

5.2.13 *non-hazardous electrical energy* — electrical energy of which voltage considered to need no further protection to be safe for human contact. Includes voltages less than the value specified as “hazardous voltage” and power less than 240 volt-amps (VA) (as used in EMO circuits and interlock circuits that must remain active during maintenance).

5.2.14 *supplier* — party who provides equipment to and communicates directly with the user. A supplier

2 European Commission, Available through the European Union On-Line at http://europa.eu.int/index_en.htm.

3 European Committee for Standardization, Available through the ON-CEN Sales Point, P.B. 130, A-1021 Vienna. Fax 43.1.213.00.818; Website: www.on-norm.at/cen/index_e.htm

4 Japanese Industrial Standards, Available through the Japanese Standards Association, 1-24, Akasaka 4-Chome, Minato-ku, Tokyo 107-8440, Japan. Telephone: 81.3.3583.8005; Fax: 81.3.3586.2014 Website: www.jsa.or.jp

5Occupational Safety and Health Administration, U.S. Government Printing Office, Washington, DC 20402, USA may be a manufacturer, an equipment distributor, or an equipment representative. [SEMI S2]

5.2.15 *user* — party who acquires equipment for the purpose of using it to manufacture semiconductors.

5.2.16 *work* — any activity performed on semiconductor manufacturing equipment, utilities connected to the equipment, or facilities associated with the equipment within the work area.

5.2.17 *work area* — room or defined space where semiconductor manufacturing equipment is located and where workers are present. This can include service chases and sub-fab areas.

5.2.18 *workers* — personnel who install, operate, maintain, service, decontaminate, or disassemble equipment.

6 General Worker Safety

6.1 The hierarchy for selecting worker protection measures should be as follows:

- Hazard elimination by design
- Engineering controls
- Administrative methods
- Personal Protective Equipment

6.2 The equipment supplier should provide information in the equipment operation, maintenance, or service manual or other appropriate documents on recommended controls to reduce the risks. These documents should conform to SEMI S13.

6.3 *Equipment Engineering System (EES) Related Safety Issues*

6.3.1 Suppliers should identify all forms of e-diagnostic communications (either standard or optional) that exist or are planned and should include the preferred method (i.e., local area network (LAN), telephone line, wireless port) that is required.

6.3.2 Suppliers should describe any communications isolation feature (e.g., cut-off switches, locations for disconnecting cables) that is available to protect equipment from being controlled remotely.

NOTE 3: Isolation of communication usually will not be acceptable to local jurisdictions as a substitute for isolation of hazardous energy in a hazardous energy control procedure.

6.4 Prior to work, employers should develop safe work procedures.

6.4.1 Development of safe work procedures should use hazard analyses and risk assessments to identify the hazards and determine which hazards warrant further mitigation.

6.4.2 Risks identified by job hazard analyses and risk assessments should be reduced to an acceptable level, using the protective measure hierarchy described above.

6.5 Employers should ensure that workers are adequately trained to perform their assigned work safely.

6.5.1 Suppliers and users should agree on training involving specific equipment.

NOTE 4: See SEMI S19, which pertains to safety training and certification for personnel working in semiconductor fabrication facilities.

6.6 The supplier should provide the user with the version of equipment installation, maintenance, service, and operation manuals that matches the specific equipment configuration as installed, contains the most current information for that configuration but is appropriate to the specific equipment for both configuration and process.

6.6.1 The user should verify that the manuals correctly reflect the equipment configuration as it was installed. If there are any discrepancies, the user and the supplier should agree on corrective actions.

6.7 The facility operator should establish site-specific safety procedures for the safety of all persons including temporary workers, visitors, and supplier representatives in the work area.

6.7.1 Site-specific hazards and appropriate protective measures including applicable safety procedures should be communicated by the facility operator to all persons.

6.8 Upon request, the facility operator should identify appropriate communication measures to ensure there is communication between workers that may be physically separated, such as between upper and lower floors or between operation and maintenance areas.

NOTE 5: Facility operators may restrict wireless communications because of interference issues. This may include wireless phones, Personal Digital Assistants (PDAs), two-way pagers, and other wireless devices.

6.9 The facility operator should ensure conformance to all applicable regulatory requirements and control of hazards in the work area. The use of industry practices should be considered in the absence of regulatory requirements.

NOTE 6: Multi-employer work site issues may be involved in some jurisdictions. Check with local site personnel for information before finalizing practices.

6.10 Hazards should be controlled based on each job category: installation, operation, maintenance and service.

6.10.1 *Installation*

6.10.1.1 Prior to equipment installation, the installation manual or other available documents should be checked to ensure that the appropriate information is available, including:

- Utilities connection diagram
- Electrical cabling information
- Hazardous energy isolation procedures
- Test procedures for safety features and performance
- Chemical information
- Safety related detector types and locations

6.10.2 *Operation*

6.10.2.1 EMO and safety interlock features should not be removed, bypassed or overridden during normal operating periods.

6.10.2.2 The location and functionality of each safety interlock feature and EMO feature should be verified before initial start-up of any system.

6.10.2.3 Periodic testing and validation of EMO and safety interlock features should be performed in accordance with the supplier's recommendations.

6.10.2.4 EMO and safety interlock systems should be tested and validated following extended shutdown for maintenance and service.

6.10.3 *Maintenance and Service*

6.10.3.1 Prior to maintenance or service, the worker should check for the following. Worker should perform their tasks in accordance with any identified procedures or requirements including the following:

- Effects of the tasks on any safety systems
- Presence of active hazardous energy sources
- Hazardous energy source isolation (lockout/tagout) requirements
- Verification of remaining hazardous energies after energy isolation
- Procedure for removal or isolation of remaining hazardous energies
- Necessity and procedures to override safety interlocks
- Proper restoration of overridden safety interlocks after completion of the work
- Personal protective measures required for the work including the use of personal protective equipment and training requirements
- Requirements to document the work

7 Chemical Hazards

7.1 The hazards of all work-related chemicals should be identified. Hazard communication should be provided for all known hazards of those chemicals.

7.2 *Hazard Communication (HAZCOM)*

7.2.1 The user should provide chemical safety data to a designated supplier representative and all potentially exposed persons. The supplier representative should be the manager responsible for field service personnel.

7.2.2 Work associated with hazardous chemicals should be performed only by personnel who have been trained in safe handling techniques and the hazards associated with exposure.

7.2.3 When performing work at the user's site, the supplier should provide the user information in advance on any chemicals that the supplier brings onto the user's site. It is the responsibility of the supplier to provide information in advance on supplier-specified hazardous chemicals and the appropriate handling procedures. It is the responsibility of the user to train workers on user-specified hazardous chemicals.

7.2.4 Chemicals and gases should be handled with special care based on specific handling instructions that are described in MSDSs and equipment manuals.

7.2.5 Material Safety Data Sheets (MSDSs) for the chemicals in use should be readily accessible while work associated with the chemicals is being performed.

7.2.6 All chemical containers and pipes should be labeled with contents and hazards according to applicable codes or standards.

NOTE 7: Process piping that may carry varying contents depending upon the timing or recipe may be labeled with the generic contents of the piping provided the hazards and protective measures can be easily identified from the label.

NOTE 8: Information about chemical labeling methods is provided in SEMI F34 and OSHA 29 CFR 1910.1200.

7.2.7 A written program for controlling hazardous chemicals should be developed by each employer.

7.2.7.1 This program should be periodically reviewed, for adequacy, by employers.

7.2.7.2 Employers should train their workers on proper implementation of the program.

7.3 *Chemical Handling and Storage*

NOTE 9: Information on chemicals used in the area and the facility-operator-required personal protective equipment (PPE) is the responsibility of the facility operator and should be available in the work area according to regulations for the location.

NOTE 10: Persons providing transient workers into the facility should coordinate to determine if there are any differences between the facility requirements for PPE and the worker employer requirements for PPE.

7.3.1 All workers should be trained on the chemical hazards, the proper use of the PPE, and the limitations of the PPE.

7.3.2 Chemical information should be presented to workers during training in a clearly understandable format (such as a table) and should include chemical names, chemical formulas, hazardous properties (flammable, corrosive), chemical states (solid, liquid, or gas), and other hazard information.

NOTE 11: It is recommended that users of this document refer to Section 12 Personal Protective Equipment for additional information on protection from chemical exposure.

7.3.3 Further information on typical chemical categories and their related hazards is provided in Table A1-1 of Appendix 1.

7.3.4 When operation, maintenance, or service tasks may include exposure to chemical mists, fumes, or vapors, the tasks should be conducted with adequate ventilation.

7.3.4.1 If there is a possibility of insufficient ventilation, employers are responsible for ensuring that their workers wear respiratory protective equipment.

7.3.5 If maintenance or service tasks require access to chemically contaminated areas of the equipment, PPE may be needed, and implementation of decontamination procedures may be necessary.

7.3.6 Workers should be trained to know when it is appropriate to clean up chemical spills. The amount that may be cleaned up is completely dependent upon the user's site hazardous material policies.

7.3.7 Workers should not attempt to clean up large or unknown spills without proper training. In these circumstances, the ERT should be contacted.

7.4 Incompatible chemicals should not be mixed or stored together in the same spill control area unless adequate controls are provided to avoid mixing of chemicals or creation of a risk of fire and explosion.

NOTE 12: Specific chemical separation requirements are defined by local regulation.

7.4.1 Chemical containers should be stored in a designated location based on hazard categories. Containers should be segregated based on incompatibility risks.

7.4.2 Compressed gas cylinders should be secured upright at all times. When cylinders are not in use, outlet and valve protective caps should be in place.

NOTE 13: Depending on the gas hazard, some jurisdictions require non-combustible securing devices (e.g., chains).

NOTE 14: Cylinders within the semiconductor manufacturing equipment may be installed horizontally if the equipment manufacturer determines this is compatible with the cylinder type to be used.

7.5 *Protection Against Unexpected Release*

7.5.1 Hazardous Energy Control or Lockout/Tagout procedures should be used to protect workers from the unexpected release of hazardous energies associated with pressurized gas, pressurized liquid chemicals or other (e.g., chemical reaction) energy. The Control of Hazardous Energy section of this document applies to all gaseous and liquid chemical energy during maintenance and service tasks.

7.6 *Oxygen Deficiency*

7.6.1 If work is to be performed where oxygen deficiency is possible, (e.g., inside a confined space, near a high volume inert gas flow), the oxygen content of the atmosphere should be monitored.

7.6.2 If a hazard exists, appropriate worker protection measures should be implemented prior to entry. If the oxygen content decreases to below 19.5%, workers who are not provided with supplied air respirators have to leave.

7.6.3 If elimination of oxygen deficiency is not practical, workers should use appropriate PPE as a means of working safely in an oxygen deficient environment.

7.6.4 The worker should be educated on the hazards and the necessary protective measures associated with oxygen deficient environments.

7.7 *Chemical Waste*

7.7.1 Spent chemical drains should be separated to the extent that chemical reactions will not cause damage to drain materials of construction or other chemical reaction hazards. The user's instructions should be followed to avoid potential hazards.

7.7.2 Solid waste should be placed in the appropriate, labeled waste container based upon user's instructions.

8 Control of Hazardous Energy

NOTE 15: Control of hazardous energy is commonly known as lock and tag or Lockout/Tagout. US OSHA regulation: 29 CFR 1910.147 is one location where detailed information can be found.

8.1 Hazardous Energy Control (lockout/tagout) is a method for isolating sources of hazardous energy from equipment and protecting workers from accidental release of the energy.

8.2 Suppliers should identify all tasks that could be affected by hazardous energy, (e.g., electrical, chemical, mechanical, hydraulic, pneumatic, stored, gravity or thermal) and should provide procedures for effectively isolating such energy and safely restoring the energy after performing each work task.

8.3 *Safe De-Energized Work Procedures*

8.3.1 *Preparation*

NOTE 16: This list is not intended to be in any specific order and the order may be changed to reflect individual conditions.

a. Identify the task to be performed.

b. Identify all energy sources and the location of the means of isolation for each source.

c. Notify potentially affected persons that the work will be performed.

d. Locate hazardous energy control procedures for the specific system and task.

e. Shut down equipment using normal shut down procedures.

f. Isolate all appropriate energy sources in the order and manner specified in the procedures.

NOTE 17: Certain procedures may require modification to account for factory-located energy isolation devices and to meet local regulatory requirements.

g. For electrical energy, turn off the power at the appropriate disconnection point.

NOTE 18: If regulations have allowed multiple electrical energy sources, (e.g., main power, emergency power, UPS power) all sources of power must be identified. Each source that may expose the worker should be isolated to ensure safe working conditions.

h. Verify absence of hazardous voltage at the equipment side of the disconnecting mechanism with an appropriate test device.

- The test device should be checked for correct operation before and after testing for the presence of hazardous electrical energy.

i. Ensure that all energy is at zero state and that any capacitors or other electrical energy storage devices are fully discharged or isolated.

j. Follow any special steps needed to eliminate stored energy (e.g., liquid or gas pressure, capacitors, compressed springs, support of a raised mass).

k. Each person performing work should apply a locking device (under exclusive control of the worker) and a tag to each isolated energy source.

NOTE 19: Some jurisdictions allow for group lockout capability. Entities creating procedures and persons performing lockout should understand the procedures for the location.

l. Verify that energy is no longer present (e.g., check pressure, presence of liquid, weight, temperature)

8.3.2 *Performing Work Tasks*

8.3.2.1 Work may only be performed by persons who are trained to work on the specific equipment.

8.3.2.2 De-energized work may only occur after the person has isolated the energy and applied a lock and tag to the energy isolation device.

8.3.2.3 Work continuing past shift change should be provided with special lockout transfer procedures (that are usually controlled by the user) to ensure locks are applied by the workers on the new shift and that workers on then previous shift have removed their locks.

8.3.3 *Restoration of Energy*

8.3.3.1 Remove all hand tools, parts and other miscellaneous items may have been inadvertently left in the area during the work.

8.3.3.2 Ensure all safety devices have been restored.

8.3.3.3 Notify all personnel who could be affected by the potential hazard.

8.3.3.4 Remove energy isolation devices (e.g., locks, tags blinds, barriers) in the order specified in the task procedures.

8.3.3.5 After verifying that all persons are clear, restart the system.

8.3.3.5.1 Apply energy in the proper sequence for safe restart (e.g., power to interlocks and controls before main energy, power to interlocks before chemical re-pressurization).

8.3.3.6 Verify equipment is operating properly.

8.3.3.7 Reset all outer enclosure interlocks and secure outer enclosures.

9 EEW at Hazardous Voltage or Energy Levels

9.1 Hazardous electrical energy should be isolated whenever it is possible to perform the work with the equipment non-energized.

9.2 When electrical energy cannot be isolated due to the type of work to be performed (e.g., trouble-shooting, power supply adjustment), suppliers should identify all tasks that include electrical-energized work and should provide procedures for safely accomplishing such work.

9.2.1 Facility operators should verify, modify if necessary, and approve procedures before EEW is performed at the facility.

NOTE 20: Appropriate levels of PPE for EEW can only be calculated with knowledge of the energy available from the source (e.g., sub-station, transformer) that provides power from the facility to the equipment circuit.

9.3 *EEW or Working on Energized Electrical Circuitry*

9.3.1 Supplier should notify the user of any EEW that may be required.

NOTE 21: Routine testing of circuits may be included in the definition of EEW in some circumstances and in some jurisdictions.

9.3.1.1 Two or more qualified persons should perform EEW, except for the routine testing of circuits.

9.3.1.2 One worker should always have access to and be ready to de-energize the system by operating the appropriate disconnecting device.

NOTE 22: Some jurisdictions or users may require persons to be trained in emergency rescue procedures such as cardio pulmonary resuscitation (CPR) electrical shock first-aid, and extracting a person from an energized circuit.

9.3.1.3 EEW should only be performed by workers wearing appropriate electrical PPE and natural fiber clothing for protection against shock, arc, flash, or burn.

NOTE 23: Electrical PPE manufacturers have been testing certain models of natural fiber or electrical protective synthetic fiber (e.g., Monofilament Nomex) for clean room purposes, however, supplier personnel and users should coordinate the use of clothing that is acceptable in the specific factory.

9.3.1.3.1 Clothing made from synthetic materials such as acetate, nylon, polyester, or rayon, either alone or in blends with cotton, should not be worn for EEW at hazardous energy levels where the exposure for arc, flash or burn exists; because it can melt and therefore fail to provide adequate protection.

NOTE 24: Normal clean room clothing is made from synthetic fabrics and caution should be taken to provide adequate protection.

NOTE 25: A Hazard/risk analysis may be used to determine available fault current and incident energy level in J/cm^2. These calculated levels establish the level of natural fiber, calorie-rated flame resistant clothing and electrical PPE necessary for protection. Calculation formulas and hazard/risk analysis methods are available in documents such as ANSI/NFPA 70E.

9.3.1.4 Metal jewelry (e.g., such as watches, rings, metal framed eyeglasses, and body-piercing jewelry) should be removed during EEW.

9.3.1.5 During EEW, access to the immediate work area should be restricted from unqualified workers by the use of barricades, safety signs, safety cones, safety tape or a human guardian.

9.4 Safe EEW procedures should be provided by supplier and should include the following:

a. Verification of valid reasons for performing the work energized.

b. Identify electrical energy sources and the location of the means of isolation for each source.

NOTE 26: Identification is required to ensure that workers know how to remove energy if an emergency develops during the work task.

c. When the hazard is remote from the equipment controls, the warning should also be provided at the point of the hazard.

d. When the EEW is complete, workers should restore the equipment to its original state and ensure that all safeguards are restored and interlocks are functioning properly.

10 Radiation-Producing Equipment

10.1.1 *Ionizing Radiation*

10.1.1.1 Initial radiation surveys should be performed as required by regulations to verify that radiation shielding is installed.

10.1.1.1.1 Additional radiation surveys should be conducted following maintenance or service tasks to ensure shielding remains in place, and is effective.

10.1.1.2 Access of unauthorized persons, to working areas where there is a risk of exposure to hazardous levels of radiation, should be restricted.

10.1.1.3 If work associated with radiation is required, the workers should be trained on the hazard characteristics and appropriate protection measures, including safe handling, use, and shielding.

NOTE 27: Certification of the people performing the work may be required, depending on the work to be performed or the type of radiation.

10.1.1.4 Prior to performing work, workers should reconfirm the instructions and other related documents to avoid any misunderstanding of the work procedure.

10.1.1.5 An appropriate method of monitoring the amount of worker exposure to radiation during work with ionizing radiation should be considered.

10.1.2 *Non-Ionizing Radiation*

10.1.2.1 When performing work with potential exposure to non-ionizing radiation, the potential exposure should be evaluated and appropriate protection provided. See SEMI S2 as a technical guide.

10.1.3 *Lasers*

10.1.3.1 Work on lasers should be performed with the laser de-energized whenever possible.

10.1.3.2 Workers performing work on laser equipment should be trained in the hazards and proper work procedures.

10.1.3.3 During work on other than Class 1 or Class 2 laser equipment, access to the area where unauthorized personnel can be exposed to energized laser beams should be controlled with a safety enclosure or other appropriate method.

NOTE 28: Laser classes greater than Class 1 and Class 2 require PPE when entering the path of an energized laser.

10.1.3.3.1 Suppliers should consider warning labels for Class 2 laser equipment to ensure workers do not inadvertently enter the laser path.

10.1.3.4 When working on an opened laser, protective measures (which may include PPE) should be taken for the appropriate hazards and level of risk.

10.2 *Extreme Temperatures*

10.2.1 When performing work with potential exposure to hazardous surface temperatures, the potential exposure should be evaluated, and appropriate protection provided, or the temperature adjusted to a safe level. See SEMI S2 for acceptable temperature ranges.

11 Physical Hazards

11.1 *Work at Elevated Heights*

NOTE 29: Work at extreme heights may require specific training or specially certified personnel. For example, Japan Labor Safety Regulations require workers working at five meters or higher to be a nationally certified chief worker.

11.1.1 If the work at an elevated position, such as the end of a platform or through an opening, poses a fall hazard, the area should be guarded with a fence, handrail, or cover, or fall protection should be worn.

11.1.2 When installing components or assemblies at heights, protective measures to prevent falling objects should be implemented. Heavy components or assemblies should be lifted into position with ergonomically acceptable lifting equipment.

11.1.3 *Work on a Stepladder*

NOTE 30: Ladders must be approved for the jurisdiction in which they are used, if applicable.

11.1.3.1 Stepladders should be stored away from chemicals and contaminants.

NOTE 31: Regulations related to ladder materials of construction acceptability may affect use of certain ladders in areas where chemicals are used or where the ladder is used for potentially energized electrical work.

11.1.3.2 Stepladders should be inspected to verify that they are in good condition. If they are not, the stepladders should be taken out of service until they are repaired or replaced. Rungs should be inspected to ensure that they are kept free from fluids and debris.

11.1.3.3 Only one person should be ascending or descending a stepladder at any time even if steps are provided on both sides of the ladder.

11.1.3.4 When ascending or descending, workers should face the stepladder, use at least one hand to grasp the stepladder and not carry any object that interrupts the worker’s view.

11.1.3.5 Stepladders should be used fully extended and with legs locked. Unstable positions such as work on top two steps, work which requires the torso to extend beyond the rails, and work which requires standing on tiptoes or a single foot should be avoided.

11.1.3.6 Work should not be performed below the stepladder when in use.

11.2 *Protection Against Falling Objects*

11.2.1 If the work involves hazards from flying or falling objects, one or more of the following safety measures should be implemented as appropriate:

- Control approach to the area
- Install a safety net
- Wear a hardhat
- Use measures to secure tools and parts used for the work

11.3 *Visual Hazard Warnings*

11.3.1 Barrier tape or another equivalent method to designate work areas involving fall hazards should be used, in addition to appropriate signage such as

“Passage Closed,” “Keep Out,” and/or “Watch Your Step.”

11.3.2 For work done from a standing height not lower than 1.5 meters or a height specified by regulation, mark the area along all of the sides with barrier tape and post appropriate signs where they are visible from all approaches to the area.

11.4 *Floor Openings*

11.4.1 If the work requires removal of floor panels, the area should be barricaded with a barrier that can support a person’s weight, or position an attendant next to the area to keep out unauthorized workers.

11.4.2 Appropriate measures (e.g., removing unnecessary materials from the work area, placing toe-boards around the opening) should be taken to prevent objects from falling into the opening.

11.4.3 Personnel below floor opening should be notified when work is being performed above them.

11.5 *Work Between Upper and Lower Floors*

11.5.1 For work on cables or piping between upper and lower floors, the worker should review the location and level of the hazards associated with the work with the facility operator.

11.5.2 Facility operators should insure workers on lower floors are protected from falling objects

11.5.3 Overhead work (e.g., utility connection activities) protection should be provided by engineering controls wherever possible.

11.5.3.1 When engineering controls are not feasible, alternative protection such as PPE (e.g., hardhats) should be provided.

11.5.3.2 Personnel should be notified when work is being performed above them.

11.5.4 When work is performed between the upper and lower floors, the worker should be secured with a safety harness and wear a hardhat to protect against falling objects.

11.5.4.1 If wearing a safety harness and hardhat increases hazards to the worker, alternative means of providing safe work conditions should be identified.

11.6 *Mechanical Hazards*

11.6.1 Prior to the installation, an appropriate equipment transfer method should be established by reviewing the installation manual or other available documents for applicable procedures or pertinent information (e.g., equipment weight, equipment sling method, lift position, and equipment anchorage method). If the installation work warrants, appropriately qualified personnel should perform the work.

11.6.2 Prior to operation, workers should be aware of any moving parts and the potential for accidental contact with them.

11.6.3 If a teaching operation is required for a robot or other system, the operation should be performed in accordance with the procedure specified in the maintenance manual or other appropriate documents.

11.6.4 Prior to maintenance, all potential hazards (e.g., pinch point hazard, mechanical crush hazard) should be identified by reviewing the maintenance manual or other available documents.

11.6.5 Prior to the disposal or disassembly of equipment, workers should be aware of all remaining mechanical hazards. This may be achieved with the use of the job or process hazard analysis.

11.7 *Ergonomic Hazards*

NOTE 32: Refer to SEMI S8, the NIOSH lifting guide or other ergonomic protection documents for guidance on whether safe lifting for performing a specific task requires two persons or requires mechanical lifting assistance.

11.7.1 Workers required to lift heavy or bulky items should be aware of the weight and size of the object before performing the lift.

11.7.2 When performing tasks in awkward positions, the duration of the task should be reduced to an appropriate length of time with adequate rest taken between each task.

12 Personal Protective Equipment

12.1 This section describes guidelines for personal protective equipment (PPE) to protect workers from potential hazards associated with semiconductor manufacturing equipment.

12.1.1 Facility operators and employers are jointly responsible for ensuring that workers wear PPE when necessary. (Refer to Appendix 2 for examples of PPE selection for protection against each type of hazard.)

NOTE 33: Some jurisdictions require employer to provide its employee with PPE. This may require that supplier employer to provide PPE for their employees working at user’s site with concurrence of the end user or facility operator.

NOTE 34: PPE in Europe must be CE-marked according to PPE directive 89/686/EEC.

12.1.2 Employers should properly train their workers in the purpose, benefits, limitations, proper use, storage, inspection, and maintenance of their PPE.

12.1.3 Facility operators should provide appropriate PPE to all employees and should recommend appropriate PPE to all non-employees when user specific process or site conditions create hazards.

12.2 *Chemical PPE*

12.2.1 Chemical PPE should be inspected by each person before each use to ensure it is not contaminated, deteriorated or damaged.

12.2.2 Chemical PPE should not be reused except when designed for reuse (e.g., safety glasses face, shields). Most PPE is designed to be single-use disposable and should be changed when contamination or deterioration is suspected.

12.3 *Eye Protection*

12.3.1 Protective eyewear should be selected based on the hazards expected to be encountered and the type of work to be performed.

12.3.2 Safety glasses, goggles and face shields should be provided and worn to protect the eyes from chemical splash, dust, electrical arc, and flying fragments.

12.3.2.1 Eye protection for electrical arc flash should be selected based on the calculated available fault energy.

NOTE 35: Certain jurisdictions may require hard side shields on safety glasses.

12.3.3 Laser goggles should be selected based upon the appropriate standards that apply, such as JIS C 6802, EN207, EN208, ANSI Z 136.1, or ANSI B11.21.

12.4 *Body Protection*

12.4.1 Protective aprons, sleeves, and full body clothes should be worn to protect the body and/or extremities from contact with hazards (e.g., hazardous chemicals, materials, electrical arc, or other substances).

12.4.2 When handling or transferring hazardous materials such as acids, bases, or organic solvents, the worker should wear a protective apron or clothes. The protective aprons and clothes should not inhibit the safe performance of workers.

12.4.3 PPE rated for protection from electrical arc/flash (e.g., hoods with shoulder coverings) can also be classified as body protection.

12.4.4 PPE for skin protection should be provided and worn when the fault energy calculation indicates the potential for exposure to ultraviolet or infrared radiation.

12.5 *Hand Protection*

12.5.1 When handling hazardous chemicals, the worker should wear gloves that the employer has selected to provide appropriate protection against exposure to the chemical in use.

NOTE 36: Certain jurisdictions will require analysis of chemical degradation, permeation and penetration testing data to establish safe working periods.

12.5.2 Gloves should be selected to ensure adequate grip.

12.5.3 Thin gloves are preferable when considering comfort and dexterity but may develop pinholes and tear easily. A worker should inspect the gloves for pinholes prior to wearing them.

12.5.4 PPE for hands for EEW should be selected per applicable standards for the voltage and arc/flash potential exposed to.

12.5.5 Hand protection against extreme temperature and sharp objects should be provided.

12.6 *Foot Protection*

12.6.1 When a worker handles heavy objects, or there is danger of foot injuries from falling or rolling objects, or the possibility of piercing the sole exists, the worker should wear safety shoes that provide appropriate safety features for toes, metatarsal bones, arch, and other parts of the foot.

12.6.2 Safety shoes may need to provide features such as:

- Non-slip or non-skid soles
- Insulation from electrical shock
- Chemical or oil resistance

12.7 *Respiratory Protection*

12.7.1 Respirators should be provided and worn when there is a possibility of an unacceptable exposure from dusts, fumes, mists, gases, smoke, or vapors.

12.7.2 Specific hazards should be identified and evaluated prior to determining the type of respiratory protection needed. A qualified person should reasonably estimate the worker's exposure to the respiratory hazards in the evaluation.

NOTE 37: SCBA (Self-Contained Breathing Apparatus), that supplies clean air via a cylinder worn on worker's back, may be required for highest protection.

12.7.3 An individual trained to assess respiratory capabilities or a regulation-defined person or entity should determine potential physical and mental effects on individuals who will wear respirators and state whether the individual can safely wear the respirator.

12.7.4 A qualified person should ensure that a respirator that provides an adequate fit and offers the most comfort is chosen for each worker.

12.7.5 A proper facepiece-to-face seal should be established each time the employee uses the respirator.

12.7.5.1 Respirator users should be capable of performing a fit check, cleaning the respirator, and distinguishing clean versus used respirators.

12.7.5.2 Respirators should be provided with a method of identifying their assigned user and who performs maintenance.

NOTE 38: Some jurisdictions require sealing of respirators in bags or another method of keeping the respirator clean.

12.7.6 If an air-purifying respirator is worn, workers need to be trained as to how often the canisters or cartridges should be changed.

12.7.7 A full-face type mask with a wide view should be used for a self-contained breathing apparatus or airline respirator system.

12.7.8 Respirators should be inspected prior to every use to ensure they are:

- in good working condition,
- pliable,
- free from damage, and
- not contaminated.

12.8 *Head Protection*

12.8.1 Hardhats that provide protection against impact and penetration should be worn in areas that may contain falling objects or bumping hazards.

12.8.2 A risk assessor should determine if head protection must provide protection from electrical shock in the situations.

12.9 *Hearing Protection*

12.9.1 Hearing protection is designed to protect ears from sound pressure hazards. In locations where workers can be exposed to excessive noise levels (greater than 80 dBA) that administrative or engineering controls cannot reduce, earplugs or muffs should be considered.

12.9.2 High audio noise should be monitored. Where potential exposure to hazardous levels of sound exists, hazard warnings should be posted, and appropriate PPE used.

NOTE 39: Protection may be required for impact noise that some equipment (pumps) generate (deep thumping noises). Consult a noise specialist if this situation arises.

13 Emergency Preparation and Managing Abnormal Situations

13.1 All workers in a facility (whether employees or temporary workers supplied under contract) should be trained in recognizing and responding to abnormal situations.

13.2 Suppliers should have their own procedures for managing abnormal situations, that may be expected, in association with the equipment the supplier manufactures.

13.2.1 Supplier employers should develop an emergency response plan for their own workers. Emergency response procedures and the methods of communication to be used in an emergency should be tested to evaluate their effectiveness and communicated to all supplier employees.

13.2.2 Supplier employers and facility operators should coordinate information to ensure both supplier employees and facility operators understand any expected actions.

13.2.3 Facility operators should have their own procedures for managing abnormal situations that may be expected from problems within the facility or from combinations of equipment conditions.

13.2.3.1 Such procedures should be based on hazard analyses and risk assessments conducted under reasonably foreseeable abnormal conditions.

13.2.4 Facility operators should make pertinent information such as emergency contact methods and phone numbers available.

13.2.5 Allowable or prohibited actions by supplier personnel and the proper chain of command for reporting emergencies should also be included.

13.2.6 Responders should be trained on the use of the plan and their specific responsibilities during an emergency.

13.2.7 All workers (both employees and outsiders) should be trained in contacting the emergency team, and safe evacuation of the area.

13.2.8 Workers who are not trained, should not be allowed to perform emergency response actions for which they have not had training.

13.3 Toxicity information (for materials provided by either the supplier or the user) should be readily available for communication to infirmaries, clinics, hospitals or other treatment facilities or personnel that may be requested to treat persons affected by abnormal conditions at the facility.

13.4 Members of any on-site responding organization (such as emergency response teams (ERTs)) should be trained on the use of the emergency response plan, and all other procedures for which they are designated responders.

13.4.1 Responders should not perform actions for which they have not been trained.

13.4.2 If on-site responders are not provided, facility operators should make provisions according to the regulations for the location and should notify all supplier employers about the extents and limits of such response provisions.

NOTE 40: Some jurisdictions require trained on-site responders at each facility. Other jurisdictions specify that only local authorities (e.g., fire departments, hazardous materials units, police) can respond to emergency situations. Certain jurisdictions allow employers to choose whether they train their employees to respond to emergencies or if they will depend upon local authorities for emergency response. Each employer should understand the requirements of each specific jurisdiction in which they will perform work.

13.4.2.1 An example of an organization that offers emergency medical training and certification is the Red Cross.

APPENDIX 1
CHEMICAL CATEGORIES AND ANTICIPATED HAZARDS BY CATEGORY

NOTICE: The material in this appendix is an official part of SEMI S21.

Table A1-1 Chemical Category and Hazards

	Description	*Hazard*	*Examples*
Compressed Gas	High pressure cylinder gas	Potential for rapid, dangerous release of contents	Argon, hydrogen, chlorine
Cryogen	Liquefied gas stored around –200° C	Frostbite/freezing tissue	Liquid oxygen, liquid nitrogen
Corrosives	Acids, bases, and some oxidizers	Burns, irritation, visible destruction or change to living tissue	Hydrochloric acid, hydrogen bromide, ammonium hydroxide
Solvents	A liquid used to dissolve or clean other materials that can produce flammable vapors	Fire, explosion	Isopropyl alcohol, acetone
Flammable gases	Can burn easily if ignited	Fire, explosion	Arsine, hydrogen
Pyrophoric gases	Gases which may ignite spontaneously upon contact with air	Fire, explosion	Silane, phosphine
Poisons	Any substance that produces a harmful effect when introduced to the body	Serious illness or death	Phosphine, diborane, arsine
Inert Gas	Non-corrosive, non-toxic and non-flammable	Simple asphyxiant	Nitrogen, argon
Oxidizers	React energetically with reducing agents	Violent reactions when mixed with other chemicals; can enhance fire	Nitric acid, hydrogen peroxide, nitrous oxide
Irritants	Corrosives, solvents, oxidizers (effects depend on concentration)	Local inflammatory response to skin, eyes or respiratory tract	Hydrochloric acid, sodium hydroxide, hydrogen peroxide, acetone
Sensitizers	Any substance that can illicit an allergic reaction	Effects range from mild skin or respiratory reactions to anaphylactic shock and death	Uncured epoxies, ethylenediamine, isocyanates

APPENDIX 2
SELECTION OF PERSONAL PROTECTIVE EQUIPMENT

NOTICE: The material in this appendix is an official part of SEMI S21.

A2-1 Introduction

A2-1.1 This appendix provides specific technical information relating to Section 12. In general, it provides Personal Protective Equipment (PPE) recommendations for specific hazards.

A2-1.2 This appendix is intended to be used as a guide to select PPE along with Section 12.

Table A2-1 PPE Selection Matrix

<table>
<tr><th colspan="2"></th><th colspan="10">Personal Protective Equipment (PPE)</th></tr>
<tr><th colspan="2">Potential Hazard</th><th>Safety Glasses, Goggles</th><th>Face Shield</th><th>Aprons, Sleeves, or Full Body Suits</th><th>Gloves</th><th>Skin Protection</th><th>Safety Shoes</th><th>Respirator</th><th>Hardhat</th><th>Hearing Protection (earplugs or muffs)</th></tr>
<tr><td colspan="2">Chemical</td><td>R</td><td>R (if splash hazard)</td><td>R (if splash hazard)</td><td>R</td><td></td><td></td><td>R (based on hazard assess-ment)</td><td></td><td></td></tr>
<tr><td colspan="2">Energized Electrical</td><td>R</td><td>R (When proper for the available fault current)</td><td>R (When proper for the available fault current)</td><td>R (for high voltage – proper for the voltage)</td><td></td><td>R (Insulation -rated proper for the voltage)</td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Ionizing Radiation</td><td>R[*1]</td><td></td><td></td><td>R[*2]</td><td></td><td></td><td>R[*1]</td><td></td><td></td></tr>
<tr><td rowspan="4">Non-ionizing Radiation</td><td>UV</td><td>R[*4]</td><td></td><td></td><td></td><td>R[*5]</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Visible</td><td>R[*4]</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>IR</td><td>R[*3, 4]</td><td></td><td></td><td></td><td>R[*5]</td><td></td><td></td><td></td><td></td></tr>
<tr><td>RF</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Noise</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>R (at levels >80 dBA)</td></tr>
<tr><td colspan="2">Extreme Temperatures</td><td></td><td></td><td>R</td><td>R</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Falling Objects, Bumping Hazards</td><td>R</td><td></td><td></td><td></td><td></td><td>R</td><td></td><td>R</td><td></td></tr>
<tr><td colspan="2">Mechanical</td><td>R</td><td></td><td></td><td>R</td><td></td><td></td><td></td><td>R</td><td></td></tr>
<tr><td colspan="2">Manual Handling</td><td></td><td></td><td></td><td>R</td><td></td><td>R</td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Oxygen Deficiency</td><td></td><td></td><td></td><td></td><td></td><td></td><td>R</td><td></td><td></td></tr>
</table>

“R” indicates “Recommended”.

Note 1: Goggles and respirator should be worn if the sources are not isolated or exhausted, and are of a nature that they could enter the eye or be inhaled.

Note 2: Gloves should be used if radioactive sources that are not sealed are being handled.

Note 3: Protective filters should be considered for long-term viewing (> 10 seconds). Where visible light doesn’t elicit the aversion response.

Note 4: Specific protection recommendations for laser radiation above the maximum permissible exposure (MPE).

Note 5: Skin protection should be used for all exposed areas including head and neck.

NOTICE: SEMI makes no warranties or representations as to the suitability of the safety guidelines set forth herein for any particular application. The determination of the suitability of the safety guidelines is solely the responsibility of the user. Users are cautioned to refer to manufacturer' s instructions, product labels, product data sheets, and other relevant literature, respecting any materials or equipment mentioned herein. These safety guidelines are subject to change without notice.

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SEMI S22-1103a
SAFETY GUIDELINE FOR THE ELECTRICAL DESIGN OF SEMICONDUCTOR MANUFACTURING EQUIPMENT

This safety guideline was technically approved by the global Environmental Health and Safety Committee. This edition was approved for publication by the global Audits and Reviews Subcommittee on April 7, 2005. It was available at www.semi.org in June 2005 and on CD-ROM in July 2005. Originally published November 2003.

NOTICE: This document contains material that has been balloted and approved by the SEMI Environmental Health and Safety Committee, but is not immediately effective. This material and the date on which it becomes effective are included in Delayed Revisions Sections 1 and 2. The provisions of this information are not an authoritative part of the document until their effective dates. The main body of SEMI S22-1103a remains the authoritative version. Some or all of the provisions of revisions not yet in effect may optionally be applied prior to the effective date, providing they do not conflict with portions of the authoritative version other than those that are to be revised or replaced as part of the deferred change, and are labeled accordingly. Material that is to be replaced by revisions that are not yet in effect is preceded by a NOTICE indicating its status.

NOTICE: Paragraphs entitled "NOTE" are not an official part of this document and are not intended to modify or supercede it.

NOTICE: Conformance to the "should" provisions of this guideline is necessary to declare conformance to this document. Conformance to "may", "suggested", "preferred", "recommended", "NOTE", or "Related Information" provisions is not necessary to declare conformance.

1 Purpose

1.1 This guideline provides a set of design based electrical safety considerations for production equipment used in the semiconductor industry.

1.2 Basic product safety concerns can be addressed by satisfying the design, construction, and testing principles set forth in this document or by satisfying the requirements of applicable electrical safety standards.

2 Scope

2.1 This safety guideline applies to semiconductor manufacturing equipment.

2.2 This document contains the following:

1. Purpose
2. Scope
3. Limitations
4. Reference Standards
5. Terminology
6. Alternate Methods of Conformity
7. Design Philosophy
8. General Considerations
9. Facilities Electrical Connection
10. Protection Against Electric Shock
11. Protection Against Risk of Electrical Fire
12. Bonding to the Protective Conductor
13. Safety Circuits

14. Interface Control
15. Electrical Enclosures
16. Conductors and Cables
17. Wiring Practices
18. Electric Motors ¼ Horsepower and Larger
19. Accessories and Lighting
20. Markings
21. Technical Documentation
22. Testing

2.3 Included in this safety guideline are design considerations for electrical safety interlocks that protect against electrical as well as non-electrical safety hazards; and non-electrical interlocks that protect against electrical safety hazards.

2.4 This document applies to the electrical design for all equipment used to manufacture, measure, assemble, and test semiconductor products unless the equipment is specifically excluded. See Section 3, Limitations.

NOTE 1: This safety guideline is most useful for semiconductor manufacturing equipment where no relevant product safety standard exists.

2.5 This safety guideline applies to equipment intended to be powered by hazardous voltages or hazardous electrical power.

NOTE 2: The official values in this guideline are expressed in the International System of Units (SI). Values that:

a) are expressed in Inch-Pound (also known as "US Customary" or "English") units,

b) are enclosed in parentheses, and

c) directly follow values expressed in SI units

are not official, are provided for reference only, and might not be exact conversions of the SI values.

NOTICE: This safety guideline does not purport to address all of the safety issues associated with its use. It is the responsibility of the users of this safety guideline to establish appropriate safety and health practices and determine the applicability of regulatory or other limitations prior to use.

3 Limitations

3.1 This safety guideline does not apply to equipment, subassemblies, and components that have been certified by an accredited testing laboratory and used within their certification parameters, or that conform to a relevant international or national product safety standard as defined by the scope of that standard.

NOTE 3: Criteria for jurisdictional acceptance may vary and should be taken into account although it is beyond the scope of this document.

3.2 This safety guideline is not intended to address any requirements pertinent to explosive atmospheres, hazardous locations, and/or hazardous process materials.

3.3 This safety guideline does not apply to support equipment that is an integral part of the facility, such as facility air conditioning, facility fire detection or fire extinguishing systems, or facility power distribution systems, which include motor-generator sets and transformers.

3.4 This safety guideline does not include design specifications for performance or functional characteristics of the equipment.

4 Referenced Standards and Documents

4.1 *SEMI Standards*

SEMI E33 — Specification for Semiconductor Manufacturing Facility Electromagnetic Compatibility

SEMI S1 — Safety Guideline for Equipment Safety Labels

SEMI S2 — Environmental, Health and Safety Guideline for Semiconductor Manufacturing Equipment

SEMI S3 — Safety Guidelines for Heated Chemical Baths

SEMI S8 — Safety Guideline for Ergonomics Engineering of Semiconductor Manufacturing Equipment

SEMI S10 — Safety Guideline for Risk Assessment and Risk Evaluation Process

SEMI S13 — Safety Guideline for Operation and Maintenance Manuals Used with Semiconductor Manufacturing Equipment

SEMI 14 — Safety Guidelines for Fire Risk Assessment and Mitigation for Semiconductor Manufacturing Equipment

4.2 *IEC Standards*[1]

IEC 60112 — Method for determining the comparative and the proof tracking indices of solid insulating materials under moist conditions

IEC 60204-1 — Safety of Machinery - Electrical Equipment of Machines, Part 1: General Requirements

IEC 60417 — Graphical Symbols for Use on Equipment

IEC 60707 — Flammability of solid non-metallic materials when exposed to flame sources - List of test methods

IEC 60950 — Safety of Information Technology Equipment

IEC 61010-1 — Safety Requirements for Electrical Equipment for Measurement, Control, and Laboratory Use — Part 1: General Requirements

IEC 61346-1 — Industrial systems, installations and equipment and industrial products - Structuring principles and reference designations

4.3 *European Documents*[2]

4.3.1 *CENELEC Standards*

EN 60529 — Degrees of Protection Provided by Enclosures

EN 61508 — Functional Safety of Electrical/electronic/programmable Electronic Safety-related Systems

4.3.2 *European Commission Directives*

89/336/EEC — Directive on Electromagnetic Compatibility

4.4 *NFPA Standards*[3]

NFPA 70 — National Electrical Code

NFPA 79 — Electrical Standard for Industrial Machinery

4.5 *UL Standards*[4]

UL 94 — Tests for Flammability of Plastic Materials for Parts in Devices and Appliances

UL 943 — Standard for Ground-Fault Circuit- Interrupters

1 International Electrotechnical Commission 3, rue de Varembé, Case Postale 131, CH-1211 Geneva 20, Switzerland. Telephone: 41.22.919.02.11; Fax: 41.22.919.03.00

2 European Union http://europa.eu.int/

3 National Fire Protection Association, 1 Batterymarch Park, PO Box 9101, Quincy, MA 02269-9101

4 Underwriters Laboratories Inc., 333 Pfingsten Rd, Northbrook, IL 60062

4.6 *ANSI Standards*[5]

ANSI/IPC 2221 Generic Standard on Printed Board Design

ANSI/ISA S84.01 Application of Safety Instrumented Systems for the Process Industries

4.7 *ISOStandards*[6]

ISO 13849-1 — Safety of Machinery – Safety-related Parts of Control Systems – Part 1: General Principles For Design

NOTICE: Unless otherwise indicated, all documents cited should be the latest published versions.

5 Terminology

5.1 *Definitions*

5.1.1 *access* — a means of approaching or touching.

5.1.2 *accessible* — having or allowing access, see definition of access.

5.1.3 *accredited testing laboratory* — an independent organization dedicated to the testing of components, devices, or systems; competent to perform evaluations based on established safety standards; and recognized by a government or regulatory body.

5.1.4 *ampacity* — the current, in amperes, that a conductor can carry continuously under the conditions of use, without exceeding the design limits for the temperature rating of the insulation, the conductor and the wire termination.

5.1.5 *basic insulation* **—** provides a single layer of protection against electric shock.

5.1.6 *bonding (bonded)* — the permanent joining of metallic parts to form an electrically conductive path that ensures electrical continuity and the capacity to conduct safely any current likely to be imposed. See *protective earthing system.*

5.1.7 *clearance distance* — the shortest path between two conductive parts normally carrying current, or between a conductive part normally carrying current and a conductive part that is connected to the protective earthing system, measured through air.

5.1.8 *Comparative Tracking Index (CTI)* — the value obtained in accordance with Method A of IEC 60112 which determines the Material Group of a printed wiring board. Where the CTI or material group is not known, Material Group IIIb should be used.

5.1.9 *conduit* — a part of a closed wiring system of circular or non-circular cross-section for insulated conductors and/or cables in electrical installations, allowing them to be drawn in and/or replaced.

5.1.10 *control device (of a machine)* — a device connected into the control circuit and used for controlling the operation of the machine (e.g. position sensor, manual control switch, relay, magnetically operated valve, etc.).

5.1.11 *convenience receptacle* — an electrical outlet provided on the equipment, which does not have any load connected to it during the normal operation of the equipment, but is intended by the equipment manufacturer to be used to power a piece of maintenance or service equipment.

5.1.12 *cord connected equipment* — equipment that is intended to be electrically connected to an electric supply by means of a flexible supply cord and attachment plug.

5.1.13 *creepage distance* — the shortest path between two conductive parts normally carrying current or between a conductive part normally carrying current and a conductive part that is bonded to the protective earthing system, measured along the surface of the insulation.

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5 American National Standards Institute, Headquarters: 1819 L Street, NW, Washington, DC 20036, USA. Telephone: 202.293.8020; Fax: 202.293.9287, New York Office: 11 West 42nd Street, New York, NY 10036, USA. Telephone: 212.642.4900; Fax: 212.398.0023, Website: www.ansi.org

6 International Organization for Standardization, ISO Central Secretariat, 1, rue de Varembé, Case postale 56, CH-1211 Geneva 20, Switzerland. Telephone: 41.22.749.01.11; Fax: 41.22.733.34.30, Website: /www.iso.ch

5.1.14 *disconnecting means* — a device, or group of devices, or other means by which the conductors of a circuit are intended to be disconnected from their source of supply.

5.1.15 *door* — a hinged enclosure panel.

5.1.16 *double insulation* — comprised of both supplementary insulation and basic insulation combined.

5.1.17 *duct* — an enclosed channel designed expressly for holding and protecting electrical conductors, cables, and bus bars. Conduits, wireways and under-floor channels are types of ducts.

5.1.18 *earthing* — see *protective earthing system*.

5.1.19 *electrical enclosure* — a panel, compartment, or other defined area housing electrical components used to enhance the safety of the equipment containing those components.

5.1.20 *electrical feed* — (referenced from the equipment) a facility supply conductor that provides electrical energy to a piece of equipment.

NOTE 4: Electrical wiring from enclosure to enclosure, routed through the facility, but provided with the equipment to power subsystems, are not considered electrical feeds.

5.1.21 *energized* — electrically connected to a source of voltage.

5.1.22 *equipment* — a specific piece of machinery, apparatus, process module, or device used to execute an operation. The term “equipment” does not apply to any product (e.g., substrates, semiconductors).

5.1.23 *exposed (as applied to energized parts)* — capable of being inadvertently touched or approached nearer than a safe distance by a person. It is applied to parts that are not suitably guarded, isolated, or insulated.

5.1.24 *fail-safe* — designed so that a failure does not result in an increased risk.

NOTE 5: For example, a fail-safe temperature limiting device would indicate an out-of-control temperature if it were to fail. This might interrupt a process, but would be preferable to the device indicating that the temperature is within the control limits, regardless of the actual temperature, in case of a failure.

5.1.25 *Fail-to-safe equipment control system (FECS)* — a safety-related programmable system of control circuits designed and implemented for safety functions in accordance with recognized standards such as ISO 13849-1 (EN 954-1) or IEC 61508, ANSI SP 84. These systems (e.g. safety Programmable Logic Controller (PLC), safety-related Input and output (I/O) modules) diagnose internal and external faults and react upon detected faults in a controlled manner in order to bring the equipment to a safe state.

NOTE 6: A FECS is a subsystem to a (PES) Programmable Electronic System as defined in IEC61508 –4.

5.1.26 failure — the termination of the ability to perform an intended function. Failure is an event, as distinguished from “fault,” which is a state.

5.1.27 *fault* — the state of an item characterized by the inability to perform its intended function; excludes the inability to perform required functions during preventive maintenance or other planned actions, or due to lack of external resources.

5.1.28 *fault-tolerant* — designed so that a reasonably foreseeable single point failure does not result in an unsafe condition.

5.1.29 *ground fault* — an unintentional, electrically conducting connection between an ungrounded or grounded conductor of an electrical circuit and the normally non-current-carrying conductors, metallic enclosures, metallic raceways, or metallic equipment.

5.1.30 *Ground-Fault-Circuit-Interrupter (GFCI)* — a device intended for the protection of personnel that functions to de-energize a circuit or portion thereof within an established period of time when a current to ground exceeds a value in the range of 4 mA to 6 mA (for further information, see UL 943, Standard for Ground-Fault Circuit-Interrupters).

5.1.31 *grounding* — see *protective earthing system.*

5.1.32 *hazard* — a condition that is a prerequisite to a mishap.

5.1.33 *hazardous voltage* — voltages greater than 30 Volts RMS, 42.4 Volts peak, or 60 Volts DC.

5.1.34 *hazardous electrical power* — power levels equal to or greater than 240VA.

5.1.35 *insulation* — a layer of non-conductive material used as the outer surface of a conductor for the purpose of protecting against electric shock.

5.1.36 *interlock* — a mechanical, electrical or other type of device or system, whose purpose is to prevent or interrupt the operation of equipment subsystems under specified conditions.

5.1.37 *interrupting capacity* — the highest current at rated voltage that a device is intended to interrupt.

NOTE 7: Also known as amperes interrupting capacity (AIC).

5.1.38 *isolated power system* — a power system that has a high impedance between its conductors and the facilities connection of the equipment. High impedance can be characterized by resistances of one meg-ohm or more. Isolated power systems are supplied power by isolation transformers or power supplies that have no direct electrical connection between their primary conductors and their secondary conductors.

NOTE 8: An isolation transformer with one leg of the secondary connected to ground is not an isolated power system.

5.1.39 *main disconnecting means* — a disconnecting means that is intended to be used to disconnect facilities electrical power from the system.

5.1.40 *maintenance* — planned activities intended to keep equipment in proper working order (see also the definition for service).

5.1.41 *material group* — a categorization of the Comparative Tracking Index (CTI) of an insulator as follows:

- Material Group I: 600 <= CTI
- Material Group II: 400 <= CTI < 600
- Material Group IIIa: 175 <= CTI < 400
- Material Group IIIb: 100 <= CTI < 175

5.1.42 *maximum nominal load* — the maximum continuous power a circuit will draw under operating conditions prescribed by the manufacturer. Non-periodic power variations of less than a second in duration are not considered continuous.

5.1.43 *multi-outlet assemblies* — assemblies whose primary function is to provide electrical connections and that have multiple receptacles which are intended for electrical connections.

5.1.44 *neutral conductor* — an earthed (grounded) AC current carrying conductor.

NOTE 9: It is distinct from protective earthing which is an earthed (grounded) non-current carrying conductor or a non-earthed (non-grounded) current carrying conductor.

5.1.45 *normal operating conditions* — the condition of the equipment reasonably foreseen by the manufacturer, including specified conditions of use, during operation, maintenance and servicing while the equipment is operated, maintained and serviced according to the manufacturer's instructions and with no unauthorized equipment modifications. Normal operating conditions should include consideration of reasonably foreseeable misuse.

5.1.46 *operator* — a person who interacts with the equipment only to the degree necessary for the equipment to perform its intended function.

5.1.47 *operator access* — an area to which, under normal operating conditions, one of the following applies: access may be gained without the use of a tool, the means of access is deliberately provided to the operator, or the operator is instructed to enter regardless of whether or not a tool is needed to gain access (if the operator is so instructed, this area becomes evaluatable as an operator accessible area).

5.1.48 *overcurrent* — any current in excess of the rated current of the equipment or the rated ampacity (current-carrying capacity) of the conductor; it may result from overload, short circuit, or ground fault.

5.1.49 *overload* — operation of equipment in excess of normal, full-load rating, or of a conductor in excess of rated ampacity that, when it persists for a sufficient length of time, would cause damage or dangerous overheating. A fault, such as a short circuit or ground fault, is not an overload (see *short circuit* and *ground fault*).

5.1.50 *permanently connected equipment* — equipment that is electrically connected to a supply by means of a connection that may be detached only by the use of a tool.

5.1.51 *pollution* — any addition of foreign matter, solid, liquid or gas, that may produce a reduction of dielectric strength or increase of surface resistivity.

5.1.52 *pollution degree* — for the purpose of evaluating clearances the following two degrees of pollution in the micro-environment are recognized for use with this document:

5.1.52.1 *pollution degree 1* — no pollution or only dry, non-conductive pollution occurs. The pollution has no influence. Cleanroom Class 1000 or less.

NOTE 10: Cleanroom Class 1000 or less is pollution degree 1, however the pollution degree in a particular area in a given piece of equipment may exceed pollution degree 1, even if the equipment is installed in a cleanroom class 1000 or less.

5.1.52.2 *pollution degree 2* — normally only non-conductive pollution occurs. Occasionally, however, a temporary conductivity caused by condensation is expected. Cleanroom Class greater than 1000.

NOTE 11: Cleanroom Class greater than 1000 is pollution degree 2, however the pollution degree in a particular area in a given piece of equipment may exceed pollution degree 2, even if the equipment is installed in a cleanroom greater than 1000.

5.1.53 *protective conductor* — a conductor that provides electrical continuity between conductive components that are not intended to be energized during normal operations and the equipment's protective earthing conductor terminal.

5.1.54 *protective earthing conductor* — a normally non-current carrying conductor connected between earth (ground) at the source of supply and the protective earthing (grounding) terminal on the equipment enclosure.

5.1.55 *protective earthing conductor terminal* — a terminal bonded to conductive parts of an equipment enclosure for safety purposes and intended to be connected to an external protective earthing (grounding) conductor (the protective earthing conductor).

5.1.56 *protective earthing system* — the earthing (grounding & bonding) system connecting accessible conductive parts of the equipment to an external earth (ground) at the source of supply. The protective earthing system may include bonded structural members, bonding jumpers, the protective earthing conductor terminal on the equipment and the protective earthing conductor in the incoming supply wiring to the equipment.

5.1.57 *raceway* — an enclosed channel of metal, or nonmetallic materials, designed expressly for holding wires, cables, or busbars.

5.1.58 *readily accessible* — capable of being reached quickly for operation or inspection, without requiring climbing over or removing obstacles or using portable ladders, chairs, etc.

5.1.59 *reinforced insulation* — a single layer of insulation that provides a degree of protection against electric shock equivalent to double insulation.

5.1.60 *risk* — the expected losses from a mishap, expressed in terms of severity and likelihood.

5.1.61 *safe shutdown condition* — a condition in which all hazardous energy sources and hazardous production materials are removed or suitably contained, unless this results in additional hazardous conditions.

5.1.62 *safety circuit* — a circuit whose intended function is to make the equipment safer. Interlocks, EMO circuits, and other protective circuits are safety circuits.

5.1.63 *service* — unplanned activities intended to return equipment that has failed to proper working order (see also *maintenance*).

5.1.64 *severity* — the extent of the worst credible loss (damage, injury, or release) from a mishap caused by a specific hazard.

5.1.65 *supplementary insulation* — applied to basic insulation in order to ensure protection against electric shock in the event of the failure of basic insulation.

5.1.66 *testing* — measurements or observations used to validate and document conformance to designated criteria.

5.1.67 *tool* — an external device used to aid a person to perform a mechanical function.

5.1.68 *types of electrical work* — defined by the electrical energy levels a person is exposed to when performing a task. All tasks that should be performed on a system fall into one of the four following type categories of electrical work:

5.1.68.1 *type 1* — equipment is fully de-energized.

5.1.68.2 *type 2* — equipment is energized. Energized circuits are covered or insulated with no exposed parts.

NOTE 12: Type 2 work includes those tasks where the energized circuits are, or may be, measured by placing probes through suitable openings in the covers or insulators.

5.1.68.3 *type 3* — equipment is energized. Energized circuits are exposed and inadvertent contact with un-insulated energized parts is possible. Potential exposures are not greater than 30 Volts rms, 42.4 Volts peak, 60 Volts DC, and 240 volt-amps in dry locations.

5.1.68.4 *type 4* — equipment is energized. Energized circuits are exposed and inadvertent contact with un-insulated energized parts is possible. Potential exposures are greater than 30 Volts rms, 42.4 Volts peak, 60 Volts DC, 240 volt-amps in dry locations, or where induced or contact radio-frequency currents exceed the limits in SEMI S2.

5.1.69 *wire guide* — any method of mechanically securing wire or cable into a restrictive routing.

6 Alternate Methods of Conformity

6.1 The criteria in this document are based on harmonized basic electrical safety considerations. It is not the intent of this document to be the only means of demonstrating the electrical safety conformance of semiconductor manufacturing equipment.

6.2 Equipment that satisfies other national or international electrical product safety standards meets the intent of this document.

7 Design Philosophy

NOTE 13: This section is intended to provide general design guidance to engineers; for specific design considerations see §8 through §22.

7.1 This document should be used during the electrical design, construction, and evaluation phases of semiconductor manufacturing equipment. The intent of this safety guideline is to provide a design based electrical document that will be useful to both design engineers and evaluators, in order to facilitate electrical safety in the equipment.

7.2 Designers that understand these general principles of safety are more likely to design safe equipment. This section is not an alternative to the more specific engineering considerations of this safety guideline, but is intended to provide designers with an appreciation of the basic safety principles.

7.3 Electric shock is due to current passing through the human body. Currents on the order of a milliampere may cause a reaction in people in good health, and may cause indirect mishap due to involuntary reactions. Higher currents may have higher severity risks.

7.4 Design of equipment should provided protection of personnel from electric shock or arc flash/blast that may result from reasonably forseeable single faults.

7.5 Service and maintenance personnel should be protected against inadvertent contact with electrical hazards.

7.6 Movable cord-connected equipment is considered to present a slightly increased risk of shock as well as overheating, due to strain on the supply cord leading to damage to the connections, insulation, and the protective earthing conductor. With portable cord-connected equipment, wear on the cord is more likely, and further hazards could arise if the equipment were dropped.

7.7 Short-circuiting between phases and phase to ground of high current supplies or high capacitance circuits may cause arcing or ejection of molten metal which may cause burns. Even low voltage circuits may be dangerous in this respect. Protection should be provided by adequate separation, by shielding, or by using safety interlocks.

7.8 When temperatures that could cause a hazard result from overloads, component failure, insulation breakdown, high resistance or loose connections, the risk of fire may be reduced by one or more of the following means:

a) taking all reasonable steps to avoid high temperatures which might cause ignition;

b) controlling the position of combustible materials in relation to possible ignition sources;

c) limiting the quantity of combustible materials used;

d) using barriers, if necessary, to limit the spread of fire within the equipment beyond the immediate vicinity of the ignition source; and/or

e) using suitable materials for the outer fire enclosures of the equipment.

NOTE 14: SEMI S14 may also be used for guidance on fire risk mitigation.

NOTE 15: Some fire retardant components or materials may be restricted or banned in certain jurisdictions.

7.9 Equipment should be designed to prevent injury due to excessive (high or low) temperatures of parts; to ensure that the equipment is mechanically stable and structurally sound; to avoid the presence of operator accessible sharp edges and points; and to provide adequate guarding or safety interlocking of hazardous moving parts.

7.10 Materials used in the construction of equipment should be selected and arranged so that they may be expected to perform in a reliable manner, without a risk of energy hazard or electric shock developing, and such that they would not contribute significantly to the development of a significant fire hazard.

NOTE 16: Some electrical components such as relays, electrolytic capacitors, batteries, solder, cathode ray tubes, finished chassis, fluorescent lights and connectors may contain materials that are restricted or banned in certain jurisdictions.

8 General Considerations

8.1 The risks associated with the electrical design, construction, and operation of the equipment should be considered as part of the overall safety assessment of the equipment. This assessment should include a fault analysis with consideration given to, but not limited to, electric shock or fire and failures of components, subsystems, and systems.

8.2 The following are some of the types of faults that should be considered:

a) faults and failures in the equipment’s circuits, and

b) possible human error associated with operator, maintenance, and service activities.

NOTE 17: This is not intended to be a comprehensive list of all possible types of faults.

8.3 The order of precedence for resolving identified hazards and satisfying equipment safety considerations should be as follows:

a) design to eliminate hazards,

b) incorporate safety devices,

c) provide hazard alerts or warning signals, and finally

d) develop administrative procedures and training (administrative procedures may include the use of personal protective equipment).

A combination of these approaches can also be used.

NOTE 18: See SEMI S2 for additional information.

8.4 *Electrical Components*

8.4.1 Where failure of components and assemblies could result in an unacceptable increase in risk of electric shock, fire, or personnel injury, those components and assemblies should be certified by an accredited testing laboratory and used in accordance with the manufacturer’s specifications and conditions of the certification, or otherwise evaluated to the relevant component standard(s). This applies to components that handle hazardous voltage or hazardous electrical power or are used in a safety circuit.

NOTE 19: Reference SEMI S2 for discussions of acceptable risk.

8.4.2 Components should be provided with overcurrent protection in accordance with §11.

8.4.3 Components should be securely mounted according to the conditions of their certification, if applicable, and their manufacturer's instructions.

8.5 *Electrical Supply*

8.5.1 The equipment should be designed to operate safely when connected to its specified electrical supply.

8.5.2 Interruptions in the facilities electrical supply should not lead to an increased risk of fire, electric shock, or other hazardous conditions.

8.6 *Un-interruptible Power Supplies (UPS)* — This subsection applies to UPSs with outputs greater than 30 Volts rms, 42.4 Volts peak, 60 Volts DC or 240 Volt-Amperes (VA). Whenever a UPS is provided with the equipment, its location and wiring should be clearly described within the relevant manufacturer supplied documentation that covers installation and maintenance.

8.6.1 Power from the UPS should be interrupted when any of the following events occur:

a) the emergency off actuator (EMO button) is pushed; or

b) the equipment main disconnecting means is opened.

EXCEPTION: Upon emergency off (EMO) activation, the UPS may continue to supply power to the EMO circuit, safety related devices, and data/alarm logging computer systems as described in the exception clauses of ¶13.3.3.

8.6.2 The UPS may be physically located within the footprint of the equipment provided that the UPS is within its own electrical enclosure, which may be the enclosure provided with the UPS and considered in the certification of the UPS. The UPS circuits may also be supplied from a facility source outside of the equipment served. If this is the case, then all the considerations discussed for facilities main disconnecting means in §9 should be taken into account for power supplied to the UPS circuits.

8.6.3 The UPS should be certified by an accredited testing laboratory.

8.6.4 The UPS wiring and terminals should be identified as "UPS Supply Output", or equivalent, at each connection point where the UPS wiring may be disconnected.

8.7 *Operating Environment* — The electrical equipment should be suitable for the environment in which it is intended to be used.

8.8 *Electromagnetic Compatibility (EMC)* — A system malfunction, as a result of the presence of anticipated electromagnetic disturbances that will be present in the end use environment, should not result in an unacceptable risk. Products that are compliant with either SEMI E33 or the EMC Directive (89/336/EEC) are considered to be compliant with this criterion.

8.9 *Contaminants*

8.9.1 Electrical equipment should be adequately protected against the entrance of solid bodies and liquids likely to be present that may increase the risk of electric shock or fire as a result of a single-point failure or reasonably foreseeable operational error.

8.9.2 Electrical insulation should be protected against chemical environments that may lead to deterioration, or be capable of withstanding the environments to which it will be exposed.

8.10 *Ionizing and Non-ionizing Radiation* — Personnel should be adequately protected against the hazards associated with ionizing and non-ionizing radiation. Compliance to the ionizing and non-ionizing radiation sections of SEMI S2 serves as verification of compliance.

8.11 *Vibration, Shock, and Bump* — Protection should be provided against likely unsafe consequences from the effects of vibrations, shocks and bumps caused by operation of the equipment, or disturbances of this type that will be present in the semiconductor manufacturing, testing, and assembly environment.

NOTE 20: See the SEMI S2 seismic section for considerations.

8.12 *Transportation and Storage* — Packing for shipment should prevent damage from humidity, vibration, and shock that may affect the safety of the equipment.

EXCEPTION: Installation considerations for checking safety related aspects of the system that may be impacted during transportation and storage may be used instead of the packing stipulations of ¶8.12.

8.13 *Provisions for Handling* — Provisions for lifting and handling sub-systems that may cause injury when moved or lifted during maintenance or service should be provided and documented in the system manuals. See SEMI S8 for further information.

8.14 *Lockout (electrical energy isolation)* — Lockable energy isolation devices should be designed into equipment to provide for safety during service and maintenance tasks. Where it is expected that it will be necessary or beneficial to work on separately operable parts of the equipment, a separate lockable energy isolation device may be provided for each such part.

8.15 *Suspension of Safeguards* — General energy isolation, local energy isolation, or safe work procedures should be used when there is a suspension of safeguards. These procedures should be defined in the maintenance manual.

9 Facilities Electrical Connection

9.1 *Incoming Supply Conductors*

9.1.1 Equipment should be designed to receive incoming electrical power from the facility to a single feed location which terminates on the specified main disconnecting means. This main disconnecting means, when opened, should remove all electrical power in the equipment from the load-side of the main disconnecting means.

EXCEPTION 1: Equipment with more than one electrical feed should be provided with provisions for energy isolation ("lockout") for each feed and be marked with the following text, or the equivalent, at each main disconnecting means: "WARNING: Risk of Electric Shock or Burn. Disconnect all [number of feed locations] sources of supply prior to servicing."

EXCEPTION 2: Multiple units mounted separately with no shared hazards and without interconnecting circuits with hazardous voltages, energy levels, or other potentially hazardous conditions may have: separate sources of power and separate supply circuit main disconnecting means; or separate EMO circuits, where all the above are clearly identified.

NOTE 21: If general lockout cannot be performed for a specific maintenance or service task the guidance in Section 8.15 should be followed.

9.1.2 Field installed supply conductors should be connected directly to the main disconnecting means with no connection to terminal blocks or other devices.

EXCEPTION: This does not apply where the plug of a cord is the main disconnecting means. However, if the plug of the cord is not the main disconnecting means then field installed supply conductors should be connected directly to the main disconnecting means with no connection to terminal blocks or other devices.

9.1.3 Terminals with hazardous potentials present after the main disconnecting means is placed in the "Off" isolation position should be identified with an appropriate hazard warning label. The label should be placed inside the electrical enclosure adjacent to the terminals.

9.1.4 The supply overcurrent protection should be rated adequately to protect components connected to the supply circuit that do not otherwise have adequate overcurrent protection.

9.1.5 The equipment should be provided with main overcurrent protection devices rated with an interrupting capacity of at least 10,000 rms symmetrical amperes interrupting capacity (AIC) for circuits rated 240VAC or less, and at least 14,000 rms symmetrical amperes interrupting capacity (AIC) for circuits rated more than 240VAC.

EXCEPTION 1: Cord connected single phase equipment, rated no greater than 2.4 kVA, may have overcurrent protection devices with an interrupting capacity of at least 5,000 rms symmetrical amperes interrupting capacity. When this exception is used, the installation manual should inform the user of the lower AIC protection provided by the equipment.

EXCEPTION 2: An equipment subsystem (e.g. mini-environment ventilation) rated no greater than 2.4 kVA, may have overcurrent protection devices with interrupting rating of at least 5,000 rms symmetrical amperes interrupting capacity (AIC).

9.1.6 *Identification of Facilities Connections*

9.1.6.1 Where a neutral conductor is used it should be clearly indicated in the equipment schematic drawings and the facilities supply connection should be labeled “N” or “Neutral”.

EXCEPTION: This marking is not necessary in cord connected equipment where the cord is not installed in the field.

9.1.6.2 At each incoming supply point, the protective earthing conductor terminal should be identified by the earthing symbol (see IEC 60417 symbol 5019). In addition to the earthing symbol, other appropriate letter designations may be applied (e.g. “PE”, “GND”).

9.1.6.3 Installation instructions should be provided for the correct identification and installation of the individual phases in a three phase system when the improper connection of phases could result in hazardous unintended rotation or sequence.

9.1.6.4 Each unearthed phase conductor in 3 phase AC power circuits should be clearly indicated in the equipment schematic drawings, and the facilities incoming supply connection should be identified with one of the following schemes adjacent to the input terminals:

a) “L1”, “L2”, and “L3",

b) “R”, “S”, and “T”, or

c) “A”, “B”, and “C”.

9.2 *Equipment Protective Earthing Connection*

9.2.1 A protective earthing conductor should enter the equipment in association with the incoming supply conductors.

9.2.2 The protective earthing conductor should be copper.

9.2.3 The protective earthing conductor should be sized in accordance with the tables in Appendix 1. See Appendix 1, Tables A1-1 through A1-5 for protective earthing conductor sizes.

9.2.4 The protective earthing conductor terminal should be dedicated for the sole purpose of connecting the protective earthing conductor to the equipment protective conductors and bonding system.

9.2.5 The protective earthing conductor and its connection to the protective earthing conductor terminal should also comply with the protective bonding section of this safety guideline (§12).

9.2.6 The protective earthing conductor should not be used as an intentional current carrying conductor for the power delivery circuit. Currents on the protective earthing conductor from EMC filters are permissible. The protective earthing conductor may also carry currents that result from incidental inductive and capacitive coupling.

9.2.7 There should be no connection between the supply neutral conductor and the protective earthing conductor or the protective earthing system inside the electrical equipment.

9.3 *Main Disconnecting Means*

9.3.1 The main energy isolation capabilities (equipment main disconnecting means) should be in a location that is readily accessible and should be lockable only in the de-energized position.

9.3.2 For equipment with multiple incoming electrical feeds, all of the main disconnecting means should be grouped in one area or a marking should be installed at each supply circuit main disconnecting means location indicating the number of all other supply circuit main disconnecting means.

NOTE 22: Grouping main disconnecting means in one area is preferred.

9.3.3 Supply conductor connections to the main disconnecting means should comply with one of the following:

a) the connections should be located in a separate electrical enclosure installed on or adjacent to the equipment enclosing the main disconnecting means only. Parts on the supply side of the main disconnecting means in the equipment which remain energized when the main disconnecting means is switched off should be guarded (finger-safe) to prevent accidental contact by service personnel; or

b) the connections should be located within the main electrical enclosure located near the top, with adequate bending space provided for supply conductor installation and no equipment located above the supply terminals. Parts on the supply side of the main disconnecting means in the equipment which remain energized when the main disconnecting means is switched off should be guarded (finger safe) to prevent accidental contact by service personnel; or

c) the connections should be located within the main electrical enclosure, where other equipment is mounted above the supply terminals. Parts on the supply side of the main disconnecting means in the equipment which remain energized when the main disconnecting means is switched off should be guarded to prevent accidental contact by service personnel or by a tool that may be dropped from above. The opening should be such that a 1-mm (0.04 inch) rod cannot come into contact with the energized parts.

EXCEPTION: Machines with a power consumption totaling 1492 Watts (2 HP) or less may be connected to a remotely mounted main disconnecting means through a flexible cord, cable, or conduit provided that the main disconnecting means is in sight from, readily accessible to, and no more than 6 m (20 feet) from the machine operator work station.

9.3.4 Wire bending space should be provided for the facility supply conductors at the main disconnecting means as specified by Appendix 1, Tables A1-1 through A1-5.

EXCEPTION: Equipment that meets the wire bending space requirements of NFPA 70 will also meet these criteria.

9.3.5 When placed in the off position the main disconnecting means should satisfy the following criteria:

a) All unearthed conductors of the supply circuit should be disconnected simultaneously.

b) Earthed conductors (neutral or grounded) should not be disconnected.

EXCEPTION: The earthed conductor (neutral) may be disconnected provided that it is disconnected simultaneously with the unearthed conductors.

NOTE 23: Some jurisdictions require disconnection of the earthed conductor (neutral).

9.3.6 The main disconnecting means should have a minimum of two marked positions, “Off” (isolated) and “On”. These positions should be clearly marked with IEC 60417 symbol 5008 for “Off” and IEC 60417 symbol 5007 for “On”.

9.3.7 The actuator of the equipment’s main disconnecting means should be readily accessible and a maximum of 2 meters above the standing surface, measured from the center of the grip.

9.3.8 Each facility main disconnecting means for the incoming electrical supply should be mechanically or electrically interlocked, or both, with the electrical disconnect enclosure door.

EXCEPTION 1: A main disconnecting means used only for maintenance of lighting circuits within electrical enclosures should not be interlocked with the electrical enclosure door. A hazard warning label should be provided when exposed parts may be energized within the main disconnect enclosure when the enclosure door is open.

EXCEPTION 2: Where an attachment plug is used as the main disconnecting means.

EXCEPTION 3: Where a remotely mounted main disconnecting means is provided, a tool is required to open the equipment enclosure door, and a hazard warning label is attached to the electrical enclosure warning of hazardous voltage inside and advising isolation of the power before opening.

EXCEPTION 4: The considerations stated in ¶9.3.8 do not apply to equipment rated less than 5KVA that has the other protections against electric shock stipulated in this document.

9.3.9 The main disconnecting means (lock-out) handle should not disengage from the main disconnecting means when the enclosure door is opened.

9.3.10 Interlocking should be provided between the main disconnecting means and its associated door to prevent both of the following:

a) closing of the main disconnecting means while the enclosure door is open, unless the interlock disconnecting power is overridden by a deliberate action (see §13), and

b) closing of the main disconnecting means until the door hardware is fully closed.

NOTE 24: A mechanical interlock is preferable to an electrical interlock.

9.4 *Cord and Plug Connections used as Facility Connection*

9.4.1 When a cord and plug connection is intended to be used as a main disconnecting means, it should either be capable of being under the exclusive supervision of the person carrying out the work, or be provided with a means for lockout (see discussion of conductors and cables in §16).

9.4.2 If a supply cord is provided with the system, the cord, as well as the installation instructions, should comply with applicable local codes where it will be installed, or the equipment should have provisions for hard wiring using a raceway.

9.4.3 If there are provisions for hard wiring, a cord and plug should not be used as a main disconnecting means.

9.4.4 If the cord and plug is used for the main disconnecting means the equipment should also have an on-off control.

NOTE 25: Uses preferred for cord and plug connection to the facility include:

a) equipment with an attachment plug and powered from a receptacle outlet to connect movable equipment to facilitate frequent interchange, and

b) the fastening means and mechanical connections of the equipment are designed to permit removal for maintenance or service.

NOTE 26: Materials are restricted by ¶16.3.1.

10 Protection Against Electric Shock

10.1 *General* — The electrical equipment should provide protection to persons against electric shock under normal operating conditions and under any reasonably foreseeable single fault condition.

10.2 *Protection Against Electric Shock During Normal Operation*

10.2.1 Where operator access to a hazardous voltage is controlled through the use of a grounded conductive or non-conductive enclosure, that enclosure should either:

1) require a tool to open and be labeled with the hazard against which it protects personnel, or

2) be interlocked.

Reference Jointed Finger Probe Access Test. Reference IEC61010-1 Annex B for the test finger.

NOTE 27: IEC 60529 “Degrees of Protection Provided by Enclosures” may be used as a reference.

10.2.2 Spacing between uninsulated energized parts and conductive enclosures should be maintained in compliance with Appendix 1 Tables A1-12 and A1-13 or determined to be adequate by dielectric testing in accordance with §22.

10.2.3 Energized parts protected by insulation should be completely covered with insulation that can be removed only by destruction. Such insulation should be capable of withstanding the mechanical, chemical, electrical, and thermal stresses to which it may be subjected under normal operation.

10.2.4 *Protection Against Electric Shock Hazards Resulting from Fault Conditions* — Use of measures to prevent the occurrence of a hazardous touch voltage may include one or more of the following:

a) Double or reinforced insulation may be used to prevent a hazardous touch voltage through contact with exposed conductive parts that results from the failure of basic insulation of the energized parts of that circuit,

b) Electrical separation (clearance and creepage) may be used to prevent a hazardous touch voltage through contact with exposed conductive parts that results from the failure of basic insulation of the energized parts of that circuit,

c) Automatic disconnection of the supply of any circuit affected by the occurrence of an insulation failure that results in a ground fault may be used to prevent contact with a hazardous voltage.

NOTE 28: See definition of GFCI.

10.3 *Maintenance and Service Personnel Potential Exposure to Hazards*

10.3.1 *Energized Electrical Work* — The equipment should be designed to minimize the need to calibrate, modify, repair, test, adjust, or maintain equipment while it is energized, and to minimize work that should be performed on components near exposed hazardous energized circuits. The equipment design should move as many tasks as practical from Type 4 to Types 1, 2, or 3. Routine Type 4 tasks, excluding troubleshooting, should have specific written instructions in the maintenance manuals. General safety procedures (e.g., appropriate PPE and barriers) for troubleshooting, including Type 4 work, should be provided in the maintenance manual.

10.3.2 *Protection of Service Personnel* — Service personnel should not be exposed to inadvertent contact with hazardous potentials or hazardous energy levels. This may be accomplished by using touch safe terminals or providing additional barriers over exposed terminals.

10.3.3 *Manual Adjustment* — Equipment requiring manual adjustment should be so designed that adjustment does not expose personnel to electrical or mechanical hazards.

10.3.4 *Access* — Maintenance and service access should be provided for maintaining and servicing equipment.

10.3.5 *Internal Barriers* — Non-conductive or earthed (grounded) conductive physical barriers or equivalent means should be provided:

a) where it is necessary to reach over, under or around, or in close proximity to hazards,

b) where dropped objects could cause short circuits or arcing,

c) where failure of liquid fittings from any part of the equipment could result in the introduction of liquids into electrical parts,

d) where maintenance or service tasks are likely to allow inadvertent contact with un-insulated energized parts containing either: potentials greater than 30 Volts rms, 42.4 Volts peak, or 60 Volts DC; or power greater than 240 volt-amps in dry locations.

NOTE 29: Removable nonconductive and noncombustible covers are preferred.

10.3.6 *Test Points* — When test points are provided they should satisfy the following:

a) located to provide unobstructed access,

b) marked or identified in the documentation,

c) protected against incidental contact, and

d) provide adequate access for a test probe.

10.3.7 *Isolated Power Systems* — This section applies only to 50-60 Hz AC applications operating at a hazardous voltage.

NOTE 30: The common purpose for using isolated power systems is to reduce sources of electronic noise by not deliberately referencing the output circuit conductors to earth (ground).

NOTE 31: Auto transformers do not provide electrical isolation.

10.3.7.1 All accessible conductive components that are likely to become energized under fault conditions should be effectively bonded to the protective earthing conductor.

EXCEPTION: If the process technology requires conductive parts that are not grounded when they are inaccessible, but grounded when they are accessible, then the intent of ¶10.3.7.2 is satisfied by ensuring such conductive parts are grounded when they become accessible.

10.3.7.2 Isolated circuits should meet the following:

a) the transformer or power supply, and any components (devices) connected to their output, should be clearly labeled adjacent to the isolated circuit(s) or on the enclosure to warn operators and service personnel of the unearthed condition, and

b) ground detection lights, a ground-fault circuit-interrupter (GFCI), or a line isolation monitor should be installed in the output circuit to indicate an isolated conductor ground-fault condition. This will aid in the detection of ground faults in isolated power systems.

10.3.8 *Protection Against Residual Voltages* — Stored electrical energy should be drained to less than a hazardous energy level (see §22 for test method).

EXCEPTION: Batteries that produce a hazardous electrical power or hazardous voltage do not need to be discharged, but other provisions for safe servicing should be made and provided in the system documentation.

11 Protection Against Risk of Electrical Fire

11.1 Measures should be provided in the design of the equipment to protect against the risk of electrical fire as a result of any reasonably foreseeable single fault due to component failure or abnormal operating conditions.

11.2 The installation documentation should include the necessary data for selecting the facility supply overcurrent protective device and the facility supply conductors.

11.3 All conductors except protective earthing conductors, protective conductors, and earthed (for example, neutral) conductors should be protected against overcurrent conditions by protective devices suitably chosen as discussed in the remainder of this section.

EXCEPTION: The earthed conductor (neutral) may be disconnected by an overcurrent device for valid safety and design reasons, providing that it is disconnected simultaneously with the unearthed conductors.

11.4 Circuit overcurrent protection devices should not exceed the ampacity of the conductors they protect.

11.5 Circuit overcurrent protection of discrete devices should not exceed 125 percent of the amperage rating of the device (see §18 for motor protection).

11.6 Circuits that cannot be characterized as serving discrete devices should be provided with overcurrent protection at 125 percent of maximum nominal load or the next largest standard size of overcurrent device, unless it can be demonstrated that no risk of electrical fire is present in the event of fault conditions (e.g., power limited).

11.7 All receptacle outlets and connectors as well as the circuits supplying these receptacles should have overcurrent protection in accordance with their rating.

11.8 *Local Lighting Circuits* — Overcurrent protection for lighting circuits should not exceed 15 amperes.

11.9 *Transformers*

11.9.1 Transformers that operate at 50/60 Hz, that have a primary rated 600VAC or less, and have no integral thermal protection should have overcurrent protection in accordance with the applicable row of Table A1-14.

11.9.2 Transformers that operate at 50/60 Hz, that have a primary rated 600VAC or less, and are equipped with thermal protection provided by the transformer manufacturer that interrupts the primary current in the event of an overload, should be protected in accordance with Table A1-14 or A1-15.

11.10 *Overcurrent Protective Devices*

11.10.1 *Overcurrent Devices* — All overcurrent protective devices should be selected and applied with proper consideration being given to the following:

a) maximum available fault current,

b) interrupting rating of the device,

c) voltage rating,

d) load characteristic,

e) normal operating current, and

f) circuit in-rush characteristics.

11.10.2 Circuit breakers and circuit protectors are preferred over fuses as overcurrent devices because they can be reset.

11.10.3 Fuse holders and fuses should be of a type that is designed to be mounted to a panel or component rail.

NOTE 32: So-called ‘inline’ fuse holders do not meet this criteria.

11.10.4 Panel-mounted fuse holders and fuses should satisfy the following:

a) fuses in screw-type fuse holders should be used as overcurrent protection in only single-phase circuits using a neutral conductor;

EXCEPTION: Fast-acting fuses in multi-phase circuits may be used where they can enhance safe design.

b) if electric shock due to incidental contact by maintenance or service personnel may occur, a touch-safe fuse holder should be used;

c) fuse holders that have exposed metal when the cap is removed (non-shockproof fuse holders) should have the line conductor connected to the end terminal and the load conductor connected to the side terminal; and

d) fuse holders should not move in a way that will loosen electrical connections when a fuse is replaced.

11.10.5 Circuit breakers and circuit protectors should satisfy the following:

a) The circuit breaker or circuit protector should be manually operable and should clear a fault even if the handle mechanism is held closed;

b) The “ON” and “OFF” position should be clearly marked. The handle should be mounted with the handle up for the “ON” position;

c) If the circuit breaker is mounted on a vertical surface it should be in a vertical or horizontal orientation only. If mounted in a vertical orientation, the handle should be up for the “ON” position. If mounted in a horizontal orientation, the handle should be to the right for the “ON” position. If mounted in two columns, horizontally oriented, the handles should be toward the center for the “on” position; or clearly marked indicating the “ON” and “OFF” positions.

d) If the circuit breaker is mounted on a horizontal surface it should be mounted so that the on position is to the right of the surface or center if there are two columns; or it should have its “ON” and “OFF” position clearly marked.

e) Overcurrent protection should be provided in all unearthed conductors.

NOTE 33: It is preferred that the supply conductors of the circuit be connected to the top of the circuit breaker or circuit protector where practical. Circuit breakers and circuit protectors marked with “line” and “load” terminals should be installed in accordance with the markings.

11.11 *Electrolytic Capacitors*

11.11.1 Large capacitor venting recommendations: Capacitors that are greater than 25.4 mm (1.0 in.) in diameter or are capable of storing more than four Joules should be self-vented or protected from rupture by equivalent means. A capacitor vent should be unobstructed for a minimum of 5.1 mm (0.2 in.). Capacitors mounted horizontally should have vent holes positioned in the upper half of the enclosure (9, 12, 3 o’clock positions).

11.11.2 Capacitors should have containment provisions within the capacitor itself or be shielded such that vapors or debris will not become hazardous to personnel.

11.11.3 Capacitor terminals should be insulated or protected from short circuits by tools. Lacquer and sealing compounds should not be relied upon to provide protection.

11.12 *Abnormal Temperatures Under Fault Conditions* — Heaters or other circuits which, under any reasonably foreseeable single fault condition, are capable of causing abnormal temperatures that create a hazardous condition with an unacceptable level of risk, should be provided with over temperature protection to detect these abnormally elevated temperatures and interrupt the source of energy driving them. Equivalent means of protection are acceptable.

11.13 In addition to satisfying the criteria of this document, the criteria of SEMI S3 should be satisfied when applicable.

11.14 Some device loads vary widely depending upon their operating conditions and operating history (such as ceramic resistive heating elements). The load values used to select overcurrent protection devices should account for the full load range during worst case, normal operating conditions.

12 The Protective Earthing System

12.1 *Bonding* — All accessible non-current carrying conductive components that may become energized under reasonably foreseeable single fault conditions, and as a result increase the risk of electric shock, should be bonded to the protective earthing system.

NOTE 34: Non-safety related bonding conductors (e.g., bonding conductors for EMC concerns) are not subject to this section.

12.2 *Parts Not Bonded to the Protective Earthing System* — If non-current carrying conductive parts do not constitute a hazard under single fault conditions, it is not necessary to bond them to the protective earthing system.

12.3 *Protective Earthing System*

12.3.1 *General* — The protective earthing system consists of those components that provide electrical continuity between the protective earthing conductor terminal and non-current carrying frames, enclosures, or components that are stipulated to be maintained at an earth potential under both normal operating conditions and single fault conditions in accordance with ¶12.1.

12.3.2 *Protective Conductors* — Copper conductors or structural members with bonding jumpers should be used for bonding to the protective earthing system.

EXCEPTION: Conductors other than copper that have equivalent ampacity to copper conductor can be used for protective conductors.

12.3.2.1 When a protective conductor is used in this way, its size should be compatible with the protective conductor ampacity given in Tables A1-1 through A1-5 that is a function of the ampacity of the current carrying conductor it is associated with.

12.3.2.2 Bus bars, and/or the equipment frame may be used as protective conductors. When bus bars or the equipment frame is used, their geometry and material should provide the same ampacity as that stipulated for the protective conductor in Tables A1-1 through A1-5.

12.3.3 Hinges, slides, and other moving parts of enclosures should not be relied on as part of the protective earthing system.

EXCEPTION: Hinges are acceptable if the enclosure and its hinges have been identified as suitable for bonding by an accredited testing laboratory.

12.3.4 Raceways, wireways, and cable trays should not be used as protective conductors, except to effect their own connection to the protective bonding circuit as may be stipulated by ¶12.1.

12.3.5 It is preferred that a protective conductor be routed with the associated current carrying conductors whenever possible.

12.3.6 The protective earthing system should not be intentionally used as a current carrying conductor, except as permitted by ¶9.2.6.

12.3.7 *Continuity of the Protective Earthing System* — The protective earthing system should be permanent, electrically continuous and capable of carrying any ground fault current likely to be imposed. See ¶22.3 “Earthing Continuity and Continuity of the Protective Bonding Circuit” for the appropriate test method.

12.3.8 Connection and bonding points to protective conductors should be designed so that their current carrying capacity is not impaired by mechanical, chemical, or any other influence that may degrade their current carrying capacity.

12.3.9 Mounting hardware and cover screws that may be removed for normal servicing should not be used for terminating the protective conductor to a component or part of the enclosure.

12.3.10 Machine parts, other than accessories or attachments, having metal-to-metal bearing surfaces should be considered as bonded to the protective earthing system. Parts separated by a nonconductive fluid or gas should not be considered as bonded.

12.3.11 When a part is removed, the continuity of the protective earthing system for the remaining parts should not be interrupted.

12.3.12 *Exclusion of Switching Devices from the Protective Bonding Circuit* — The protective earthing system should not incorporate switching or interruption devices.

EXCEPTION: For technologies requiring isolated potentials (i.e. no ground reference) during operation, ground interrupting devices are acceptable provided the device automatically provides continuity of the protective earthing system when the related components are accessible and that the device is fault tolerant.

12.3.13 *Interruption of the Protective Earthing System* — Where the continuity of the protective earthing system can be interrupted by means of connectors (e.g., plug and socket connections), and this could result in increased risk of electric shock, the following considerations should be satisfied:

a) the protective earthing system should be interrupted only after the energized conductors have been interrupted, and

b) the continuity of the protective earthing system should be re-established before any energized conductor is reconnected.

12.4 *Bonding Terminations to The Protective Earthing System*

12.4.1 The protective conductors should be bonded to a single designated termination (the protective earthing conductor terminal) that will not be disturbed by any other conductor terminations.

12.4.2 All non-conductive coatings, such as paint or enamel, should be removed from contact surfaces where protective conductors terminate.

12.4.3 When terminal lugs are used for bonding to the protective earthing system, they should be ring-tongue type, with lock or star washers. (Refer to ¶17.2(a).)

12.4.4 Terminal lugs used to make connections to the protective earthing system do not need to be insulated.

12.5 Cord and plug connected equipment should pass a leakage current test in accordance with the test described in §22.

13 Safety Circuits

13.1 *General* — Transformers or power supplies should be used for supplying safety circuits. Such transformers should have electrical isolation between the primary and the secondary windings. Safety circuits should be designed using non-hazardous voltage and power levels consistent with the correct operation of the control circuit.

NOTE 35: See ¶13.3.3 Exception 2 for specific EMO function exception.

13.2 *Start Functions*

13.2.1 Start functions should operate by energizing the relevant circuit.

13.2.2 *Prevention of Unexpected Start-up* — The engineering design should prevent unexpected start-up.

13.3 *Emergency Off*

13.3.1 The equipment should have an “emergency off” (EMO) circuit. An EMO actuator (e.g., button), when activated, should place the equipment into a safe shutdown condition, without generating any additional hazard to personnel or the facility.

EXCEPTION 1: Cord- and plug-connected single phase equipment, rated no greater than 240 Volts line-to-line/150 Volts line-to-earth and no greater than 2.4 kVA, where the hazards are only electrical in nature, do not need to have a separate EMO circuit if the main disconnecting means is readily accessible to the operator and maintenance personnel. This main disconnecting means should be red and labeled indicating its On/Off status.

EXCEPTION 2: Assemblies that are not intended to be used as stand-alone equipment, but rather within an overall integrated system, and which receive their power from the end-user system, may not have a separate emergency off circuit. The assembly's installation manual should provide clear instructions to the equipment installer to connect the assembly to the integrated system's emergency off circuit.

NOTE 36: It is recommended that the emergency off function not reduce the effectiveness of safety devices or of devices with safety-related functions (e.g., magnetic or braking devices) necessary to bring the equipment to a safe shutdown condition effectively.

13.3.2 *EMO Interfaces* — External EMO interfaces should be provided where the equipment is likely to be integrated and is likely to have shared hazards with other assemblies in the end user's facility. If an external EMO interface is provided, the supplier should include instructions for connecting to the interface.

13.3.3 *EMO Function* — Activation of the emergency off circuit should de-energize all hazardous voltage and all power greater than 240 volt-amperes in the equipment beyond the main power enclosure.

EXCEPTION 1: A non-hazardous voltage EMO circuit (typically 24 Volts) may remain energized.

EXCEPTION 2: Safety related devices (e.g., smoke detectors, gas/water leak detectors, pressure measurement devices, etc.) may remain energized from a non-hazardous power source.

EXCEPTION 3: A computer system or PLC performing data/alarm logging and error recovery functions may remain energized, provided that the breaker and receptacle supplying the power to the computer system are clearly labeled as remaining energized after EMO activation.

NOTICE: ¶13.3.4 below will be withdrawn upon July 1, 2006 publication and replaced by the new ¶13.3.4 including: figures and tables as shown in Delayed Revisions §2, however, the EH & S Committee has voted that implementation of the information is OPTIONAL before the effective date.

13.3.4 *EMO Design* — The design of the EMO circuit should include all the following:

a) the EMO circuit should not include controls that enable it to be defeated or bypassed;

b) the EMO circuit should consist of electro-mechanical components;

c) resetting the EMO switch should not re-energize circuits, equipment, or subassemblies that create a hazard to personnel or the facility;

d) the EMO circuit should shut down the equipment by de-energizing rather than energizing control components; and

e) the EMO actuator should be non-lockable and self-latching.

EXCEPTION 1: Solid-state devices and components may be used, provided the system or relevant parts of the system are evaluated and found suitable for use. The components should be evaluated and found suitable considering abnormal conditions such as over voltage, under voltage, power supply interruption, transient.

NOTE 37: For equipment intended for use in locations where fire or explosion hazards may exist, it is recommended that a pneumatic or intrinsically safe EMO circuit be considered.

13.3.5 *EMO Identification* — The EMO identification should include the following:

a) the emergency off actuator should be red and mushroom shaped;

b) a yellow background for the EMO should be provided;

c) all Emergency Off actuators should be clearly labeled as “EMO,” “Emergency Off,” or the equivalent, and should be clearly legible from the viewing location. The label may appear on the actuator or on the yellow background; and

d) Emergency Off buttons should be located or guarded to minimize accidental activation.

13.3.6 *EMO Location and Size* — Emergency Off buttons should be readily accessible from operating and regularly scheduled maintenance locations and appropriately sized to enable activation by the heel of the palm.

13.3.7 No operator or regularly scheduled maintenance location should require more than 3 meters (10 feet) travel to the EMO button.

13.4 *Operating Modes* — When a system has more than one operating mode, and operating mode selection can result in a hazardous condition, mode selection should be restricted to trained service or maintenance personnel.

13.5 Suspension of safeguards should satisfy ¶8.15.

13.6 *Safety Controls*

13.6.1 *Hold-to-run Controls* — Hold-to-run controls should only be used if a hazard analysis determines that they are an appropriate and adequate means to mitigate a hazard. When hold-to-run controls are used, they should necessitate continuous actuation of the control devices to achieve operation.

13.6.2 *Two Handed Controls* — When dual series-connected hand controls are used to isolate the operator from hazards, the hand controls and/or control circuit should comply with the following:

a) the hand controls should be momentary contact switches with black or green heads. Each hand control should be protected against unintended operation;

b) each hand control should be arranged by design, construction, and/or separation so that the use of both hands is needed to start the machine cycle. Preferably, they are mounted at least 610 mm (24 in.) apart at the same height;

c) two hand controls should be designed so that both hand controls need to be depressed within one second of each other for the machine to cycle and both hand controls need to be held depressed until the hazard no longer exists; and

d) the control system should incorporate an anti-repeat feature that limits the machine to one cycle for each depression of the hand controls. The control system should incorporate an anti-tie-down feature that demands the release of both hand controls between cycles.

13.6.3 *Combined Start and Stop Controls* — Controls that alternately initiate and stop motion should only be used when no hazardous condition can arise from their operation.

13.7 *Safety Interlock Circuits*

13.7.1 *Protection against Fault Conditions* — When a single point failure can result in an unacceptable level of risk, a safety interlocking circuit or other suitable means should be provided to protect against the consequences of that single point failure.

13.7.2 *Safety interlock Function* — Safety interlocks should be designed such that the equipment is automatically brought to a safe condition before personnel can access the point of hazard. Each safety interlock, when activated, should alert the operator immediately.

EXCEPTION: If a safety interlock triggers the emergency off (EMO) circuit, or otherwise removes power to the user interface, notification to the operator is not needed.

NOTE 38: An explanation of the cause is preferred upon activation of a safety interlock.

NOTICE: ¶13.7.3 below will be withdrawn upon July 1, 2006 publication and replaced by the new ¶13.7.3 including: figures and tables as shown in Delayed Revisions §1, however, the EH & S Committee has voted that implementation of the information is OPTIONAL before the effective date.

13.7.3 *Safety Interlock Design* — Electromechanical devices and components are preferred. Solid state devices and non-programmable solid state components may be used provided that the safety interlock system or relevant parts of the system are evaluated for suitability for use in accordance with appropriate standard(s). The evaluation for suitability should take into consideration abnormal conditions such as overvoltage, undervoltage, power supply interruption, transient overvoltage, ramp voltage, electromagnetic susceptibility, electrostatic discharge, thermal cycling, humidity, dust, vibration, jarring, or interfacing to a network.

NOTICE: ¶13.7.3.1 below will be withdrawn upon July 1, 2006 publication and replaced by the new ¶13.7.3.1 including: figures and tables as shown in Delayed Revisions §1, however, the EH & S Committee has voted that implementation of the information is OPTIONAL before the effective date.

13.7.3.1 FECS may be used in conjunction with electromechanical or solid state devices and components provided the programmable safety control system conforms to an appropriate standard for electronic safety systems. Components of the FECS should be tested and certified according to the requirements of the standard used. Examples of recognized electronic safety systems standards include IEC 61508, ISO 13849-1, (EN 954-1), ANSI/ISA SP84.01, DIN/V/VDE-0801.

EXCEPTION: Where the severity of a reasonably foreseeable mishap is deemed to be minor per SEMI S10, a software-based safety interlock may be considered suitable.

NOTE 39: ¶8.4.1 states additional assessment criteria for safety-related components and assemblies.

NOTE 40: A FECS is a subsystem to a (PES) Programmable Electronic System. IEC 61508 is the preferred standard for complex PES.

13.7.4 *Safety Interlock Override* — The safety interlock system should be designed to minimize the need to override safety interlocks during maintenance activities.

13.7.5 When maintenance access to areas protected by safety interlocks is necessary, safety interlocks that can be defeated may be used, provided that they require an intentional operation to bypass. Safety interlocks that safeguard operator tasks should not be able to be defeated without the use of a tool. Upon exiting or completing the maintenance mode, all safety interlocks should be automatically restored.

13.7.6 If a safety interlock is defeated, the maintenance manual should identify administrative controls to safeguard personnel and to minimize the hazard.

13.7.7 The restoration of a safety interlock should not automatically initiate machine motion or operation where this can give rise to a hazardous condition.

13.7.8 *Safety Interlock Circuit Connection* — To reduce the risk of interlocks not functioning correctly from short circuiting of the device or wiring to ground, switches, contacts, and other safety interlock control devices should not be connected to the earthed side of the circuit.

13.7.9 *Shunt Trip Circuits* — Shunt trips should not be used as safety interlocks because they are not fail-safe.

13.8 *Multiple Points of Control*

13.8.1 Where multiple points of control are provided on a system, a hardware based device which meets the considerations of ¶13.7 should be used to ensure a single point of control when multiple points of control can cause an unacceptable risk.

13.8.2 The control point selection hardware-based device should either be lockable or be able to be under the immediate control of the person(s) exposed to the hazard.

14 Interface Control

14.1 *Hand Control Devices* — Hand control devices should be located so that their intended use does not cause an unacceptable risk.

14.1.1 Hand control devices should be designed and mounted to minimize inadvertent operation if an unacceptable risk could result from inadvertent activation.

14.1.2 Control devices should withstand the stresses of normal use and foreseeable misuse. Considerations should be given to normal operation as well as fault conditions. Factors such as chemical exposure to insulation, mechanical and thermal stress, radiation, and other environmental factors that may result in unacceptable risks, should be taken into account.

14.2 *Push-actuators (buttons)*

14.2.1 *Colors* — The color of the start/on actuator should be white, gray, black, or green. Green is preferred. Red should not be used for the start/on actuator.

14.2.1.1 The color red should be used for EMO actuators. A yellow background for the EMO should be provided. Refer to ¶13.3.

14.2.1.2 Non-EMO actuators should be differentiated from the EMO actuator.

14.2.1.3 The colors for stop/off actuator should be red, black, gray or white. A red, non-mushroom shaped actuator is preferred. Green should not be used for the stop/off actuator.

NOTE 41: NFPA 79 prefers that all pushbuttons for STOP or OFF functions be colored red, but will permit black, white, or gray.

14.2.1.4 Contact push-actuators that cause operation while they are actuated and cease the operation when they are released should be colored white, gray, or black. The colors red, yellow, and green should not be used.

14.2.1.5 Reset push-actuators should be colored blue, white, gray, or black. Reset push-actuators should not be colored the same as stop/off actuators.

14.2.2 *Markings* — All controls should be marked with their functional identification in accordance with Section 20.3.

14.3 *Indicator Lights and Displays*

14.3.1 *Colors* — Indicator light lenses should be color-coded in accordance with Tables A1-8 through A1-10 in Appendix 1.

14.3.2 *Flashing Lights* — Flashing lights should be used when the application requires a compelling safety indication to the operator. Single LED indicators should not be used for this application.

14.3.3 *Illuminated Push-actuators* — Illuminated push-actuators should be color-coded in accordance with Appendix 1 Tables A1-8 through A1-10. The color red for the emergency off actuator should not depend on the illumination.

14.4 Actuators used to initiate a function should be designed and mounted to minimize inadvertent activation if an unacceptable risk could result from that inadvertent activation.

14.5 *Disconnects* — All main disconnecting means should meet the considerations of ¶9.3.6. The means of energy isolation for maintenance and servicing should be consistent with procedures described in the manuals.

15 Electrical Enclosures

15.1 *Construction of Electrical Enclosures*

15.1.1 Electrical enclosures should provide protection against contact with hazardous voltages as defined in Section 10 of this guideline.

15.1.2 Electrical enclosures should prevent the ingress of substances that may cause electrical faults within the electrical enclosure. These substances may be emitted by the equipment under fault conditions or would be expected in the equipment's intended use environment.

NOTE 42: Facilities activation of sprinklers is not intended to be covered under this paragraph.

15.1.3 Electrical enclosures should have a complete bottom sufficient to prohibit the emission of molten material or burning insulation under fault conditions.

NOTE 43: Baffling or equivalent construction techniques can be used to satisfy ¶15.1.1 through ¶15.1.3 and still meet the functional needs of adequate ventilation.

15.1.4 Electrical enclosures should be of suitable substantial construction to withstand normal intended use and reasonably foreseeable misuse. Enclosure walls and covers should have adequate strength to withstand deflection that reduces electrical clearances below an acceptable value or prevent contact with energized parts. Enclosures should be evaluated by inspection or testing in accordance with the enclosure test criteria in ¶22.14.

15.2 *Access* — All panels providing access to electrical components should be located and mounted to facilitate:

a) accessibility and maintenance, and

b) protection against the external influences that may result in safety hazards.

NOTE 44: This section only applies to circuits that handle hazardous voltage or power.

15.3 *Location and Mounting*

15.3.1 All components within electrical enclosures should be placed and oriented so that they can be identified without moving components or the wiring. Components should not be mounted on panels that are intended to be removed for routine maintenance.

EXCEPTION 1: Moveable panels are acceptable if they are well bonded, secured to the equipment, and the supply wires are routed such that moving the slide panel will not deteriorate their insulation.

EXCEPTION 2: Devices supplied with non-hazardous voltages and power levels may be mounted on normally removable panels.

15.3.2 Components should be located to permit inspection for correct operation and routine maintenance without dismantling equipment or parts of the machine.

15.3.3 Where a special tool is necessary to remove an electrical component, the tool should be supplied.

15.3.4 Where electrical components are connected through plug-in arrangements, their association should be made clear by type (shape), marking, or reference designation, whether singly or in combination.

15.3.5 Plug-in devices that are handled during normal operation should be provided with non-interchangeable features where the lack of such a feature can result in an unacceptable risk.

15.3.6 Creepage and clearances should meet the criteria of basic insulation between primary parts and the earthed electrical enclosure for the working voltages involved (See Appendix 1 Tables A1-12 and A1-13).

15.3.7 When components that handle hazardous voltage and hazardous power are mounted on swing panels, the swing panels that have those components mounted on them should swing open adequately to provide access. The wiring that flexes during servicing should be provided with additional mechanical protection at all points where it is flexed.

EXCEPTION: Wiring that passes the flexing test described in ¶22.16 does not need to have additional mechanical protection.

15.4 *Component Identification* — Components should be labeled on the surface of the panel where the component is mounted so the component may be identified from the documentation as discussed in §21.

EXCEPTION: Engineering documentation that provides a layout of the electrical enclosure with component identification may serve this function.

16 Conductors and Cables

16.1 *General* — Conductors and cables should be rated for the voltage and load current at which they are used. Proper overcurrent protection in accordance with Sections 10 and 11 should be provided. Conductor insulation or covering should also be rated to withstand any external influences that they may be subjected to under normal operating conditions, as well as under single fault conditions (e.g., the presence of water, corrosive substances, mechanical stress, and thermal stress).

16.2 *Conductor Construction* — Wire conductors should be constructed of copper. Conductors should be constructed of materials compatible with the materials and ratings of the devices they will be connected to and the environment in which they will be used.

NOTE 45: Most of the components used in the semiconductor industry are not compatible with aluminum wiring.

16.2.1 *Conductor Ampacity* — Conductors should meet one of the following considerations:

c) be certified by an accredited testing laboratory to be used in a manner other than that described in Tables A1-1 through A1-6 in Appendix 1 and used in accordance with their certification; or

d) be sized in accordance with Tables A1-1 through A1-6 in Appendix 1.

EXCEPTION: Conductors that have been demonstrated to be adequate for their application by testing in accordance with IEC 61010.

16.2.2 *Printed Circuit Boards* — Printed wire assemblies of flame-retardant material should be allowed in place of conductor assemblies provided that they are within electrical enclosures and are mounted in such a way as to minimize flexing or stress. All printed circuit boards should have a flammability rating of V-1 or better (See IEC 60707 or UL 94); or a rating of FR-4 or FR-5 (ANSI/IPC 2221).

16.2.3 *Bus Bars* — Non-insulated bus bars should be sized according to Appendix 1, Table A1-7.

16.2.4 *Insulation* — The insulation on each conductor should be rated to take into account:

a) the electrical, thermal and mechanical strength for the maximum voltages and currents that can be applied to the conductor,

b) the worst environment (e.g., temperature, pressure, humidity, vibration and pollution) where the conductor may be routed, and

c) resistance to flame spread.

16.2.5 Natural rubber and materials containing asbestos should not be used as insulation.

16.2.6 *Hazards Associated with Insulation* — Where the insulation of conductors and cables can constitute hazards due to the propagation of fire or the emission of toxic or corrosive fumes under single fault conditions, additional protections should be provided or alternative conductor or cable assemblies should be considered.

16.2.7 *Dielectric Strength of Wire and Cable Insulation* — A test mark from an accredited testing laboratory on the wire or cable may be used to demonstrate suitability of the wire when it is used in accordance with its voltage rating. An alternate means of compliance can be obtained by the test described below. Cables and wires operating at a nominal voltage of higher than 50 V AC or 120 V DC should withstand a dielectric test voltage of 1000 V plus two times their working rated voltage or 2000 V AC for 5 minutes, whichever is higher. This test for dielectric breakdown should be applied between the wire or cable conductor and foil wrapped around the conductor insulation.

16.2.8 *Insulation Strength* — The mechanical strength and thickness of the insulation should be such that the insulation cannot be damaged in normal operation or as a result of reasonably foreseeable abuse, so as to fail to provide adequate protection.

16.3 *Flexible Cables*

16.3.1 Flexible cords, cables and power cord sets are permitted inside electrical enclosures for internal wiring:

a) when equipped with an attachment plug and powered from a receptacle outlet inside the electrical enclosure to connect one or more assemblies to primary power inside the enclosure; and

b) when the insulation on the individual conductors of the flexible cord or cable are suitable for the application without consideration of the outer jacket insulation; and

c) when the AC flexible cord, AC power cord set, AC receptacles, and AC appliance coupler are all used in accordance with their ratings.

NOTE 46: Power cord sets are preferred over non-detachable cords to facilitate replacement of assemblies without modifying or removing the flexible cord.

16.3.2 Exposed flexible cords and cables installed along the structure of the equipment or system or in the chassis of the machinery is allowable when they are not subject to physical damage from normal operations. Exposed cables should be installed to closely follow the surface and structural members of the machinery.

17 Wiring Practices

17.1 *Connections and Routing*

17.1.1 All connections should be secured against accidental loosening. Terminals should be sized appropriately for the conductors that are being terminated. The connection of two or more conductors to one terminal is allowable only where the terminal is designed and identified for that purpose. All soldered connections should be mechanically secured before soldering. Terminals on terminal blocks should be clearly identified to correspond with markings on the diagrams, or terminal identification should be provided in system manuals or another equivalent means of identification should be provided.

17.1.2 The installation of flexible conduits and cables should be such that liquids drain away from the fittings.

17.1.3 Terminal blocks should be mounted and wired so that the internal and external wiring does not cross over the terminals.

17.1.4 Conductors and cables should be connected from terminal to terminal without splices.

17.1.5 Where circuits operate at different voltages, the conductors of each voltage level should be separated by suitable barriers, or routed separately and secured, or all conductors grouped or bundled together should be insulated for the highest voltage present in the group or bundle.

17.1.6 Conductors smaller than 1/0 AWG should not be connected in parallel to the same terminations to attain the necessary ampacity.

17.1.7 Conductors should not be exposed to temperatures greater than their temperature rating. If the wire termination has a lower temperature rating than the conductor, the lower temperature rating should be used to evaluate the suitability of the conductor.

17.2 *Terminal Lugs* — Terminal lugs should be utilized according to the following:

a) *Ring Tongue* — Desired for all terminations not routinely disconnected for access and service;

b) *Flat Spade* — not desired for terminating hazardous potentials or hazardous energy levels and not suitable for bonding or earthing (grounding).

c) *Flanged Spade* — not desired for earthing except on a captive screw;

d) *Female Tab* — Desired only for terminations to fixed male tabs on components or panels.

17.3 *Attachment Plugs, Cord Connectors, and Receptacles* — If an unacceptable risk can result from misconnection, then receptacles and cord connectors should not accept an attachment plug with a different voltage or current rating.

17.3.1 Only female cord connectors should be used to supply power.

17.3.2 Receptacles should be rated for at least 125 percent of the maximum rated design load (current) intended for the circuit.

17.3.3 Each receptacle should be individually bonded to the protective earthing system.

17.3.4 Series connection of the protective conductor from receptacle to receptacle should not be used.

17.3.5 Convenience receptacles accessible from the exterior of the equipment should be protected by a ground-fault circuit-interrupter (GFCI).

NOTE 47: A receptacle that is used to supply power to a subsystem is not a convenience receptacle.

17.4 *Temporary Power Taps* — Temporary power taps (commercial power strips) should not be used for installation in or on equipment.

EXCEPTION: Permanently installed fixed power strips that are suitable for industrial equipment are acceptable if they have been evaluated by an accredited testing laboratory for this application.

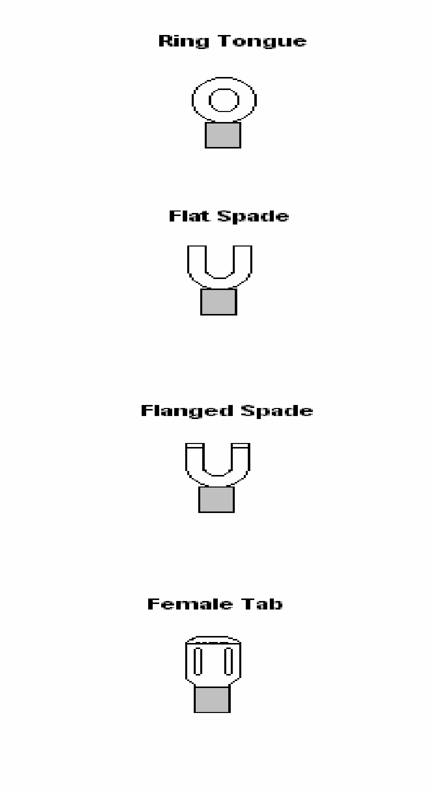

Figure 1
Terminal Lugs

17.5 Multi-Outlet Assemblies — Multi-outlet power assemblies should:

a) contain receptacles suitable for commercial or industrial application, and

b) be a minimum size of 70 mm (2.75 in.) by 36.6 mm (1.44 in).

17.6 *Identification of Conductors*

17.6.1 Each conductor should be identified by a number, letter, color, a combination of the above or other scheme consistent with the product documentation.

17.6.2 Where color is used for the sole means of identification, it is acceptable to apply appropriate colored tape or sleeve at the conductor ends. The tape or sleeve should be wrapped around, or otherwise reliably secured to, the conductor.

17.6.3 *Identification of the Protective Conductor* — Electrical wiring for protective conductors should be labeled for easy identification at both ends of the wire. The protective conductor should be readily distinguishable by shape, location, marking, or color.

17.6.3.1 When color alone is used to identify the protective conductor, the bicolor combination green and yellow should be used throughout the length of the conductor. The bicolor combination green and yellow should be such that on any 15 mm length, one of the colors covers at least 30 percent and not more than 70 percent of the surface of the conductor with the other color covering the remainder of the surface.

EXCEPTION: Solid green can be used to identify protective conductors if the documentation describes this means of identifying protective earth.

17.6.3.2 Green and yellow or green alone should not be used to identify any other conductor.

17.6.4 *Identification of the Earthed (Neutral) Conductor* — Where color alone is used to identify the earthed (neutral) conductor, white or gray should be used.

EXCEPTION: Light blue will be acceptable if the earthed (neutral) conductor is identified by an additional means.

NOTE 48: Light blue may not be accepted in some jurisdictions.

17.6.4.1 White, gray, and light blue should not be used to identify any other conductors.

17.6.5 *Identification of Other Conductors* — Where color alone is used to identify other conductors, black should be used for all unearthed AC and DC power circuits.

17.7 *Wiring Inside Electrical Enclosures*

17.7.1 Wiring that carries hazardous voltage located inside enclosures should be securely routed to avoid mechanical abuse during maintenance or troubleshooting.

17.7.2 Wiring should be protected from contact with liquids that may be present under reasonably foreseeable single fault conditions, unless the wiring is suitably rated for a wet environment.

17.7.3 Wires should be routed away from sharp edges or surfaces that may degrade their insulation.

17.7.4 Wire guides may be used for wire routing. However, these guides should be constructed so as not to adversely affect the insulation of the wires they secure.

17.8 *Wiring Outside Electrical Enclosures*

17.8.1 Conductors external to the electrical enclosure(s) should be enclosed in suitable ducts, raceways, or run in suitable multi-conductor cable. Fittings used with ducts, raceways, or multi-conductor cable should be suitable for the anticipated physical environment. Cables should not be subjected to physical stress (e.g. pinching, crushing, foot traffic, or abrasion).

17.8.2 Flexible conduit or flexible multi-conductor cable should be used where it is necessary to employ flexible connections to pendant push-actuator stations. The weight of the pendant stations should be supported by means other than the flexible conduit or the flexible multi-conductor cable, except where the conduit or cable is specifically designed for that purpose.

17.8.3 Cables that exit an electrical enclosure should be provided with adequate strain relief to ensure a mechanical pull cannot dislodge the cable's termination points. Compliance is verified by conducting a strain relief test in accordance with ¶22.7 Strain Relief Test.

17.8.4 Flexible cables installed in or on machines should be protected to avoid insulation breakdown due to normal operating conditions, single fault conditions, or foreseeable misuse. Some of the factors that should be considered are:

a) moving machine parts,

b) brackets or cable guides on the machine,

c) abrasion,

d) exposure to liquids and gas,

e) exposure to radiation, and

f) temperature deviations.

NOTE 49: Natural rubber can be degraded by chemicals normally present in semiconductor fabrication facilities.

17.8.5 Where cables are subject to movement or are routed close to moving parts, precautions should be taken to maintain a space of at least 25 mm (1 inch) between the moving parts and the cables. Where that distance is not practicable, fixed barriers should be provided between the cables and the moving parts.

17.8.6 Where flexible conduit is adjacent to moving parts, the construction and supporting means should satisfy the following:

a) It should prevent damage to the flexible conduit under normal operating conditions.

b) It should prevent damage to the insulation on the wire inside the conduit under single fault conditions.

17.8.7 *Plug/Receptacle Combinations* — Where equipment is portable, connections to it should be made through a polarized plug/receptacle combination.

17.8.8 Field wiring terminals connected at the time of installation should meet the wire bending space criteria in Appendix 1, Tables A1-1 through A1-5.

EXCEPTION: Equipment that meets the wire bending space requirements of NFPA 70 will also meet these criteria.

17.8.9 *Ducts and Connection Boxes*

17.8.9.1 *General* — Cables used in ducts should be suitably rated.

17.8.9.2 *Fill of Ducts and Raceways* — The total cross sectional area of conductors permitted in raceways and ducts should not exceed 50 percent of the interior cross sectional area of the raceway or duct.

NOTE 50: All other limiting factors for wires and cables should be taken into account. For example, temperature limitations may reduce the number of allowable conductors.

17.8.9.3 *Conduit and Fittings* — Non-flexible and flexible conduit and fittings should be suitable for the anticipated conditions of use. Conduits should be securely held in place and supported at each end.

17.8.9.4 Fittings should be compatible with the conduit and appropriate for the application.

17.8.9.5 Fittings should be secured by a means that requires a tool to remove.

17.8.9.6 Conduit bends should be made in such a manner that the conduit should not be damaged and the internal diameter of the conduit should not be effectively reduced.

17.8.9.7 *Connection Boxes* — Connection boxes should provide protection against the intrusion of substances that may damage insulation or may cause ground-faults.

17.8.9.8 The size of the connection box should be sufficient to allow dissipation of heat generated during normal operation.

17.9 *Subsystem Interconnection* — Conductors that are connected between subsystems at the time of installation should have wire bending space in accordance with ¶9.3.4 and phase identification in accordance with ¶9.1.6.3.

EXCEPTION: Equipment that meets the wire bending space requirements of NFPA 70 will also meet these criteria.

17.10 Conductors should be designed so that their current carrying capacity is not impaired by mechanical, chemical, or any other influences.

18 Electric Motors 186 Watts (1/4 Horsepower) and Larger

18.1 *General* — The considerations provided in this section apply to electric motors and their electrical enclosures. This includes the considerations for overcurrent protection. This section applies to AC and DC motors, 600 V or less, 186 Watts (1/4 HP) and larger.

18.1.1 Remotely installed (for example, in a chase or sub-floor) motors should have a means of disconnecting all unearthed conductors within sight of and not more than 3 meters (10 feet) travel distance of the motor.

18.1.2 Motors should be protected from ingress of liquids that may lead to increased risk of electric shock or fire. The motor terminations to supply conductors should be in the motor housing or a separate enclosure provided for this purpose.

NOTE 51: Assessment of risk generally involves consideration of single-fault tolerance (see ¶7.4 and ¶10.1).

18.1.3 The motor should be marked with the manufacturer's name and part number. The motor should be marked with directional arrows, if lack of this information could result in a safety concern.

NOTE 52: Phase identification is one method of identifying correct connection for motor direction.

18.1.4 Motors should be marked with their voltage, current and frequency rating.

EXCEPTION: This information can be provided in support documentation if it can be traced to the manufacturer's name and part number on the motor.

18.1.5 Under-voltage protection should be provided for all motors that could initiate hazardous equipment motion when power is returned after an under-voltage condition.

18.2 *Motor Mounting And Compartments*

18.2.1 Each motor and its associated couplings, belts and pulleys, or chains, should be so mounted that they are adequately guarded and may be serviced without putting personnel at risk of injury.

18.2.2 Construction should ensure proper cooling and that any rise in temperature remains within the limits of the motors' insulation class.

18.2.3 Applicable points on the motor should be accessible for lubrication, maintenance, and replacement.

18.2.4 Sufficient air circulation to maintain temperature within the motor rating should be provided.

18.3 *Mechanical Brakes* — Where the operation of a mechanical brake increases the potential for entrapment or other hazards, a method of brake release should be provided.

18.4 *Protection of Motors*

18.4.1 Overcurrent protection should be provided for motors. This protection should be sufficient to protect against overcurrent conditions due to faults in the insulation, locked rotor, or overload conditions. The overcurrent protection should open all unearthed conductors.

18.4.2 Where an overcurrent protection device may permit motor starting and still provide overload protection it may be used for both purposes. However, a single device may not be suitable for both overcurrent and overload. In such cases two separate devices should be used; one suitable device for short circuit and ground-fault protection and the other for overload protection.

18.4.3 Overload protection should be in the form of one of the following:

a) overload relay,

b) thermal protection internal or external to the motor, or

c) impedance protection.

18.4.4 The incoming circuit or feeder to power conversion equipment, included as part of an adjustable speed drive system, should be based on the rated input to the power conversion equipment. Unless the power conversion equipment is certified by an accredited testing laboratory to indicate that overload protection is included and suitable for the motor, additional overload protection should be provided.

18.4.5 Over-speed protection should be provided in cases where over-speed may cause a hazardous condition.

19 Accessories and Lighting

19.1 *Lighting Circuits*

19.1.1 One conductor of all equipment lighting and maintenance lighting circuits should be bonded to the equipment protective earthing system in accordance with ¶19.1.2 or 1¶9.1.3. See ¶17.6.3 for conductor identification.

19.1.2 Where the lighting circuit is supplied by a separate transformer, the earthing should occur at the transformer.

19.1.3 When the protective conductor is connected to a screw-shell lamp holder, it should be connected to the screw shell.

19.1.4 The conductors connected to stationary lights used as an integral part of the equipment should be suitable for their application.

19.1.5 Equipment work lights should not contain switches or receptacles such that exposure to liquids or other substances may increase the risk of electric shock or fire.

NOTE 53: Switches or receptacles should be located where liquids or other substances will not increase the risk of electric shock.

19.2 *Attachment Plugs and Receptacles*

19.2.1 Attachment plugs and receptacles should be rated and labeled for the applied voltage and current.

19.2.2 Where used in circuits of 300 Volts or more, attachment plugs and receptacles should be rated for the application (load break or no-load break), and constructed to contain any arc generated when a connection is made or broken.

19.2.3 Attachment plugs and receptacles should be designed or installed to prevent the ingress of substances that may increase the risk of electric shock or fire.

19.2.4 Receptacles internal to the electrical enclosure should be permitted only for maintenance equipment or AC power distribution within the enclosure to assemblies designed and approved for cord-and-plug connection. See ¶17.3 for more details regarding receptacles.

20 Markings

20.1 *General* — Hazard alert signs, nameplates, markings, and identification plates should have sufficient durability to withstand the anticipated physical environment where the equipment will be installed.

20.2 *Hazard Alert Signs* — Enclosures should be labeled to inform the end user of the hazards that they enclose. These labels should comply with SEMI S1.

EXCEPTION: This labeling is not necessary where the enclosures are interlocked with non-defeatable interlocks to disconnect the hazards in question.

20.3 *Functional Identification* — Control devices, visual indicators, and displays should be clearly and durably marked with their functions either on, or adjacent to, the items. Refer to ¶14.2.2, Markings.

20.4 *Equipment Nameplate* — A permanent nameplate should be attached to the main electrical enclosure or equipment where it is plainly visible after installation. This nameplate should include the following information:

a) the manufacturer's name and address,

b) the equipment name, model, and serial number,

c) supply voltage,

d) number of phases,

e) number of wires,

f) frequency,

g) full-load current,

h) ampere rating of the largest motor or load,

i) short-circuit interrupting rating of the equipment main overcurrent protective device,

j) ampere rating of the overcurrent protective device where furnished as part of the equipment, and

k) the electrical diagram number(s) or the number of the index to the electrical diagrams (bill of material).

20.5 Where more than one incoming supply circuit is to be provided, the nameplate should state the above information for each supply circuit.

EXCEPTION: Where the only load is a single motor or motor controller, the motor nameplate is permitted to serve as the electrical equipment nameplate when it is plainly visible.

20.6 *Full Load Current* — The full-load current shown on the nameplate should not be less than the full-load currents for all motors and other equipment that may be in operation at the same time under normal conditions of use. Where unusual loads or duty cycles require oversized conductors, the necessary capacity should be included in the full-load current specified on the nameplate.

20.7 *Overcurrent Marking* — Where overcurrent protection is provided in accordance with ¶9.1.5, the equipment should be marked "overcurrent protection provided at machine supply terminals." A separate nameplate may be used for this purpose.

20.8 *Reference Designations* — All enclosures, assemblies, control devices, and components should be plainly identified with the same reference designation as shown in the technical documentation or identified through equivalent means.

21 Technical Documentation

21.1 *Installation Diagram* — The installation instructions should give all the information necessary for complete installation and safe start up of the system. This should include:

a) a comprehensive description of the equipment, installation and mounting, and the connection to the electrical supply or supplies, and

b) an explanation of the equipment's installation instructions including facilities supply conductors.

21.2 *Block (system) Diagrams and Functional Diagrams* — When it is necessary to facilitate the understanding of the principles of operation, a block (system) diagram should be provided. A block (system) diagram symbolically represents the electrical equipment together with its functional interrelationships without necessarily showing all of the interconnections.

21.3 *Circuit Diagrams* — Circuit diagrams or schematics for power distribution, EMO and interlock circuits should be provided. Where a block (system) diagram does not sufficiently detail the elements of the electrical equipment for safe installation and servicing, circuit schematics should be furnished.

21.4 *Operating Instructions* — The end user documentation should include operating instructions detailing proper procedures for operation of the equipment. Particular attention should be given to the safety measures provided and to the improper methods of operation that are anticipated.

21.5 *Maintenance Instructions* — The technical documentation should contain maintenance instructions detailing procedures for servicing and maintaining the equipment. Attention should be given to how these procedures may be performed safely. A preventative maintenance schedule should be provided with the equipment.

21.6 *Functional Description of Interlocks* — A functional description of interlocks should be provided which provides sufficient detail to explain their operation.

21.7 *Method for Identifying Replacement Parts* — A method of identifying parts that are anticipated to be replaced by the user should be included in the instructions provided with the equipment.

21.8 *Translations* — Where required by law, the information should be provided in the primary language of the location in which the equipment is to be used. However, the language in which the information was created should be identified.

21.9 *Applicable to All Documentation* — The document reference designation system should be in accordance with IEC 61346-1; or a reference key should be provided.

NOTE 54: Additional criteria pertaining to installation, operation, and maintenance instructions are provided in SEMI S2 and SEMI S13.

22 Testing

22.1 *General* — The tests outlined in this document are to be performed by trained and qualified personnel who have knowledge of the techniques and the test apparatuses described herein.

22.1.1 All test equipment should be calibrated and traceable to a calibration standards organization (e.g., National Institute of Standards and Technology (NIST) in the United States or the National Metrology Institute in Japan).

22.1.2 The calibration interval for test equipment should be appropriate to the test equipment; usually this should not exceed one year.

22.1.3 Except where noted otherwise, the equipment should be tested under the least favorable conditions within the manufacturer's operating specifications. These conditions include:

a) supply potential,

b) supply frequency,

c) position of movable parts,

d) operating mode (e.g., full temperature conditions, motors in operation), and

e) adjustment of thermostats, regulating devices, or similar controls in operator-accessible areas.

NOTE 55: Least favorable conditions are those conditions in the manufacturer’s operating specifications under which the equipment is least likely to pass the test.

22.1.4 To determine the least favorable supply potential for a test, consider:

a) multiple-nominal rated potentials (e.g., 120/240 V), and

b) extremes of nominal rated potential ranges (e.g., 208-240 V).

NOTE 56: Consideration of the tolerance on a nominal rated potential (e.g., 120 ± 5 percent) is not necessary.

NOTE 57: Some standards (e.g., IEC 61010-1 and IEC 60950) may specify 90 percent and 110 percent of any rated supply voltage.

22.1.5 To determine the least favorable supply frequency for a test, consider the nominal frequencies as specified (e.g., 50 Hz, 60 Hz., or 50/60 Hz).

NOTE 58: Consideration of the tolerance on a nominal rated frequency (e.g., 50 ± 0.5 Hz) is not usually necessary.

22.1.6 As an alternative to carrying out tests on the complete equipment, tests may be conducted on circuits, components and sub-assemblies independent of the equipment, provided that the results of the tests would be representative of those performed as part of the assembled equipment.

EXCEPTION: The leakage current and earthing (grounding) continuity tests identified in ¶22.2 and ¶22.3 should be completed only on fully assembled equipment.

22.2 *Leakage Current Test for Cord-and-Plug Equipment*

22.2.1 *Test Equipment* — A 1500 ohm resistor shunted by a 0.15μF capacitor (impedance network) and a true RMS voltmeter with an accuracy of 1.0 percent. The impedance network may be a separate assembly or incorporated within a leakage current measuring instrument.

22.2.2 *Procedure* — For equipment connected to the facility branch circuit with a cord-and-plug (plug/socket combination), ensure that the equipment is isolated (e.g., by placing the equipment on a wooden or other non-conductive surface). Connect the equipment to its rated source of supply with the protective earthing conductor disconnected and operate it at the least favorable conditions specified by the manufacturer. Connect the impedance network between each accessible metal part and the protective earthing conductor. In determining accessibility of energized parts, remove all doors, panels, etc. that are to be removed by the operator during normal operation. Using a true RMS voltmeter, measure the voltage drop across the impedance network. Calculate the leakage current using the formula:

$$I_{\text{leakage}} = \frac{\text{Voltage}_{\text{measured}}}{1500 \text{ ohms}}$$

22.2.3 *Acceptable Results* — The maximum calculated leakage current does not exceed 3.5 mA.

NOTE 59: This test is to be conducted only on cord and plug connected equipment.

22.3 *Earthing Continuity and Continuity of the Protective Bonding Circuit Test*

22.3.1 *Test Equipment* — Low range ohmmeter with a range to measure 0.10 ohm with an accuracy of 1.0 percent. The alternate test demands a low voltage current source capable of 10 Amps, a current meter to measure 10 amps with an accuracy of 1 percent, and a voltage meter with a range to measure 0.01 Volts and an accuracy of 1 percent.

22.3.2 *Procedure — Complete the test using one of the following procedures:*

22.3.2.1 Disconnect the equipment from the supply. For equipment installed with fixed wiring methods, disconnect the protective earthing conductor from the protective earthing conductor terminal. Measure the resistance between the protective earthing terminal and each accessible metal part (handle, monitor, doors, etc.) on the equipment using a low-range ohm-meter. Upon test completion, reconnect the protective earthing conductor to the protective earthing conductor terminal.

22.3.2.2 Disconnect the equipment from the supply. For equipment installed with fixed wiring methods, disconnect the protective earthing conductor from the protective earthing conductor terminal. Connect the low voltage current source between the protective earthing conductor terminal and each accessible metal part (handle, monitor, doors, etc.) on the equipment frame or cover. With a current of 10 amps injected, measure the voltage drop between the equipment connection point and the protective earthing conductor terminal. Calculate the resistance by dividing the measured voltage by the injected current. Upon test completion, reconnect the protective earthing conductor to the protective earthing conductor terminal.

EXCEPTION: Earthing Continuity Test does not need to be conducted where accessible metal surfaces are not likely to become energized in a single fault condition.

NOTE 60: Some standards (e.g., IEC 60204-1, IEC 61010-1) may specify this test to be performed using a current injection method using more than 10 Amps.

22.3.3 *Acceptable Results* — The resistance between the protective earthing conductor terminal and each accessible part should not exceed 0.1 ohm.

22.4 *Starting Current Test*

22.4.1 *Test Equipment* — None

22.4.2 *Procedure* — Start the equipment in accordance with manufacturer's instructions three times from a completely stopped condition. Ensure that the time interval between successive starts is sufficient to allow the equipment to return to ambient conditions.

22.4.3 *Acceptable Results* — None of the equipment's overcurrent protective devices should trip during this test.

NOTE 61: It is recommended that the peak inrush starting current be measured using an appropriate current measuring device and recorded in the test report.

22.5 *Input Test*

22.5.1 *Test Equipment* — True RMS current measuring equipment, with accuracy of 3.0 percent.

22.5.2 *Procedure* — Measure the input current to the equipment under the maximum normal operating load conditions (i.e., with all motors, heaters, etc. running at manufacturer's specified maximum loading conditions).

22.5.3 *Acceptable Results* — The measured current does not exceed 110 percent of the rated full load current value specified on the equipment nameplate.

22.6 *Dielectric Test*

22.6.1 *Test Equipment* — Timer with accuracy of ± 5 seconds. Dielectric Withstand Tester with means of indicating test potential, as well as an audible or visual indicator of dielectric breakdown, or an automatic-reject feature for any unacceptable unit. In an alternating current test, the test equipment should include a transformer having sinusoidal output. This transformer should have a rating of 500 VA or greater unless it is provided with a voltmeter that directly measures the applied output potential.

22.6.2 *Procedure* — With the equipment disconnected from its supply, apply a dielectric withstand potential of 1500 Volts AC or 2121 Volts DC between energized metal parts of the primary circuit(s) and dead metal parts. Surge suppression components and devices, and electronic components certified by an accredited testing laboratory that may be damaged may be disconnected from the circuit for this test. For this test, the following conditions need to be set:

a) the equipment should be at its maximum operating temperature;

b) switches should be placed in the "on" position; and

c) circuits through contactors should be completed by manually engaging the contacts or bypassing the contactor terminals.

22.6.2.1 Achieve the test potential gradually, starting from zero and holding at the maximum value for a period of one minute.

EXCEPTION: Where line-to-earth filter components are installed in the equipment, the DC dielectric potential specified above may be used as an equivalent.

NOTE 62: An earthed conductor (neutral), if used in the circuit, is considered to be an energized conductor.

22.6.3 *Acceptable Results* — The equipment does not have a dielectric breakdown.

NOTE 63: Breakdown is often indicated by an abrupt decrease or nonlinear advance of voltage as the voltage is increased. Similarly, a breakdown is often indicated by an abrupt increase in current. Partial discharge (corona) and similar phenomena are disregarded during application of the test voltage.

22.7 *Strain Relief Test* — Either Procedure One or Procedure Two may be used to demonstrate compliance to this test.

22.7.1 *Test Equipment* — Timer with accuracy of ± 5 seconds. A calibrated weight to apply a force of 156 Newtons (35 lb) ± 1.56 Newtons (0.35 lb). A supporting surface on which to secure the equipment.

22.7.2 *Procedure One*

22.7.2.1 For cord-and-plug connected equipment, strain relief is provided to prevent mechanical stress such as a pull or twist being transmitted to terminals, splices or interior wiring. Support the equipment on a surface so it will not move when the force is applied to the cord. Apply a direct pull of 156 N (35 pounds) to the equipment supply cord from the least favorable angle. If necessary, use pulleys or other means to adjust the angle of force applied to the strain relief on the equipment. Apply the force gradually by slowly suspending the weight on the cord and maintain the applied force for a period of one minute.

22.7.2.2 *Acceptable Results For Procedure One* — The equipment supply cord does not displace to the extent that stress could be applied to the internal connections.

22.7.3 *Procedure Two*

22.7.3.1 Support the equipment on a surface so it will not move when the force is applied to the cord. Disconnect the internal connections for the cord. Mark the external portion of the cord with tape where it meets the strain relief. Apply a direct pull of 156 N (35 pounds) to the equipment supply cord from the least favorable angle. If necessary, use pulleys or other means to adjust the angle of force applied to the strain relief on the equipment. Apply the force gradually by slowly suspending the weight on the cord and maintain the applied force for a period of one minute.

22.7.3.2 *Acceptable Results For Procedure Two* — No displacement of the tape demonstrates an acceptable result.

22.8 *Transformer Output Short Circuit Test*

22.8.1 *Test Equipment* — Timer with accuracy of ± 5 minutes. A substantial conductor suitable for carrying the short circuit current.

22.8.2 *Procedure* — With the equipment in its standby condition, short circuit the output of each power transformer.

NOTE 64: If overcurrent protection is connected to the output of the transformer under test, connect the short-circuit jumper after this protective device.

EXCEPTION 1: Where the overcurrent protective devices on the input or output of the transformer are rated at not more than 125 percent of the rated current of the transformer respectively and the overcurrent protective devices are certified by an accredited testing laboratory, the transformer need not be subjected to this test.

EXCEPTION 2: A thermally-protected or impedance-protected transformer that is certified by an accredited testing laboratory need not be subjected to this test.

22.8.3 *Acceptable Results* — A hazardous condition (e.g., smoke, fire, or molten material) does not exist within 8 hours or before activation of overcurrent protection, thermal protection, or other protective circuit/device, whichever occurs first.

22.9 *Power Supply Output Short Circuit Test*

22.9.1 *Test Equipment* — Timer with accuracy of ± 5 minutes. A substantial conductor suitable for carrying the short circuit current.

22.9.2 *Procedure* — With the equipment in its standby condition, short circuit the output of each power supply, one at a time.

NOTE 65: If overcurrent protection is connected to the output of the power supply under test, connect the short circuit jumper after this protective device.

EXCEPTION: A power supply that is certified by an accredited testing laboratory and used in accordance with its certification and the manufacturer's instructions need not be subjected to this test.

22.9.3 *Acceptable Results* — A hazardous condition (e.g., smoke, fire, or molten material) does not exist within 8 hours or before activation of overcurrent protection, thermal protection, or other protective circuit/device, whichever occurs first.

22.10 *Safety Circuit Function Test*

22.10.1 *Test Equipment* — Contingent on safety devices being tested.

22.10.2 *Procedure* — Functionally test each safety circuit by actuation and resetting.

22.10.3 *Acceptable Results* — The following sections provide the acceptable results for the applicable safety systems:

a) When the EMO is actuated, all hazardous voltage and all power greater than 240 volt-amps in the equipment beyond the main power enclosure should be de-energized, except where permitted by ¶13.3.3.

b) Actuation of the emergency stop and safety interlocks causes the equipment, or relevant parts of the equipment, to be automatically brought to a safe condition.

c) Resetting of the safety circuit should not cause the system to resume operation.

NOTE 66: This test documents the electrical functionality of the safety circuit(s). It is not intended to determine or document the appropriateness of the shutdown actions taken.

22.11 *Safety Circuit Conductor Disconnection Test*