SEMI S2-0310
ENVIRONMENTAL, HEALTH, AND SAFETY GUIDELINE FOR SEMICONDUCTOR MANUFACTURING EQUIPMENT

This safety guideline was technically approved by the global Environmental Health & Safety Committee. This edition was approved for publication by the global Audits & Reviews Subcommittee on December 16, 2009. Initially available at www.semi.org in February 2010. Originally published in 1991; previously published July 2009.

NOTICE: Paragraphs entitled "NOTE" are not an official part of this safety guideline and are not intended to modify or supersede the official safety guideline. These have been supplied by the committee to enhance the usage of the safety guideline.

1 Purpose

1.1 This safety guideline is intended as a set of performance-based environmental, health, and safety (EHS) considerations for semiconductor manufacturing equipment.

2 Scope

2.1 *Applicability* — This guideline applies to equipment used to manufacture, measure, assemble, and test semiconductor products.

2.2 *Contents* — This document contains the following sections:

1. Purpose

2. Scope

3. Limitations

4. Referenced Standards and Documents

5. Terminology

6. Safety Philosophy

7. General Provisions

8. Evaluation Process

9. Documents Provided to User

10. Hazard Warning Labels

11. Safety Interlock Systems

12. Emergency Shutdown

13. Electrical Design

14. Fire Protection

15. Heated Chemical Baths

16. Ergonomics and Human Factors

17. Hazardous Energy Isolation

18. Mechanical Design

19. Seismic Protection

20. Automated Material Handlers

21. Environmental Considerations

22. Exhaust Ventilation

Documents Document Sharing Hub

Full document details: SEMI S2-0310

23. Chemicals

24. Ionizing Radiation

25. Non-Ionizing Radiation and Fields

26. Lasers

27. Sound Pressure Level

28. Related Documents

Appendix 1 — Enclosure Openings

Appendix 2 — Design Guidelines for Equipment Using Liquid Chemicals

Appendix 3 — Ionizing Radiation Test Validation

Appendix 4 — Non-Ionizing Radiation (Other than Laser) and Fields Test Validation

Appendix 5 — Fire Protection: Flowchart for Selecting Materials of Construction

Appendix 6 — Laser Data Sheet – SEMI S2

2.3 *Precedence of Sectional Requirements* — In the case of conflict between provisions in different sections of this guideline, the section or subsection specifically addressing the technical issue takes precedence over the more general section or subsection.

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 for use by supplier and user as a reference for EHS considerations. It is not intended to be used to verify compliance with local regulatory requirements.

3.2 It is not the philosophy of this guideline to provide all of the detailed EHS design criteria that may be applied to semiconductor manufacturing equipment. This guideline provides industry-specific criteria, and refers to some of the many international codes, regulations, standards, and specifications that should be considered when designing semiconductor manufacturing equipment.

3.3 Existing models and subsystems should continue to meet the provisions of SEMI S2-93A. Models with redesigns that significantly affect the EHS aspects of the equipment should conform to the latest version of SEMI S2. This guideline is not intended to be applied retroactively.

3.4 In many cases, references to standards have been incorporated into this guideline. These references do not imply applicability of the entire standards, but only of the sections referenced.

4 Referenced Standards and Documents

4.1 *SEMI Standards and Safety Guidelines*

SEMI E6 — Guide for Semiconductor Equipment Installation Documentation

SEMI F5 — Guide for Gaseous Effluent Handling

SEMI F14 — Guide for the Design of Gas Source Equipment Enclosures

SEMI F15 — Test Method (SF_6 Tracer Gas) for Enclosures Has Been Moved to SEMI S6

SEMI S1 — Safety Guideline for Equipment Safety Labels

SEMI S3 — Safety Guideline for Process Liquid Heating System

SEMI S6 — EHS Guideline for Exhaust Ventilation of Semiconductor Manufacturing Equipment

SEMI S7 — Safety Guidelines for Environmental, Safety, and Health (ESH) Evaluation of Semiconductor Manufacturing Equipment

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

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

SEMI S12 — Guidelines for Equipment Decontamination

SEMI S13 — Environmental, Health and Safety Guideline for Documents Provided to the Equipment User for Use with Semiconductor Manufacturing Equipment

SEMI S14 — Safety Guidelines for Fire Risk Assessment and Mitigation for Semiconductor Manufacturing Equipment

SEMI S22 — Safety Guideline for the Electrical Design of Semiconductor Manufacturing Equipment

4.2 *ANSI Standards*[1]

ANSI/IEEE C95.1 — Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz

ANSI/RIA R15.06 — Industrial Robots and Robot Systems – Safety Requirements

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

4.3 *CEN/CENELEC Standards*[2]

CEN EN 775 — Manipulating Industrial Robots – Safety

CEN EN 1050 — Safety of Machinery – Principles of Risk Assessment

CEN EN 1127-1 — Explosive Atmospheres – Explosion Prevention and Protection – Part 1: Basic Concepts and Methodology

4.4 *DIN Standards*[3]

DIN V VDE 0801 — Principles for Computers in Safety-Related Systems

4.5 *IEC Standards*[4]

IEC 60825-1 — Safety of Laser Products – Part 1: Equipment Classification, Requirements

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

IEC 61508 — Functional Safety of Electrical/Electronic/Programmable Electronic Safety-Related Systems

4.6 *ISO Standards*[5]

ISO 10218-1 — Robots for Industrial Environments – Safety Requirements – Part 1: Robot

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

4.7 *NFPA Standards*[6]

NFPA 12 — Standard on Carbon Dioxide Extinguishing Systems

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1 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; http://www.ansi.org

2 European Committee for Standardization (CEN)/European Committee for Electrotechnical Standardization (CENELEC), Central Secretariat: rue de Stassart 35, B-1050 Brussels, Belgium; http://www.cen.eu

3 Deutsches Institut für Normung e.V., Available from Beuth Verlag GmbH, Burggrafenstrasse 4-10, D-10787 Berlin, Germany; http://www.din.de

4 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; http://www.iec.ch

5 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; http://www.iso.ch

6 National Fire Protection Association, 1 Batterymarch Park, Quincy, MA 02269, USA. Telephone: 617.770.3000; Fax: 617.770.0700; http://www.nfpa.org

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NFPA 13 — Standard for Installation of Sprinkler Systems

NFPA 72 — National Fire Alarm Code

NFPA 497 — Recommended Practice for the Classification of Flammable Liquids, Gases, or Vapors and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas

NFPA 704 — Standard System for the Identification of the Hazards of Materials for Emergency Response

NFPA 2001 — Standard on Clean Agent Fire Extinguishing Systems

4.8 *Underwriters Laboratories Standard*[7]

UL 508A — Industrial Control Panel

4.9 *US Code of Federal Regulations*[8]

21 CFR Parts 1000-1050 — Food and Drug Administration/Center for Devices and Radiological Health (FDA/CDRH), Performance Standards for Electronic Products, Title 21 Code of Federal Regulations, Parts 1000-1050

4.10 *Other Standards and Documents*

ACGIH, Industrial Ventilation Manual[9]

ASHRAE Standard 110 — Method of Testing Performance of Laboratory Fume Hoods[10]

Burton, D.J., Semiconductor Exhaust Ventilation Guidebook[11]

Uniform Building Code™ (UBC)[12]

Uniform Fire Code™[13]

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

5 Terminology

5.1 *Abbreviations and Acronyms*

5.1.1 *ACGIH®* — American Conference of Governmental Industrial Hygienists (ACGIH is a registered trademark of the American Conference of Governmental Industrial Hygienists.)

5.1.2 *ASHRAE* — American Society of Heating, Refrigeration, and Air Conditioning Engineers

5.1.3 *MPE* — Maximum Permissible Exposure

5.1.4 *NOHD* — Nominal Ocular Hazard Distance

5.2 *Definitions*

NOTE 1: Composite reports using portions of reports based upon earlier versions of SEMI S2 and SEMI S10 may require understanding of the SEMI S2-0703 or SEMI S10-1296 definitions for the terms hazard, likelihood, mishap, severity, and risk.

5.2.1 *abort switch* — a switch that, when activated, interrupts the activation sequence of a fire detection or fire suppression system.

5.2.2 *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 governmental or regulatory body.

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7 Underwriters Laboratory, 333 Pfingsten Rd, Northbrook, IL 60062, USA. Telephone: 877.854.3577; Fax: 847.407.1395; http://www.ul.com

8 United States Food and Drug Administration/ Center for Devices and Radiological Health (FDA/CDRH). Available from FDA/CDRH; http://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfcfr/cfrsearch.cfm

9 ACGIH, 1330 Kemper Meadow Road, Cincinnati, OH 45240, USA. http://www.acgih.org

10 ASHRAE, 1791 Tullie Circle, NE, Atlanta, GE 30329, USA. http://www.ashrae.org

11 IVE, Inc., 2974 South Oakwood, Bountiful, UT 84010, USA. http://www.eburton.com

12 International Conference of Building Officials, 5360 Workman Mill Road, Whittier, CA 90601-2298, USA. http://www.icbo.org

13 International Fire Code Institute, 5360 Workman Mill Road, Whittier, CA 90601-2298, USA. http://www.ifci.org

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Full document details: SEMI S2-0310

5.2.3 *baseline* — for the purposes of this document, "baseline" refers to operating conditions, including process chemistry, for which the equipment was designed and manufactured.

5.2.4 *breathing zone* — imaginary globe, of 600 mm (two foot) radius, surrounding the head.

5.2.5 *capture velocity* — the air velocity that at any point in front of the exhausted hood or at the exhausted hood opening is necessary to overcome opposing air currents and to capture the contaminated air at that point by causing it to flow into the exhausted hood.

5.2.6 *carcinogen* — confirmed or suspected human cancer-causing agent as defined by the International Agency for Research on Cancer (IARC) or other recognized entities.

5.2.7 *chemical distribution system* — the collection of subsystems and components used in a semiconductor manufacturing facility to control and deliver process chemicals from source to point of use for wafer manufacturing processes.

5.2.8 *cleanroom* — a room in which the concentration of airborne particles is controlled to specific limits.

5.2.9 *combustible material* — for the purpose of this guideline, a combustible material is any material that does propagate flame (beyond the ignition zone with or without the continued application of the ignition source) and does not meet the definition in this section for noncombustible material. See also the definition for *noncombustible material*.

5.2.10 *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) that may be damaged as a result of equipment failure.

5.2.11 *face velocity* — velocity at the cross-sectional entrance to the exhausted hood.

5.2.12 *facilitization* — the provision of facilities or services.

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

NOTE 2: 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.

5.2.14 *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 3: A FECS is a subsystem to a (PES) Programmable Electronic System as defined in IEC61508-4 Definitions.

NOTE 4: Related Information 13 provides additional information on applications of FECS design.

5.2.15 *failure* — the termination of the ability of an item to perform a required function. Failure is an event, as distinguished from "fault," which is a state.

5.2.16 *fault* — the state of an item characterized by inability to perform a required function, excluding the inability during preventive maintenance or other planned actions, or due to lack of external resources.

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

5.2.18 *flammable gas* — any gas that forms an ignitable mixture in air at 20°C (68°F) and 101.3 kPa (14.7 psia).

5.2.19 *flammable liquid* — a liquid having a flash point below 37.8°C (100°F).

5.2.20 *flash point* — the minimum temperature at which a liquid gives off sufficient vapor to form an ignitable mixture with air near the surface of the liquid, or within the test vessel used.

5.2.21 *gas cylinder cabinet* — cabinet used for housing gas cylinders, and connected to gas distribution piping or to equipment using the gas. Synonym: gas cabinet.

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5.2.22 *gas panel* — an arrangement of fluid handling components (e.g., valves, filters, mass flow controllers) that regulates the flow of fluids into the process. Synonyms: gas jungle, jungle, gas control valves, valve manifold.

5.2.23 *gas panel enclosure* — an enclosure designed to contain leaks from gas panel(s) within itself. Synonyms: jungle enclosure, gas box, valve manifold box.

5.2.24 *harm* — physical injury or damage to health of people, or damage to equipment, buildings, or environments.

5.2.25 *hazard* — condition that has the potential to cause harm.

5.2.26 *hazardous production material (HPM)* — a solid, liquid, or gas that has a degree-of-hazard rating in health, flammability, or reactivity of class 3 or 4 as ranked by NFPA 704 and which is used directly in research, laboratory, or production processes that have as their end product materials that are not hazardous.

5.2.27 *hazardous voltage* — unless otherwise defined by an appropriate international standard applicable to the equipment, voltages greater than 30 volts rms, 42.4 volts peak, 60 volts dc are defined in this document as hazardous voltage.

NOTE 5: The specified levels are based on normal conditions in a dry location.

5.2.28 *hinged load* — a load supported by a hinge such that the hinge axis is not vertical.

5.2.29 *hood* — in the context of § 22 of this guideline, "hood" means a shaped inlet designed to capture contaminated air and conduct it into an exhaust duct system.

5.2.30 *incompatible* — as applied to chemicals: in the context of § 23 of this guideline, describes chemicals that, when combined unintentionally, may react violently or in an uncontrolled manner, releasing energy that may create a hazardous condition.

5.2.31 *intended reaction product* — chemicals that are produced intentionally as a functional part of the semiconductor manufacturing process.

5.2.32 *interlock* — a mechanical, electrical or other type of device or system, the purpose of which is to prevent or interrupt the operation of specified machine elements under specified conditions.

5.2.33 *ionizing radiation* — alpha particles, beta particles, gamma rays, X-rays, neutrons, high-speed electrons, high-speed protons, and other particles capable of producing ions in human tissue.

5.2.34 *laser* — any device that can be made to produce or amplify electromagnetic radiation in the wavelength range from 180 nm to 1 mm primarily by the process of controlled stimulated emission.

5.2.35 *laser product* — any product or assembly of components that constitutes, incorporates, or is intended to incorporate a laser or laser system (including laser diode), and that is not sold to another manufacturer for use as a component (or replacement for such component) of an electronic product.

5.2.36 *laser source* — any device intended for use in conjunction with a laser to supply energy for the excitation of electrons, ions, or molecules. General energy sources, such as electrical supply mains, should not be considered to be laser energy sources.

5.2.37 *laser system* — a laser in combination with an appropriate laser energy source, with or without additional incorporated components.

5.2.38 *lifting accessory* — a component (e.g., eyehook, shackle, hoist ring, wire rope, chain, or eyebolt) which is part of a lifting fixture or is attached directly between the lifting device and the load in order to lift it.

5.2.39 lifting device — a mechanical or electro-mechanical structure that *is* provided for the purpose of raising and lowering a load during maintenance or service tasks, and *may be* capable of moving the load in one or more horizontal directions.

5.2.40 *lifting equipment* — lifting devices, lifting fixtures and lifting accessories.

5.2.41 *lifting fixture* — a mechanical device or an assembly of lifting accessories (e.g., hoisting yoke, wire rope sling, webbing sling, or chain assembly) placed between the lifting device (but not permanently attached to it) and the load, in order to attach them to each other.

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5.2.42 *likelihood* — the expected frequency with which harm will occur. Usually expressed as a rate (e.g., events per year, per product, or per substrate processed).

5.2.43 *local exhaust ventilation* — local exhaust ventilation systems operate on the principle of capturing a contaminant at or near its source and moving the contaminant to the external environment, usually through an air cleaning or a destructive device. It is not to be confused with laminar flow ventilation. Synonyms: LEV, local exhaust, main exhaust, extraction system, module exhaust, individual exhaust.

5.2.44 *lower explosive limit* — the minimum concentration of vapor in air at which propagation of flame will occur in the presence of an ignition source. Synonyms: LEL, lower flammability limit (LFL).

5.2.45 *maintenance* — planned or unplanned activities intended to keep equipment in good working order. See also the definition for *service.*

5.2.46 *mass balance* — a qualitative, and where possible, quantitative, specification of mass flow of input and output streams (including chemicals, gases, water, de-ionized water, compressed air, nitrogen, and by-products), in sufficient detail to determine the effluent characteristics and potential treatment options.

5.2.47 *material safety data sheet (MSDS)* — written or printed material concerning chemical elements and compounds, including hazardous materials, prepared in accordance with applicable standards.

5.2.48 *maximum permissible exposure (MPE)* — level of laser radiation to which, under normal circumstances, persons may be exposed without suffering adverse effects.

5.2.49 *nominal ocular hazard distance (NOHD)* — distance at which the beam irradiance or radiant exposure equals the appropriate corneal maximum permissible exposure (MPE).

NOTE 6: Examples of such standards are USA government regulation 29 CFR 1910.1200, and Canadian WHMIS (Workplace Hazardous Material Information System).

5.2.50 *noncombustible material* — a material that, in the form in which it is used and under the conditions anticipated, will not ignite, burn, support combustion, or release flammable vapors when subjected to fire or heat. Typical noncombustible materials are metals, ceramics, and silica materials (e.g., glass and quartz). See also the definition for *combustible material*.

5.2.51 *non-ionizing radiation* — forms of electro-magnetic energy that do not possess sufficient energy to ionize human tissue by means of the interaction of a single photon of any given frequency with human tissue. Non-ionizing radiation is customarily identified by frequencies from zero hertz to 3×10^{15} hertz (wavelengths ranging from infinite to 100 nm). This includes: static fields (frequencies of 0 hertz and infinite wavelengths); extremely low frequency fields (ELF), which includes power frequencies; subradio-frequencies; radiofrequency/microwave energy; and infrared, visible, and ultraviolet energies.

5.2.52 *non-recycling, deadman-type abort switch* — a type of abort switch that must be constantly held closed for the abort of the fire detection or suppression system. In addition, it does not restart or interrupt any time delay sequence for the detection or suppression system when it is activated.

5.2.53 *occupational exposure limits (OELs)* — for the purpose of this document, OELs are generally established on the basis of an eight hour workday. Various terms are used to refer to OELs, such as permissible exposure levels, Threshold Limit Values®, maximum acceptable concentrations, maximum exposure limits, and occupational exposure standards. However, the criteria used in determining OELs can differ among the various countries that have established values. Refer to the national bodies responsible for the establishment of OELs. (Threshold Limit Value is a registered trademark of the American Conference of Governmental Industrial Hygienists.)

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

5.2.55 *parts-cleaning hood* — exhausted hood used for the purpose of cleaning parts or equipment. Synonym: equipment cleaning hood.

5.2.56 *placed on the market* — made physically available, regardless of the legal aspects of the act of transfer (loan, gift, sale, hire).

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5.2.57 *positive-opening* — as applied to electromechanical control devices. The achievement of contact separation as a direct result of a specified movement of the switch actuator through non-resilient members (i.e., contact separation is not dependent upon springs).

5.2.58 *potentially hazardous non-ionizing radiation emissions* — for the purposes of this guideline, non-ionizing radiation emissions outside the limits shown in Appendix 4 are considered potentially hazardous.

5.2.59 *pyrophoric material* — a chemical that will spontaneously ignite in air at or below a temperature of 54.4°C (130°F).

5.2.60 *radio frequency (rf)* — electromagnetic energy with frequencies ranging from 3 kHz to 300 GHz. Microwaves are a portion of rf extending from 300 MHz to 300 GHz.

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

5.2.62 *recognized* — as applied to standards; agreed to, accepted, and practiced by a substantial international consensus.

5.2.63 *rem* — unit of dose equivalent. Most instruments used to measure ionizing radiation read in dose equivalent (rems or sieverts). 1 rem = 0.01 sievert.

5.2.64 *reproductive toxicants* — chemicals that are confirmed or suspected to cause statistically significant increased risk for teratogenicity, developmental effects, or adverse effects on embryo viability or on male or female reproductive function at doses that are not considered otherwise maternally or paternally toxic.

5.2.65 *residual* — as applied to risks or hazards: that which remains after engineering, administrative, and work practice controls have been implemented.

5.2.66 *risk* — the expected magnitude of losses from a hazard, expressed in terms of severity and likelihood.

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

5.2.68 *safety critical part* — discrete device or component, such as used in a power or safety circuit, whose proper operation is necessary to the safe performance of the system or circuit.

5.2.69 *service* — unplanned activities intended to return equipment that has failed to good working order. See also the definition for *maintenance.*

5.2.70 *severity* — the extent of potential credible harm.

5.2.71 *short circuit current rating* — the maximum available current to which an equipment supply circuit is intended, by the equipment manufacturer, to be connected.

NOTE 7: Short circuit current rating for an electrical system is typically based on the analysis of short circuit current ratings of the components within the system. See UL 508A and Related Information 2 of SEMI S22 for methods of determining short circuit rating.

5.2.72 *sievert (Sv)* — unit of dose equivalent. Most instruments used to measure ionizing radiation read in dose equivalent (rems or sieverts). 1 Sv = 100 rems.

5.2.73 *standard temperature and pressure* — for ventilation measurements, either dry air at 21°C (70°F) and 760 mm (29.92 inches) Hg, or air at 50% relative humidity, 20°C (68°F), and 760 mm (29.92 inches) Hg.

5.2.74 *supervisory alarm* — as applied to fire detection or suppression systems; an alarm indicating a supervisory condition.

5.2.75 *supervisory condition* — as applied to fire detection or suppression systems; condition in which action or maintenance is needed to restore or continue proper function.

5.2.76 *supplemental exhaust* — local exhaust ventilation that is used intermittently for a specific task of finite duration.

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Full document details: SEMI S2-0310

5.2.77 *supplier* — party that provides equipment to, and directly communicates with, the user. A supplier may be a manufacturer, an equipment distributor, or an equipment representative. See also the definition for *user*.

5.2.78 *testing* — the term "testing" is used to describe measurements or observations used to validate and document conformance to designated criteria.

5.2.79 *trouble alarm* — as applied to fire detection or suppression systems; an alarm indicating a trouble condition.

5.2.80 *trouble condition* — as applied to fire detection or suppression systems; a condition in which there is a fault in a system, subsystem, or component that may interfere with proper function.

5.2.81 *user* — party that acquires equipment for the purpose of using it to manufacture semiconductors. See also the definition for *supplier*.

5.2.82 *velocity pressure (VP)* — the pressure required to accelerate air from zero velocity to some velocity V. Velocity pressure is proportional to the kinetic energy of the air stream. Associated equation:

$$VP = (V/4.043)^2 \tag{3}$$

where:

V = air velocity in m/s

VP = velocity pressure in mm water gauge (w.g.)

$$\text{U.S. units: } VP = (V/4005)^2 \tag{4}$$

where:

V = velocity in feet per second

VP = velocity pressure in inches water gauge (w.g.)

5.2.83 *volumetric flow rate (Q)* — in the context of § 22 of this guideline, Q = the volume of air exhausted per unit time. Associated equation:

$$Q = VA \tag{5}$$

where:

V = air flow velocity

A = the cross-sectional area of the duct or opening through which the air is flowing at standard conditions.

5.2.84 *wet station* — open surface tanks, enclosed in a housing, containing chemical materials used in the manufacturing of semiconductor materials. Synonyms: wet sink, wet bench, wet deck.

5.2.85 *yield strength* — the stress at which a material exhibits a specified permanent deformation or set. This is the stress at which, the strain departs from the linear portion of the stress-strain curve by an offset unit strain of 0.002.[14]

6 Safety Philosophy

6.1 A primary objective of the industry is to eliminate or control hazards during the equipment's life cycle (i.e., the installation, operation, maintenance, service, and disposal of equipment).

6.2 The assumption is made that operators, maintenance personnel, and service personnel are trained in the tasks that they are intended to perform.

6.3 The following should be considered in the design and construction of equipment:

- regulatory requirements;
- industry standards;
- this guideline; and
- good engineering and manufacturing practices.

14 *Roark's Formulas for Stress and Strain,* Seventh Edition, McGraw-Hill (2002): p. 826.

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6.4 This guideline should be applied during the design, construction, and evaluation of semiconductor equipment, in order to reduce the expense and disruptive effects of redesign and retrofit.

6.5 No reasonably foreseeable single-point failure condition or operational error should allow exposure of personnel, facilities, or the community to hazards that could result in death, significant injury, or significant equipment damage.

NOTE 8: The intent is to control single fault conditions that result in significant risks (i.e., Very High, High, or Medium risks based on the example risk assessment matrix in SEMI S10).

NOTE 9: The risk category of "Very High" corresponds identically to the risk category, used in previous SEMI documents (e.g., SEMI S10-1296, SEMI S2, and SEMI S14) of "Critical." The term was changed to facilitate translation from English.

6.6 Equipment safety features should be fail-safe or of a fault-tolerant design and construction.

6.7 Components and assemblies should be used in accordance with their manufacturers' ratings and specifications, where using them outside the ratings would create a safety hazard.

6.8 A hazard analysis should be performed to identify and evaluate hazards. The hazard analysis should be initiated early in the design phase, and updated as the design matures.

6.8.1 The hazard analysis should include consideration of:

- the application or process;
- the hazards associated with each task;
- anticipated failure modes;
- the probability of occurrence and severity of harm;
- the level of expertise of exposed personnel and the frequency of exposure;
- the frequency and complexity of operating, servicing and maintenance tasks; and
- safety critical parts.

NOTE 10: EN 1050 contains examples of hazard analysis methods.

NOTE 11: The term mishap was replaced with the results of harm in the SEMI S10-1103 revision.

NOTE 12: Related Information 15 provides some discussion of safety considerations related to equipment remote control.

6.8.2 The risks associated with hazards should be characterized using SEMI S10.

6.9 The order of precedence for resolving identified hazards should be as follows:

6.9.1 *Design to Eliminate Hazards* — From the initial concept phase, the supplier should design to eliminate hazards.

NOTE 13: It is recommended that the supplier continue to work to eliminate identified hazards.

6.9.2 *Incorporate Safety Devices* — If identified hazards cannot be eliminated or their associated risk adequately controlled through design selection, then the risk should be reduced through fixed, automatic, or other protective safety design features or devices.

NOTE 14: It is recommended that provisions be made for periodic functional checks of safety devices, when applicable.

6.9.3 *Provide Warning Devices* — If design or safety devices cannot effectively eliminate identified hazards or adequately reduce associated risk, a means should be used to detect the hazardous condition and to produce a warning signal to alert personnel of the hazard.

6.9.4 *Provide Hazard Warning Labels* — Where it is impractical to eliminate hazards through design selection or adequately reduce the associated risk with safety or warning devices, hazard warning labels should be provided. See § 10 for label information.

6.9.5 *Develop Administrative Procedures and Training* — Where hazards are not eliminated through design selection or adequately controlled with safety or warning devices or warning labels, procedures and training should be used. Procedures may include the use of personal protective equipment.

6.9.6 A combination of these approaches may be needed.

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Full document details: SEMI S2-0310

7 General Provisions

7.1 This guideline should be incorporated by reference in equipment purchase specifications. The user and supplier should agree on deviations from this guideline. The intent is for the user to purchase equipment conforming with SEMI S2, not to design the equipment.

7.2 The equipment must comply with laws and regulations that are in effect at the location of use. All equipment requiring certification or approval by government agencies must have this certification or approval as required by regulations.

NOTE 15: It is recommended that the supplier request from the user information regarding local laws and regulations.

7.3 The manufacturer should maintain an equipment/product safety program to identify and eliminate hazards or control risks in accordance with the order of precedence (see § 6.9).

7.3.1 The supplier should provide the user's designated representative with bulletins that describe safety related upgrades or newly identified significant hazards associated with the equipment. This should be done on an ongoing basis as needed.

7.4 Model-specific tools and accessories necessary to operate, maintain, and service equipment safely should be provided with the equipment or specified by the supplier.

NOTE 16: The official values in this guideline are expressed in The International System of Units (SI). Values that:

- are expressed in Inch-Pound (also known as "US Customary" or "English") units,
- are enclosed in parentheses,
- directly follow values expressed in SI units, and
- are not official, are provided for reference only, and might not be exact conversions of the SI values.

8 Evaluation Process

8.1 This section describes the evaluation of equipment to this guideline, the contents of the evaluation report, and supporting information needed to perform the evaluation.

8.2 *General* — The evaluating party (see § 8.4) should evaluate the equipment <u>and related end user documentation</u> according to this guideline and create a written evaluation report.

NOTE 17: The intent is that the "should" provisions of this guideline be used as the basis for evaluating conformance. The intent is also that the "may," "suggested," "preferred," "recommended," and "NOTE" provisions of this guideline not be used for evaluating conformance.

8.2.1 Conformance to specific paragraphs of SEMI S2 may be achieved by instructions included in the supplier's equipment installation instructions (reference SEMI E6) or other documentation.

8.3 *Evaluation Report Contents: General* — The evaluation report should include only the manuals (see § 9.6) and the design-specific sections (see §§ 10–27). The Appendices should be used in the evaluation, and referenced in the report, only as they pertain to the specific application.

8.3.1 For each numbered paragraph, the evaluation report should state one of the following, and provide supporting rationale, according to the criteria in §§ 8.3.3 thru 8.3.5:

- "N/A"
- "Conforms to the Stated Criteria"
- "Conforms to the Performance Goal"
- "Does not Conform"

EXCEPTION 1: If all of a particular section is found to be "N/A", then the report may state the section is "N/A" rather than state "N/A" for each subordinate paragraph.

EXCEPTION 2: If the equipment aspects to which a paragraph pertains are found to be a mix of "Conforms to the Stated Criteria" and "Conforms to the Performance Goal", then both findings should be indicated in the report (with appropriate supporting rationale) instead of only one or the other.

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Full document details: SEMI S2-0310

NOTE 18: "Conforms to the Stated Criteria" and "Conforms to the Performance Goal" are both findings indicating conformance. The findings are differentiated, as the appropriate supporting rationale for these findings differs.

8.3.2 Within § 8.3, "equipment" means the equipment under evaluation, or the related end user documentation provided with the equipment, as appropriate. (See SEMI S13 for the meaning of "end user documentation.")

8.3.3 *Not Applicable* — A finding of "Not Applicable" should be given if the evaluator concludes there are no equipment aspects to which the paragraph pertains.

8.3.4 *Conformance Findings ("Conforms to the Stated Criteria" and "Conforms to the Performance Goal")*

8.3.4.1 A finding of "Conforms to the Stated Criteria" should be given if the evaluator concludes the equipment aspects to which the paragraph pertains match the criteria stated in the text of the paragraph.

8.3.4.2 The supporting rationale for "Conforms to the Stated Criteria" should include a description of the equipment aspects, and the objective information demonstrating the conformance of each to the criteria (e.g., testing, measurements, observation).

8.3.4.3 A finding of "Conforms to the Performance Goal" should be given if the evaluator concludes the equipment aspects to which the paragraph pertains do not match the stated criteria, but they do meet the performance goal of the paragraph and they present a Low or Very Low Risk according to the risk assessment method of SEMI S10.

8.3.4.4 The supporting rationale for "Conforms to the Performance Goal" should include:

8.3.4.4.1 a description of the equipment aspects,

8.3.4.4.2 and, to support the conclusion of meeting the performance goal;

- a statement of the performance goal as it is understood by the evaluator,
- the logical argument which demonstrates the performance goal has been met,
- the objective evidence used to support the argument, and
- bibliographic information for references made in the argument (e.g., document title, website, reference number, author, publication date, revision).

8.3.4.4.3 and, to support the risk assessment;

- the specific hazards presented by the equipment aspects,
- the scenarios in which the hazards are foreseen to cause harm,
- the harm foreseen in each scenario, and
- the severity and likelihood analyses for each scenario.

8.3.4.5 If a standard is used in whole or in part to support the performance goal argument, the supporting rationale should include information demonstrating why the standard is applicable, the section or sections used for the evaluation, and why the sections are relevant. For the purpose of this paragraph, a standard is applicable if the equipment aspect under consideration is properly within scope, and the sections are relevant if they contain criteria having demonstrable bearing to the equipment aspects (e.g., addressing similar design considerations).

8.3.5 *Does Not Conform*

8.3.5.1 A finding of "Does Not Conform" should be given if the evaluator concludes that one or more equipment aspects:

- to which the paragraph pertains do not conform to the stated criteria and do not conform to the performance goal; or
- for which there is insufficient information available to the evaluator to reach a conclusion for these or the "N/A" finding.

8.3.5.2 The supporting rationale for this finding should include a description of the non-conforming equipment aspect(s), a description of the non-conforming characteristics, and a determination per SEMI S10 of the associated risk; or a description of the information needed to reach a conclusion for one of the conformance findings or the "N/A" finding; as appropriate.

Documents
Document Sharing Hub
Full document details: SEMI S2-0310

NOTE 19: For example, "circuit breaker 42" is an equipment aspect; "circuit breaker 42" being a supplementary overcurrent protector rather than a circuit breaker is a characteristic.

8.3.5.3 The evaluator may include any information they wish about remaining equipment aspects which conform to the stated criteria or conform to the performance goal. None the less, it should be clear in the report that the overall finding is "Does Not Conform."

8.4 *Evaluation Report Contents: Other Information* — The evaluation report should also include:

- manufacturer's model number;
- serial number of unit(s) evaluated;
- the date(s) that the equipment was evaluated;
- a system/equipment description including configuration, options, and essential diagrams; and
- a statement of the qualifications of the evaluating party. An in-house body, independent laboratory, or product safety consulting firm ("third party") meeting the provisions of SEMI S7 may be used to supply testing or evaluation of conformance to this document.

8.5 *Supporting Information Provided to Evaluator* — The following documentation should be provided to, or developed by, the evaluator, as necessary to demonstrate conformance to the provisions of this guideline.

NOTE 20: It is recommended that the manufacturer's typical configuration and process be used for evaluation purposes. Alternatively, a process agreed upon between the user and the supplier may be used.

NOTE 21: Special options or configurations that may pose additional hazards and are not included in the initial evaluation may need a separate review. It is recommended that upgrades, retrofits, and other changes that affect the safety design of the equipment be evaluated for conformance.

8.5.1 *General Information*

- Written system description, including hardware configuration and function(s), power requirements, power output, and other information necessary to understand the design and operation of the equipment.
- Engineering data used to provide the rationale that the equipment and subassembly seismic anchorages are designed to satisfy the applicable design loads (see § 19, Seismic Protection).
- Descriptions of the purpose and function of safety devices, such as: emergency off devices (EMOs), interlocks, pressure relief devices, and limit controls.
- A hazard analysis (see § 6.8).
- Ergonomics evaluation (see § 16).
- A list of safety critical parts and, for each one, evidence of certification, or documentation showing that the component is suitable for its application.
- A residual fire risk assessment as described in § 14.2.
- Tests results, certifications, and design specifications that are necessary to evaluate the equipment with respect to fire safety. Descriptions of the fire detection and suppression equipment and controls should also be provided.

8.5.2 *Industrial Hygiene Information*

8.5.2.1 An industrial hygiene report, which should include, as applicable:

- ventilation assessment (see § 22);
- chemical inventory and hazard analysis (see § 23);
- ionizing radiation assessment (see § 24);
- non-ionizing radiation assessment (see § 25);
- laser assessment (see § 26); and
- audio sound pressure level assessment (see § 27).

8.5.3 *Environmental Information* (see § 21) — Documentation substantiating the following:

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Full document details: SEMI S2-0310

- consideration or inclusion of features that conserve resources (e.g., energy, water, de-ionized water, compressed gases, chemicals, and packaging);
- consideration of features that would promote equipment and component reuse or refurbishing, or material recycling upon decommissioning;
- consideration or inclusion of features for resource recycling or reuse;
- chemical selection methods and criteria (see § 21.2.3);
- consideration of integrating effluent and emission controls into the equipment; and
- efforts to reduce wastes, effluents, emissions, and by-products.

NOTE 22: For purposes of § 8.5.3, documentation may include design notes, metrics (whether normalized or not), meeting minutes, pareto evaluations, or other analyses.

9 Documents Provided to User

9.1 This section describes the documents that the supplier provides to the user.

9.2 *Evaluation Report* — Upon request by the user, the supplier should provide the user with a summary of the SEMI S2 evaluation report (see § 8) or the full report.

9.2.1 Non-conformances noted in the report should be addressed by the supplier, by providing either an action plan or a justification for acceptance. The justification should include countermeasures in place and a risk characterization per SEMI S10.

9.3 *Seismic Information* — Refer to § 19 of this document.

9.4 *Environmental Documentation* — The manufacturer should provide the user with the following environmental documentation as applicable:

9.4.1 Energy consumption information, including idle, average, and peak operating conditions, for the manufacturer's most representative ("baseline") process.

9.4.2 Mass balance, including idle, average, and peak operating conditions, for the manufacturer's most representative ("baseline") process.

NOTE 23: The mass balance may include resource consumption rates, chemical process efficiencies, wastewater effluent and air emission characterization, solid and hazardous waste generation (quantity and quality), and by-products.

9.4.3 Information regarding routes of unintended release (of effluents, wastes, emissions, and by-products) and methods and devices to monitor and control such releases. This should include information on features to monitor, prevent, and control unintended releases (see § 21.2.4).

9.4.4 Information regarding routes of intended release (of effluents, wastes, and emissions) and features to monitor and control such releases (see § 21.2.5).

9.4.5 A list of items that become solid waste as a result of the operation, maintenance, and servicing of the equipment, and that are constructed of or contain substances whose disposal might be regulated (e.g., beryllium-containing parts, vapor lamps, mercury switches, batteries, contaminated parts, maintenance wastes).

9.5 *Industrial Hygiene and Exhaust Ventilation Information* — Refer to §§ 22–27 of this document and to SEMI S6.

NOTE 24: Documentation criteria appear in various locations in SEMI S6. In SEMI S6-0707, these include ¶ 7.2.3.3.2, ¶ 7.7.3.4.1, § 8, § 9, Appendix 2, Appendix 3, Appendix 4, Appendix 5, and Appendix 6.

9.6 *Manuals*

9.6.1 The supplier should provide the user with manuals based on the originally intended use of the equipment. The manuals should describe the scope and normal use of the equipment, and provide information to enable safe facilitization, operation, maintenance, and service of the equipment.

9.6.2 The manuals should conform to SEMI S13.

NOTE 25: Fire suppression agents, and chemicals used to test fire detection or suppression systems, fall under the MSDS provisions of SEMI S13 when they are provided with the equipment.

Documents
Document Sharing Hub
Full document details: SEMI S2-0310

NOTE 26: Hazardous energies within fire detection or suppression systems fall under the hazardous energy control provisions of SEMI S13 when fire detection or suppression systems are provided with the equipment.

9.6.3 In addition to the provisions of SEMI S13, the manuals should include:

- specific written instructions on routine Type 4 tasks, excluding troubleshooting (refer to § 13.3);
- instructions for energy isolation ("lockout/tagout") (refer to § 17.2);
- description of the emergency off (EMO) and interlock functions;
- a list of hazardous materials (e.g., lubricants, cleaners, coolants) required for maintenance, ancillary equipment or peripheral operations, including anticipated change-out frequency, quantity, and potential for contamination from the process;
- a list of items that become solid waste as a result of the operation, maintenance, and servicing of the equipment, and that are constructed of or contain substances whose disposal might be regulated (e.g., berylium-containing parts, vapor lamps, mercury switches, batteries, contaminated parts, maintenance wastes);
- maintenance and troubleshooting procedures needed to maintain the effectiveness of safety design features or devices (i.e., engineering controls); and
- instructions for proper use, maintenance, and inspection of lifting equipment supplied by the SME supplier, including any guidance on specific inspection intervals. For lifting equipment specified or recommended, but not supplied, by the SME supplier, the documentation provided by the SME supplier should specify that such instructions be obtained by the user from its lifting equipment supplier.

9.6.4 Information should be provided regarding potential routes of unintended releases (see § 21.2.4).

9.6.5 Recommended decontamination and decommissioning procedures should be provided in accordance with SEMI S12, and should include the following information:

- identity of components and materials of construction, in sufficient detail to support recycling, refurbishment, and reuse decisions (see § 8.5.3); and
- residual hazardous materials, or parts likely to become contaminated with hazardous materials, that may be in the equipment prior to decommissioning.

NOTE 27: It is recommended that the manual state that changes to the typical process chemistry or to the equipment could alter the anticipated environmental impact.

9.6.6 *Maintenance Procedures with Potential Environmental Impacts* — The supplier's recommended maintenance procedures should:

- identify procedural steps during which releases might occur, and the nature of the releases; and
- identify waste characteristics and methods to minimize the volume of effluents, wastes, or emissions generated during maintenance procedures.

9.7 *Fire Protection Documentation* — The equipment supplier should provide:

- a summary fire protection report as described in § 14.3;
- descriptions of optional fire risk mitigation features (see § 14.3.2);

NOTE 28: It is recommended that this be provided prior to purchase.

- fire detection system operations, maintenance, and test manuals;
- fire suppression system operations, maintenance, and test manuals;
- acceptance documents provided by licensed designers and installers (see § 14.4.4.12 and § 14.4.5.16); and
- a list of any special apparatus needed to test the fire detection or suppression features of the equipment. The list should note whether the apparatus is included with the equipment, or is sold separately.

10 Hazard Warning Labels

10.1 Where it is impractical to eliminate hazards through design selection or to adequately reduce the associated risk with safety or warning devices, hazard warning labels should be provided to identify and warn against hazards.

Documents Document Sharing Hub
Full document details: SEMI S2-0310

10.2 Labels should be durable and suitable for the environment of the intended use.

10.3 Labels should conform to SEMI S1.

EXCEPTION: Some hazard label formats and content are dictated by law (e.g., laser labeling and chemical hazard communication labeling in certain countries of use) and may not conform to SEMI S1.

11 Safety Interlock Systems

11.1 This section covers safety interlocks and safety interlock systems.

NOTE 29: If a fire detection or suppression system is provided with the equipment, see § 14 for additional information.

11.2 Where appropriate, equipment should use safety interlock systems that protect personnel, facilities, and the community from hazards inherent in the operation of the equipment.

NOTE 30: Safety critical parts whose primary function is to protect the equipment (e.g., circuit breakers, fuses) are typically not considered to be safety interlocks.

11.3 Safety interlock systems should be designed such that, upon activation of the interlock, the equipment, or relevant parts of the equipment, is automatically brought to a safe condition.

NOTE 31: Timing is relevant to risk; a safe condition includes bringing the equipment to a safe state before the hazard can be accessed by personnel.

11.4 Upon activation, the safety interlock should alert the operator immediately.

EXCEPTION: Alerting the operator is not expected if a safety interlock triggers the EMO circuit (see § 12) or otherwise removes power to the user interface.

NOTE 32: An explanation of the cause is preferred upon activation of a safety interlock.

11.5 Safety interlock systems should be fault-tolerant and designed so that the functions or set points of the system components cannot be altered without disassembling, physically modifying, or damaging the device or component.

EXCEPTION: When safety interlock systems having adjustable set points or trip functions are used, access should be limited to maintenance or service personnel by requiring a deliberate action, such as using a tool or special keypad sequences, to access the adjustable devices or to adjust the devices.

NOTE 33: This section does not address the defeatability of safety interlocks. See § 11.7 for additional information.

11.6 Electromechanical devices and components are preferred. Solid-state devices and 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, and jarring.

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

NOTE 34: Where a safety interlock is provided to safeguard personnel from severe or catastrophic harm as categorized by SEMI S10, consideration of positive-opening type switches is recommended.

NOTE 35: Evaluation for suitability for use may also include reliability, self-monitoring, and redundancy as addressed under standards such as NEMA ICS 1.1 and UL 991.

NOTE 36: Solid-state devices include operational amplifiers, transistors, and integrated circuits.

11.6.1 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, ANSI/ISA SP84.01, DIN V VDE-0801.

NOTE 37: ¶ 13.4.3 states additional assessment criteria for safety-related components and assemblies.

Documents
Document Sharing Hub
Full document details: SEMI S2-0310

NOTE 38: A FECS is a subsystem of a (PES) Programmable Electronic System. IEC 61508 is the preferred standard for complex PES.

NOTE 39: Related Information 13 provides additional information on applications of FECS design.

11.7 The safety interlock system should be designed to minimize the need to override safety interlocks during maintenance activities.

11.7.1 Safety interlocks that safeguard personnel during operator tasks should not be defeatable without the use of a tool.

11.7.2 When maintenance access is necessary to areas protected by interlocks, defeatable safety interlocks may be used, provided that they require an intentional operation to bypass.

11.7.2.1 Upon exiting or completing the maintenance mode, all safety interlocks should be automatically restored.

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

11.8 The restoration of a safety interlock should not initiate equipment operation or parts movement where this can give rise to a hazardous condition.

11.9 Switches and other control device contacts should be connected to the ungrounded side of the circuit so that a short circuit to ground does not result in the interlocks being satisfied.

11.10 Where a hazard to personnel is controlled through the use of an enclosure, the enclosure should either: require a tool to gain access and be labeled regarding the hazard against which it protects personnel; or be interlocked. In addition to enclosures, physical barriers at the point of hazard should be included where inadvertent contact is likely.

NOTE 40: Where the removal of a cover exposes a hazard, consider additional labels. See § 10 for guidance.

12 Emergency Shutdown

12.1 The equipment should have an "emergency off" (EMO) circuit. The 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: An EMO circuit is not needed for equipment rated 2.4 kVA or less, where the hazards are only electrical in nature, provided that the main disconnect meets the accessibility provisions of § 12.5.2 and that the effect of disconnecting the main power supply is equivalent to activating an EMO circuit.

EXCEPTION 2: Assemblies that are not intended to be used as stand-alone equipment, but rather within an overall integrated system, and that receive their power from the user's system, are not required to have an 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 41: 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 chucks or braking devices) necessary to bring the equipment to a safe shutdown condition effectively.

NOTE 42: If a fire detection or suppression system is provided with the equipment, see § 14 for additional information.

12.1.1 If the supplier provides an external EMO interface on the equipment, the supplier should include instructions for connecting to the interface.

12.2 Activation of the emergency off circuit should de-energize all hazardous voltage and all power greater than 240 volt-amps in the equipment beyond the main power enclosure.

EXCEPTION 1: A non-hazardous voltage EMO circuit (typically 24 volts) and its supply 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 performing data/alarm logging and error recovery functions may remain energized, provided that the energized breaker(s), receptacle(s), and each energized conductor termination are

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Full document details: SEMI S2-0310

clearly labeled as remaining energized after EMO activation. Hazardous energized parts that remain energized after EMO activation should be insulated or guarded to prevent inadvertent contact by personnel.

EXCEPTION 4: Multiple units mounted separately with no shared hazards and without interconnecting circuits with hazardous voltages, energy levels or other hazardous conditions may have:

- separate sources of power and separate supply circuit disconnect means if clearly identified, or
- separate EMO circuits, if they are clearly identified.

12.2.1 The EMO circuit should not include features that are intended to allow it to be defeated or bypassed.

12.2.2 The EMO circuit should consist of electromechanical components.

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 over voltage, ramp voltage, electromagnetic susceptibility, electrostatic discharge, thermal cycling, humidity, dust, vibration and jarring. The final removal of power should be accomplished by means of electromechanical components.

EXCEPTION 2: FECS may be used provided the FECS 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. IEC 61508 and ISO 13849-1 are examples of internationally recognized electronic safety systems standards. The final removal of power should be accomplished by means of electromechanical components.

NOTE 43: ¶ 13.4.3 states additional assessment criteria for safety-related components and assemblies.

NOTE 44: A FECS is a subsystem of a (PES) Programmable Electronic System. IEC 61508 is the preferred standard for complex PES.

12.2.3 All EMO circuits should be fault-tolerant.

12.2.4 Resetting the EMO switch should not re-energize circuits, equipment, or subassemblies.

12.2.5 The EMO circuit should shut down the equipment by de-energizing rather than energizing control components.

12.2.6 The EMO circuit should require manual resetting so that power cannot be restored automatically.

12.3 The emergency off button should be red, mushroom shaped, and self latching. A yellow background for the EMO should be provided.

12.4 All emergency off buttons 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 button or on the yellow background.

12.5 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.

12.5.1 Emergency off buttons should be located or guarded to minimize accidental activation.

12.5.2 No operation or regularly scheduled maintenance location should require more than 3 m (10 feet) travel to an EMO button.

12.5.3 The person actuating or inspecting the EMO button should not be exposed to serious risks of tripping or falling or of coming in contact with energized electrical parts, moving machinery, surfaces or objects operating at high temperatures, or other hazardous equipment.

12.6 See § 13.5 for additional EMO guidelines when EMOs are used with UPSs.

13 Electrical Design

13.1 This section covers electrical and electronic equipment that use hazardous voltages.

Documents
Document Sharing Hub
Full document details: SEMI S2-0310

13.2 *Types of Electrical Work* — The following are the four types of electrical work defined by this guideline:

- *Type 1* — Equipment is fully de-energized.
- *Type 2* — Equipment is energized. Energized circuits are covered or insulated.

NOTE 45: Type 2 work includes tasks where the energized circuits are or can be measured by placing probes through suitable openings in the covers or insulators.

- *Type 3* — Equipment is energized. Energized circuits are exposed and inadvertent contact with uninsulated energized parts is possible. Potential exposures are no greater than 30 volts rms, 42.4 volts peak, 60 volts dc or 240 volt-amps in dry locations.
- *Type 4* — Equipment is energized. Energized circuits are exposed and inadvertent contact with uninsulated energized parts is possible. Potential exposures are greater than 30 volts rms, 42.4 volts peak, 60 volts dc, or 240 volt-amps in dry locations. Potential exposures to radio-frequency currents, whether induced or via contact, exceed the limits in Table A4-1 of Appendix 4.

13.3 *Energized Electrical Work* — The supplier should design the equipment to minimize the need to calibrate, modify, repair, test, adjust, or maintain equipment while it is energized, and to minimize work that must be performed on components near exposed energized circuits. The supplier should move as many tasks as practical from category 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., wearing appropriate Personal Protective Equipment and establishing barriers) for troubleshooting, including Type 4 work, should be provided.

13.4 *Electrical Design* — Equipment should conform to the appropriate international, regional, national or industry product safety requirements.

13.4.1 Non-conductive or grounded conductive physical barriers should be provided:

- Where it is necessary to reach over, under, or around, or in close proximity to hazards.
- Where dropped objects could cause shorts or arcing.
- Where failure of liquid fittings from any part of the equipment would result in the introduction of liquid into electrical parts.
- Over the line side of the main disconnect.
- Where maintenance or service tasks on equipment in dry locations are likely to allow inadvertent contact with uninsulated 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.

NOTE 46: A dry location can be considered to be one that is not normally subject to dampness or wetness.

NOTE 47: Removable nonconductive and noncombustible covers are preferred.

13.4.2 Where test probe openings are provided in barriers, the barriers should be located, and the probe openings should be sized, to prevent inadvertent contact with adjacent energized parts, including the energized parts of the test probes.

13.4.3 Where failure of components and assemblies could result in a risk of electric shock, fire, or personal injury, those components and assemblies should be certified by an accredited testing laboratory and used in accordance with the manufacturer's specifications, or otherwise evaluated to the applicable standard(s).

NOTE 48: With the exception of implementation of ground fault protection, shunt trip units that require power to trip (actuate) are not recommended to be used in a safety control circuit, because they are not fail-safe.

13.4.4 Electrical wiring for power circuits, control circuits, grounding (earthing) and grounded (neutral) conductors should be color coded according to appropriate standard(s) per § 13.4, or labeled for easy identification at both ends of the wire. Where color is used for identification, it is acceptable to wrap conductor ends with appropriate colored tape or sleeving; the tape or sleeving should be reliably secured to the conductor.

EXCEPTION 1: Internal wiring on individual components (e.g., motors, transformers, meters, solenoid valves, power supplies).

EXCEPTION 2: Flexible cords.

Documents Document Sharing Hub
Full document details: SEMI S2-0310

EXCEPTION 3: Nonhazardous voltage multi-conductor cables (e.g., ribbon cables).

EXCEPTION 4: When proper color is not available for conductors designed for special application (e.g., high-temperature conductors used for furnaces and ovens).

13.4.5 Grounding (earthing) conductors and connectors should be sized to be compatible in current rating with their associated ungrounded conductors according to appropriate standard(s) per § 13.4.

13.4.6 Electrical enclosures should be suitable for the environment in which they are intended to be used.

13.4.7 Enclosure openings should safeguard against personnel access to un-insulated energized parts (refer to Appendix 1 for examples of openings for protection against access from operators).

13.4.8 Top covers of electrical enclosures should be designed and constructed to prevent objects from falling into the enclosures (refer to Appendix 1 for examples of acceptable top enclosure openings).

13.4.9 The short circuit current rating of the equipment or its industrial control panel, for each supply circuit from the facility to the equipment, should be identified in the equipment installation instructions.

13.4.10 The equipment should be provided with main overcurrent protection devices and main disconnect devices rated for at least 10,000 rms symmetrical amperes interrupting capacity (AIC).

NOTE 49: Some facilities may require higher AIC ratings due to electrical distribution system design.

EXCEPTION: Cord- and plug-connected single phase equipment, rated no greater than 240 volts line-to-line/ 150 volts line-to-ground and no greater than 2.4 kVA, may have overcurrent protection devices with interrupting capacity of at least 5,000 rms symmetrical amperes interrupting capacity (AIC).

13.4.11 Equipment should be designed to receive incoming electrical power from the facility to a single feed location that terminates at the main disconnect specified in § 13.4.9. This disconnect, when opened, should remove all incoming electrical power in the equipment from the load side of the disconnect. The disconnect should also have the energy isolation ("lockout") capabilities specified in § 17.

EXCEPTION 1: Equipment with more than one 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 disconnect: "**WARNING**: Risk of Electric Shock or Burn. Disconnect all [number of feed locations] sources of supply prior to servicing." It is preferred that all of the disconnects for the equipment be grouped in one location.

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 disconnect means, if they are clearly identified; or
- separate EMO circuits, if they are clearly identified.

13.4.12 A permanent nameplate listing the manufacturer's name, machine serial number, supply voltage, number of phases, frequency, short circuit current rating of the equipment or its industrial control panel, and full-load current should be attached to the equipment where plainly visible after installation. Where more than one incoming supply circuit is to be provided, the nameplate(s) should state the above information for each circuit.

NOTE 50: Additional nameplate information may be required depending on the location of use.

13.5 *Uninterruptable Power Supplies (UPSs)* — This section applies to UPSs with outputs greater than: 30 volts rms, 42.4 volts peak; 60 volts dc; or 240 volt-amps.

13.5.1 Whenever a UPS is provided with the equipment, its location and wiring should be clearly described within the installation and maintenance manual.

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

- the emergency off actuator (button) is pushed; or
- the main equipment disconnect is opened; or
- the main circuit breaker is opened.

EXCEPTION: Upon EMO activation, the UPS may supply power to the EMO circuit, safety related devices, and data/alarm logging computer systems as described in the exception clauses of § 12.2.

Documents
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Full document details: SEMI S2-0310

13.5.3 The UPS may be physically located within the footprint of the equipment provided that the UPS is within its own enclosure and is clearly identified.

13.5.4 The UPS should be certified by an accredited testing laboratory and be suitable for its intended environment (e.g., damp location, exposure to corrosives).

13.5.5 The UPS wiring should be identified as "UPS Supply Output" or equivalent at each termination point where the UPS wiring can be disconnected.

13.6 *Electrical Safety Tests*

13.6.1 Equipment connected to the facility branch circuit with a cord and plug should not exhibit surface leakage current greater than 3.5 milliampere (mA) as determined by testing completed in accordance with "Leakage Current Test for Cord-and-Plug Equipment" in SEMI S22, Testing section.

EXCEPTION: Equipment with leakage current exceeding 3.5 mA is acceptable if documentation is provided to substantiate that the equipment is fully compliant with an applicable product safety standard that explicitly permits a higher leakage current.

13.6.2 Equipment protective grounding circuits should have a measured resistance of one-tenth (0.1) ohm or less as determined by testing in accordance with "Earthing Continuity and Continuity of the Protective Bonding Circuit Test" in SEMI S22.

13.7 Equipment in which flammable liquids or gases are used should be assessed to determine if additional precautions (e.g., purging) in the electrical design are necessary.

NOTE 51: NFPA 497 and EN 1127-1 provide methods for making this assessment.

14 Fire Protection

14.1 *Overview* — This section applies to fire hazards that are internal to the equipment.

14.1.1 This section provides minimum safety considerations for fire protection designs and controls on the equipment.

14.1.2 This section also provides minimum considerations for fire detection and suppression systems when provided with the equipment.

NOTE 52: Detailed guidance on fire risk assessment and mitigation for semiconductor manufacturing equipment is provided in SEMI S14.

14.2 *Risk Assessment*

14.2.1 A documented risk assessment should be performed or accepted by a party qualified to determine and evaluate fire hazards and the potential need for controls. The risk assessment should consider normal operations and reasonably foreseeable single-point failures within the equipment. It should not consider exposure to fire or external ignition sources not within the specified use environment.

NOTE 53: This risk assessment can be combined with the overall hazard analysis performed for this guideline, provided the risk assessor has the required professional expertise to perform risk assessments for fire hazards. SEMI S7 describes qualifications for such an assessor.

14.2.2 If an accurate risk assessment depends on the user's adherence to specified procedures or conditions of use, the supplier should describe such procedures or conditions and state their importance.

14.2.3 SEMI S14 should be used to assess and report risks to property and the environment.

14.3 *Reporting*

14.3.1 A summary report should be provided to the user. The summary should include the following characterizations, per SEMI S10, for each residual fire hazard identified:

- the assigned Severity;
- the assigned Likelihood; and
- the resulting Risk Category.

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Full document details: SEMI S2-0310

14.3.2 Optional fire risk reduction features should be described in the pre-purchase information provided to the user.

14.3.3 The scope and effectiveness of the means of fire risk reduction should also be identified and reported, including the expected risk reduction (as described in § 14.3.1).

14.3.4 If, due to fire hazards within the equipment, thermal or non-thermal (e.g., smoke) damage is possible outside of the equipment, then this possibility should be reported to the user. This report should include a qualitative description of the foreseen scenario.

14.4 *Fire Risk Reduction*

14.4.1 *Materials of Construction* — Equipment should be constructed of noncombustible materials wherever reasonable. If process chemicals do not permit the use of noncombustible construction, then the equipment should be constructed of materials, suitable for the uses and compatible with the process chemicals used, that contribute least to the fire risk.

NOTE 54: Some regional codes (e.g., Uniform Fire Code) may require construction with noncombustible materials.

14.4.1.1 The flowchart in Appendix 5 may be used for the selection of materials of construction for equipment.

14.4.1.2 Any portion of equipment that falls within the scope of SEMI F14 (Guide for the Design of Gas Source Equipment Enclosures) should be designed in accordance with that guide.

14.4.2 *Elimination of Process Chemical Hazards* — The option of substituting non-flammable process chemicals for flammable process chemicals should be considered.

14.4.3 *Engineering Controls*

14.4.3.1 Fire risks resulting from process chemicals may be reduced using engineering controls (e.g., preventing improper chemical mixing, preventing temperatures from reaching the flash point).

14.4.3.2 Fire risks resulting from materials of construction may be reduced using engineering controls (e.g., non-combustible barriers that separate combustible materials of construction from ignition sources, installing a fire suppression system that extinguishes ignited materials).

14.4.3.3 Equipment power and chemical sources that present unacceptable fire risks should be interlocked with the fire detection and suppression systems to prevent start-up of the equipment or delivery of chemicals when the fire detection or suppression is inactive.

NOTE 55: Some jurisdictions require interlocking.

NOTE 56: Refer to § 6.5 for criteria for acceptability.

14.4.3.4 Shutdown or failure of a fire detection or suppression system need not interrupt the processing of product within the equipment by immediately shutting down the equipment, but should prevent additional processing until the fire detection or suppression is restored. Software or hardware may be used for this function.

14.4.3.5 Controlling smoke by exhausting it (using the supplier-specified equipment exhaust) from the cleanroom may be used to reduce fire risks from the generation of products of combustion. When used, this reduction method should be combined with detection or suppression when flames can be propagated.

NOTE 57: Controlling smoke may be sufficient when smoke is the only consequence (e.g., smoldering components that generate smoke).

NOTE 58: For controlling smoke to be effective, the smoke must be removed not only from the equipment, but also from the cleanroom. This is typically accomplished by using ducted exhaust.

NOTE 59: The use of exhaust to remove smoke may be subject to regulations, such as building and fire codes.

NOTE 60: The use of exhaust to remove smoke may create hazards within the exhaust system. Therefore, a description of the expected discharge (i.e., anticipated air flow rate, temperature, and rate of smoke generation) into the exhaust system may be important information for installation of equipment.

14.4.4 *Fire Detection* — The following criteria apply to any fire detection system determined to be appropriate for fire protection by the fire risk assessment:

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Document Sharing Hub
Full document details: SEMI S2-0310

NOTE 61: Heat detectors, smoke sensing devices, and other devices used solely for monitoring equipment status may not need to meet these requirements. Some local jurisdictions, however, may require that all smoke detectors be connected to building systems and be compliant with all applicable fire alarm codes.

14.4.4.1 The fire detection system, which includes detectors, alarms and their associated controls, should be certified by an accredited testing laboratory and suitable for the application and for the environment in which it is to be used.

NOTE 62: Such certifications typically require that the components of fire detection systems are readily identifiable and distinguishable from other components in the equipment.

14.4.4.2 The fire detection, alarm and control system should be installed in accordance with the requirements of the certification in § 14.4.4.1, and in accordance with requirements of the appropriate international or national codes or standards (e.g., NFPA 72).

14.4.4.3 The fire detection system should be capable of interfacing with the facility's alarm system. It may be preferable for the equipment supplier to specify the location and performance of detectors, but not provide them, so that the user may better integrate the detection in the equipment with that in the facility. This alternative should be negotiated explicitly with the user.

14.4.4.4 The fire detection system should activate alarms audibly and visually at the equipment.

14.4.4.5 Manual activation capability for the fire detection system should be considered, for the purpose of providing notification to a constantly attended location.

14.4.4.6 Activation of trouble or supervisory conditions should result in all of the following:

- notification of the operator;
- allowing the completion of processing of substrates in the equipment;
- prevention of processing of additional substrates until the trouble or supervisory condition is cleared; and
- providing, through an external interface, a signal to the facility monitoring system or a constantly attended location.

NOTE 63: Some local jurisdictions require that such alarms signal the building/facility fire alarm systems.

14.4.4.7 The fire detection system should be capable of operating at all times, including when the equipment is inoperable (e.g., equipment controller problems) or in maintenance modes (e.g., some or all of the equipment's hazardous energies are isolated ("locked out"). For the purpose of this section, "inoperable" includes the equipment states after an EMO is activated and after the equipment has had its hazardous energies isolated (i.e., has been "locked out"). Therefore, the detection system should not require hazardous voltages (e.g., line alternating current) to operate anything other than the equipment within the detection system's control enclosure. Sensors and other devices outside the detection system's control enclosure should not require hazardous voltage.

EXCEPTION: Operability is not required during maintenance of the fire detection system.

14.4.4.7.1 Power at a hazardous voltage may be supplied to the detection system controller enclosure after the equipment EMO is activated or after the equipment has had its hazardous energies isolated only if the wiring providing the hazardous voltage is separated from other wiring and is suitably labeled.

14.4.4.7.2 If the hazardous voltage supply to the detection system controller is not disconnected by the energy isolation method that removes the other hazardous voltages from the equipment, there must also be separate hazardous energy isolation capability for the hazardous voltage supplies to the detection system controller enclosure.

14.4.4.8 A battery or other regulatory agency acceptable emergency power alternative, capable of sustaining the detection system for 24 hours, should be provided.

NOTE 64: Back-up power must be provided in accordance with local regulations. The requirements for back-up power vary among jurisdictions.

14.4.4.9 The fire detection system should remain active following EMO activation.

14.4.4.10 There may be cases where the internal power supply for a detection system cannot supply power for the full length of extended maintenance procedures (i.e., procedures longer than the expected duration of the back-up

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Full document details: SEMI S2-0310

power supply). In such cases, the supplier should provide written procedures for either removing the fire hazard or safely supplying power to the fire detection system.

14.4.4.11 Activation of the fire detection system should shut down the equipment within the shortest time period that allows for safe equipment shutdown. This includes shutdown of any fire-related hazard source that could create additional fire risks for the affected module or component.

NOTE 65: See § 14.4.3.3 and § 14.4.3.4 for related provisions.

EXCEPTION 1: A non-recycling, deadman abort switch is acceptable on detection systems that are used for equipment shutdown, but not on those used for activation of a suppression system.

EXCEPTION 2: Activation of the fire detection system should not remove power from fire and safety systems.

14.4.4.12 The equipment design and configuration should not prevent licensed parties from certifying the design and installation of fire detection systems.

NOTE 66: This is not meant to suggest installation by licensed parties; however, some jurisdictions require fire detection and suppression system installers to be licensed as specified by the jurisdiction.

14.4.5 *Fire Suppression* — The following criteria apply to any fire suppression system determined to be appropriate by the fire risk assessment.

NOTE 67: As a fire detection system is generally required to provide the initiating sequence for the suppression system, it is the intention of this guideline that this be the same fire detection system described in § 14.4.4.

14.4.5.1 The fire suppression system, which includes nozzles, actuators, and their associated controls, should be certified by an accredited testing laboratory and suitable for the application and for the environment in which it to be used.

NOTE 68: Such certifications typically require that the components of fire suppression systems are readily identifiable and distinguishable from other components in the equipment. This includes adequate labeling of piping.

14.4.5.2 The fire suppression agent should be accepted for the application by an accredited testing laboratory. The suppression agent selection process should include an evaluation of the amount and storage location of the suppression agent and of potential damage to a cleanroom and the environment. The least damaging effective agent should be selected. If more than one agent is effective, the options should be specified to the user so that the user may specify which agent should be provided with the equipment. The supplier should also specify if the user may provide the agent.

14.4.5.3 The fire suppression agent and delivery system should be designed and installed in accordance with the appropriate international or national standard (e.g., NFPA 12, NFPA 13, NFPA 2001). It may be preferable for the equipment supplier to specify the location and performance of suppression system components, but not provide them, so that the user may better integrate the suppression in the equipment with that in the facility. This alternative should be negotiated explicitly with the user.

14.4.5.4 The assessment of the equipment to SEMI S2 should include the risks associated with the suppression systems.

NOTE 69: This includes risks (e.g., chemical exposure, noise, and asphyxiation) introduced by the incorporation of the suppression system.

14.4.5.5 Activation of the fire suppression system should alarm audibly and visually at the equipment. This may be done by the same system that initiates activation.

14.4.5.6 If the discharge is likely to present a risk to personnel, the alarm should provide adequate time to allow personnel to avoid the hazard of the agent discharge.

14.4.5.6.1 If there is a confined space in the equipment, the asphyxiation hazard posed by the suppression system should be assessed.

14.4.5.7 The fire suppression system should be capable of operating at all times, including when equipment is inoperable and during equipment maintenance.

NOTE 70: For the purpose of this section, “inoperable” includes the equipment state after the EMO is activated.

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Full document details: SEMI S2-0310

EXCEPTION: Most suppression systems contain sources of hazardous energy. These sources should be capable of being isolated (i.e., "locked out") to protect personnel.

14.4.5.8 The fire suppression system should remain active following EMO activation.

14.4.5.9 There may be cases where the internal power supply for a suppression system cannot supply power for the full length of extended maintenance procedures (i.e., procedures longer than the expected duration of the back-up power supply). In such cases, the supplier should provide written procedures for either removing the fire hazard or safely supplying power to the fire suppression system.

14.4.5.10 Allowances can be made to provide for the deactivation of an automatic discharge of the suppression system when in the maintenance mode. Such deactivation switches should be supervised (i.e., if the suppression system is deactivated, there should be an indication to the user and the resumption of production in the equipment should be prevented.)

NOTE 71: Hazardous energies associated with the fire suppression system may be isolated (i.e., "locked out") using an energy isolation procedure (see § 17) during equipment maintenance.

NOTE 72: The permissibility of deactivation of suppression systems varies among jurisdictions.

14.4.5.11 A back-up power supply, capable of sustaining the suppression system for 24 hours, should be included where the suppression system requires independent power from the detection system used to activate the suppression.

NOTE 73: The requirements for back-up power vary among jurisdictions.

14.4.5.12 The fire suppression system should be capable of interfacing with the facility's alarm system. This may be done via the fire detection system.

14.4.5.13 Activation of the fire suppression system should shut down the equipment within the shortest time period that allows for safe equipment shutdown.

NOTE 74: See § 14.4.3.3 and § 14.4.3.4 for related provisions.

EXCEPTION: Activation of the fire suppression system should not remove power from fire and safety systems.

14.4.5.14 The fire suppression system should be capable of manual activation, which should shut down the equipment and activate an alarm signal locally and at a constantly attended location.

14.4.5.15 The fire suppression system should be tested on a representative sample of the equipment. The test procedure should include a suppression agent discharge test, unless precluded for health or environmental reasons. This test may be performed at the equipment supplier's or other similar facility, but should be performed under conditions that adequately duplicate any factors (e.g., equipment exhaust) that may reduce the effectiveness of the suppression. This representative sample need not be fully operational, but should duplicate those factors (e.g., exhaust, air flow) that could negatively affect the performance of the system.

14.4.5.16 Procedures for controlling access to the suppression agent source (e.g., protecting agent cylinders from disconnection by unauthorized personnel) should be provided.

14.4.5.17 The equipment design and configuration should not prevent licensed parties from certifying the design and installation of fire suppression systems.

NOTE 75: This is not meant to suggest installation by licensed parties; however, some jurisdictions require fire detection and suppression system installers to be licensed as specified by the jurisdiction.

14.4.5.18 *Installation of Piping for Fire Suppression Agent* — The fire suppression piping system should be:

- made from corrosion-resistant components,
- designed to minimize water accumulation around components and control other conditions that promote corrosion, and
- designed so mechanical inspections are easily performed.

14.4.5.19 Piping should be designed, installed, and tested to ensure that it is capable of containing the high pressures generated by the discharge of the suppression agent.

14.4.5.20 The supplier should provide information necessary for proper field installation of piping.

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Full document details: SEMI S2-0310

14.5 *Warnings and Safe Work Practices* — Warnings and safe work practices related to fire detection and suppression features of the equipment (e.g., restrictions on using open flames within range of active fire detection systems, hazardous stored energy in pressurized suppression systems) should be part of the documentation provided by the supplier.

14.6 *Maintenance and Testing of Fire Detection and Suppression Systems* — The equipment supplier should provide detailed maintenance and testing procedures for the fire systems provided with each piece of equipment. These procedures should include testing frequency, as well as details of special equipment required for testing.

14.6.1 Chemical generating test apparatus (e.g., canned smoke) should be avoided for cleanroom applications.

NOTE 76: Information about UV/IR generating sources used for testing fire detection systems may require consideration of § 25 (Non-Ionizing Radiation).

14.6.2 The maintenance testing procedure should include testing of the facility interface and verifying that all the equipment fire detection and suppression systems are functional.

14.6.3 The detection and suppression systems should be designed so that preventative maintenance of components does not degrade their performance (e.g., by resulting in displacement or destruction of sensors).

14.6.4 Supplier should document the sound pressure level generated during suppression agent discharge, if the test is performed.

14.6.5 Materials or procedures used for testing and maintenance of the fire detection and suppression system should not degrade the equipment's ability to perform its intended function.

14.6.6 Suppliers should describe hazardous energies present in fire detection and suppression systems, and provide instructions for their proper isolation (see § 17.2).

14.7 *Environmental* — Suppliers should provide guidance to users regarding the impact on emissions of any fire suppression agents used in the equipment.

15 Heated Chemical Baths

15.1 Refer to SEMI S3 for the minimum safety design considerations for heated chemical baths. Each heated chemical bath should have the following:

- grounded or GFCI-protected heater;
- power interrupt;
- manual reset;
- automatic temperature controller;
- liquid level sensor;
- fail-safe over-temperature protection;
- proper construction materials;
- exhaust failure interlock; and
- overcurrent protection.

NOTE 77: See § 14 for fire protection risk assessment considerations for baths using combustible or flammable chemicals.

16 Ergonomics and Human Factors

16.1 *General* — Ergonomics and human factors design principles should be incorporated into the development of equipment to identify and eliminate or mitigate ergonomics- and human factors-related hazards.

16.2 *Provisions for Conformance* — Equipment should be assessed to the guidelines set forth in SEMI S8. The Supplier Ergonomic Success Criteria (SESC; see SEMI S8), or the equivalent, should be used to document the assessment.

Documents
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Full document details: SEMI S2-0310

17 Hazardous Energy Isolation

17.1 *General*

17.1.1 Lockable energy isolation capabilities should be provided for tasks that may result in contact with hazardous energy sources.

17.1.2 Where service tasks may be safely performed on subassemblies, energy isolation devices (e.g., circuit breakers, disconnect switches, manual valves) may be provided for the subassemblies for use as an alternative to shutting down the entire equipment system. The isolation devices should isolate all hazardous energy to the subassemblies and be capable of being locked in the position in which the hazardous energy is isolated.

17.1.3 The person actuating or inspecting an energy isolating device should not be exposed to serious risks of tripping or falling or of coming in contact with energized electrical parts, moving machinery, surfaces or objects operating at high temperatures, or other hazardous equipment.

NOTE 78: Hazardous energies include electrical, stored 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.

NOTE 79: In order to minimize down-time and provide ease of use, it is preferred to have energy isolation devices located in the areas where maintenance or service is performed.

NOTE 80: Energy isolation devices for incompatible hazardous energy sources (e.g., electrical and water, incompatible gases) are recommended to be separated.

NOTE 81: Isolation of hazardous energy may include: de-energizing of hazardous voltage; stopping flow of hazardous production material (HPM); containing HPM reservoirs; depressurizing or containing HPM and pneumatic lines; de-energizing or totally containing hazardous radiation; discharging of residual energy in capacitors; stopping of hazardous moving parts; and shutting off hazardous temperature sources.

NOTE 82: Energy isolation devices with integral locking capabilities are preferred, but may not be feasible or commercially available, in which case detachable lockout adapters may be used.

NOTE 83: See § 14 for information on fire protection hazardous energies.

17.2 *Installation and Maintenance Manuals*

17.2.1 Installation and maintenance manuals should identify the types of hazardous energies within the equipment.

17.2.2 Installation and maintenance manuals should provide specific instructions for the equipment on how to:

- shut down the equipment in an orderly manner;
- locate and operate all the equipment's energy isolating devices;
- affix energy isolating ("lockout/tagout") devices;
- relieve any stored energies;
- verify that the equipment has actually been isolated and de-energized; and
- properly release the equipment from its isolated state.

17.2.3 Where the manufacturer provides written maintenance procedures for tasks within subassemblies, and intends that these tasks be performed without controlling hazardous energies at the entire equipment level, the installation and maintenance manuals should provide appropriate energy isolation procedures at the subassembly level.

17.3 *Electrical Energy Isolation*

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

NOTE 84: For equipment with multiple incoming supply sources, it is recommended that all of the energy isolation devices be located in one area.

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Full document details: SEMI S2-0310

17.4 *Non-Electrical Energy Isolation*

17.4.1 The equipment should include provisions and procedures so that hazardous energy sources, such as pressurized systems and stored energy, can be isolated or reduced to a zero energy state prior to maintenance or service work.

17.4.2 The hazardous energy isolation devices should be in a location that is readily accessible.

17.4.3 The hazardous energy isolation devices should be capable of being locked in the position in which the hazardous energy is isolated.

18 Mechanical Design

18.1 This section covers hazards due to the mechanical aspects of the equipment.

NOTE 85: This is similar to the essential requirements of European Union directives. The supplier has the option of demonstrating compliance by choosing standards that are appropriate to the machine and application.

NOTE 86: Pressurized vessels must meet applicable codes and regulations.

18.2 *Machine Stability* — Equipment, components, and fittings should be designed and constructed so that they are stable under reasonably foreseeable shipping, installation, and operating conditions. The need for special handling devices and anchors should be indicated in the instructions. Unanchored equipment in its installed condition should not overbalance when tilted in any direction to an angle of 10° from its normal position.

NOTE 87: See IEC 61010-1 for an example of stability tests.

18.3 *Break-up During Operation* — The various parts of the equipment and its linkages should be able to withstand the stresses to which they are subjected when used as designed. Precautions should be taken to control risks from falling or flying objects.

18.3.1 The potential effects of fatigue, aging, corrosion, and abrasion for the intended operating environment should be considered as part of the mechanical hazards risk assessment.

18.3.2 Where a risk of rupture or disintegration remains despite the measures taken (e.g., a substrate chuck that loses its vacuum), the moving parts should be mounted and positioned in such a way that, in case of rupture, their fragments will be contained.

18.3.3 Both rigid and flexible pipes carrying liquids or gases should be able to withstand the foreseen internal and external stresses and should be firmly attached or protected against external stresses and strains. Based on the application, an appropriate factor of safety should be included.

18.4 *Moving Parts* — The moving parts of equipment should be designed, built, and positioned to avoid hazards. Where hazards persist, equipment should be fitted with guards or protective devices that reduce the likelihood of contact that could lead to injury.

18.4.1 Where the machine is designed to perform operations under different conditions of use (e.g., different speeds or energy supplies), it should be designed and constructed in such a way that selection and adjustment of these conditions can be performed safely.

18.4.2 *Selection of Protection Against Hazards Related to Moving Parts* — Guards or protective devices used to protect against hazards related to moving parts should be selected on the basis of a risk assessment that includes the:

- hazards that are being guarded against;
- probability of occurrence and severity of injury of each hazard scenario; and
- frequency of removal of guards.

18.4.3 Guards and protection devices. Guards should:

- reduce the risk that personnel will contact the mechanical hazard to an acceptable level; and
- not give rise to additional risk.

18.5 *Lifting Equipment* — Lifting equipment used for maintenance and service of SME should conform to each applicable criterion of ¶ 18.5 and its subordinate paragraphs.

Documents
Document Sharing Hub
Full document details: SEMI S2-0310

NOTE 88: The purpose of this section is to encourage that the hazards and potential consequences related to lifting operations (e.g., falling loads, collisions, tipping) be given appropriate consideration during design and development of SME.

EXCEPTION: Lifting equipment that has documentation indicating conformance with an applicable standard, code, or regulation need conform to only ¶ 18.5.3, ¶ 18.5.4, and their subordinate paragraphs, in addition to the applicable standard, code, or regulation.

18.5.1 *Lifting Equipment Design Criteria*

18.5.1.1 *Mechanical Strength* — Lifting equipment should be designed such that it has as a minimum factor of safety of 3, with the factor of safety determined as the ratio of yield strength to stress on each component, in the least favorable condition. For the purposes of § 18.5, "least favorable condition" is the position and orientation of fixed or moveable elements that places the greatest stress on the components of the lifting equipment. It may be necessary to test more than one condition so that each element is tested in its "least favorable" condition. These elements include:

- fixed or removable booms,
- end effectors or grippers used in conjunction with fixed or removable booms, and
- fixtures designed to provide interconnection between the load and the lifting device, excluding slings.

NOTE 89: A minimum factor of safety of 3 appears in several standards (e.g., ASME B30.20 *Below-the-hook Lifting Device* subparagraph 20-1.2.2 General Construction[15]).

NOTE 90: Other factors of safety are required by codes, laws, and regulations, as they pertain to other types of lifting equipment, these must be met as well (e.g., EN 1492 requires a safety factor (SF) of 7 for webbing slings, MIL-STD-1365 B requires a SF of 5 for hoist rings, and ASME B18.15M requires a SF of 5 for lifting eyes). Conformance with these criteria for things other than the lifting device is typically evaluated separately from lifting equipment used in support of SME.

18.5.1.2 Materials should be appropriate for their intended use. Materials should be chosen with particular consideration to the effects of corrosion, abrasion, impact, and ageing.

18.5.2 *Design Verification* — The conformance to these criteria should be demonstrated for the particular lifting equipment under consideration, or a representative sample thereof.

18.5.2.1 Lifting equipment should undergo testing and verification that includes the following:

- Classical engineering calculations;
- Risk Assessment, such as Failure Modes and Effects Analysis (FMEA), and
- Physical Testing, as described below for subsequently produced lifting equipment.

18.5.2.2 A written report, including photographs or drawings of how the testing was conducted along with written test specifications and results of all tests should be prepared.

18.5.2.3 Documentation, including the elements in ¶¶ 18.5.1–18.5.2.2, and ¶ 9.6.3 (user documentation) should be prepared and kept for a sufficient time period to support the equipment while in service and for a sufficient period of time (typically a minimum of ten years) after the equipment is placed on the market. Conformance with this criterion may be demonstrated by making the documentation from design verification available to the assessor and providing the assessor evidence that the equipment supplier has a program that will retain the records for an appropriate period.

NOTE 91: Several standards and directives (e.g., ISO 2415 (forged shackles), and 98/37/EC (Machinery Directive)) require keeping records for 10 years or more beyond the time the last unit was produced, tested and shipped.

18.5.3 *Subsequently Produced Lifting Equipment* — Each individual piece of lifting equipment should have testing and record keeping specifications in accordance with the criteria for static and dynamic load testing. Test certificates should accompany each unit upon delivery. The supplier should retain a copy of test records for at least 10 years from the date of shipment.

EXCEPTION: Lifting accessories permanently affixed to and tested as a part of a lifting fixture do not need individual testing.

15 American Society of Mechanical Engineers, Three Park Avenue, New York, NY 10016-5990, USA. Telephone: 800.843.2763 (U.S./Canada), 95.800.843.2763 (Mexico), 973.882.1167 (outside North America); http://www.asme.org

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18.5.3.1 *Static Load Testing*

18.5.3.1.1 Static load testing should be conducted on each lifting device at 150% of the rated load and with the mechanical elements of the structure in their least favorable conditions (see ¶ 18.5.1.1 for guidance as to determining the "least favorable condition").

NOTE 92: Static load test (proof load testing) of a new design is part of the process of validating the design's maximum working load.

18.5.3.1.2 The static test should be conducted for a minimum of 2 minutes beyond the time that the test load has stabilized (stopped moving).

18.5.3.1.3 A static test should be considered acceptable if no permanent deformation or other physical damage is found once the test load has been removed and equipment examined. A static test resulting in damage or abnormality should be considered to be a failed test.

18.5.3.2 *Dynamic Load Testing*

18.5.3.2.1 Dynamic load testing should be performed on each lifting device, as this term is defined within this document.

NOTE 93: Dynamic load testing is conducted to confirm that the lifting equipment has been properly assembled, operated with account taken of the dynamic behavior of the lifting equipment and that all operational features, including mechanical stops, limit switches, brakes (if fitted) and all safety related features are fully adjusted and operational.

18.5.3.2.2 Dynamic load testing should be performed on lifting fixtures or lifting accessories, only if the number of load cycles to which they are foreseen to be subjected is sufficient to make such testing appropriate.

NOTE 94: The American Welding Society (AWS) Standard D14.1 Table 3 considers cyclic loading of 20,000 cycles and below to be equivalent to static loading. Thus, there is no need to consider dynamic testing of welded metal lifting fixtures or lifting accessories if the foreseen number of cycles in the fixture's or accessory's life is less than 20,000.

18.5.3.2.3 Dynamic load testing should be conducted;

- using 110% of the working (rated) load,
- and with the mechanical elements of the structure in their least favorable conditions,
- for a minimum of two complete cycles at maximum operational speed of each axis of motion, and
- if the control circuit allows for a number of simultaneous movements (e.g., rotation and displacement of the load), by combining the movements concerned.

NOTE 95: For manual actuation of lifting equipment using a crank, it is recommended that the cranking speed be agreed upon by the supplier and evaluator based on the lifting device and the cranking mechanism. Manual cranks are not normally designed to a maximum cranking speed. The intent of this test is to verify that the cranking force is not sufficient to damage the lifting device when the device is exercised throughout its full operational range of motion. It is recommended that an agreed typical person be used to perform the cranking for this evaluation.

18.5.3.2.4 *Acceptance Criteria*

18.5.3.2.4.1 There should be no noticeable signs of improper assembly.

18.5.3.2.4.2 There should be no noticeable signs of excessive wear.

18.5.3.2.4.3 There should be no noticeable signs improper operation or incorrect adjustment of operational features, including mechanical stops, limit switches, and brakes (if fitted).

18.5.3.2.4.4 There should be no noises that indicate a problem other than that a simple adjustment is required.

18.5.3.2.4.5 All safety features should be operational and perform their intended function.

18.5.3.2.4.6 There should be no permanent set (yielding) of any mechanical or structural member.

18.5.4 *Marking Criteria*

18.5.4.1 Lifting equipment should be clearly marked in a lasting, and legible manner on a portion of the equipment that cannot be removed.

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EXCEPTION: Lifting accessories permanently affixed to and tested as a part of a lifting fixture do not need individual marking.

NOTE 96: Components of fixtures (e.g., individual components that make-up a larger lifting fixture) that could be used independently of their parent fixtures should be marked.

18.5.4.1.1 There should not be conflicting marks on any piece of lifting equipment. The working (rated) load should be visible and readable from the floor or working position.

18.5.4.1.2 The following minimum information should be included;

- name and address of the manufacturer, or registered trade mark,
- working (rated) load,
- date of construction and initial testing of that unit, and
- serial number, if any.

NOTE 97: There are additional marking requirements, imposed by various standards and regulations, depending on equipment type (e.g., hoist, slings, and accessories). The supplier must ensure that such additional information be considered and provided as required. This includes any markings required by directives or regional requirements (e.g., the CE mark for the EU).

18.5.5 *Ergonomic Considerations*

18.5.5.1 Lifting equipment is subject to the ergonomic design and assessment criteria, described elsewhere in this Safety Guideline, that are applicable to the SME. Therefore, ergonomic factors should be considered in the design of lifting equipment.

18.5.5.2 Handles or coupling points should be provided for use on lifting equipment that are to be positioned manually. Handles or coupling points should be positioned such that their use does not promote awkward postures. Postures and space requirements during movement of the lifting equipment should be evaluated as part of the overall ergonomic evaluation of the SME.

18.5.5.3 It is recommended that handles or coupling points be provided or identified for manually driven axes in an effort to discourage the user from grabbing the load itself or the hoisting rope to maneuver the load in the horizontal plane. However, there are conditions where the controlling of a load in order to place the load into a specific location or orientation will require the user to grab the load itself and provide guidance. This is acceptable, but it is recommended that moving a load, more than 5 cm (2 inches), be done using handles or specific coupling points identified on the lifting device for that purpose.

18.6 *Mechanisms Supporting and Moving Hinged Loads*

18.6.1 *Applicability of § 18.6*

18.6.1.1 Hinges and mechanisms that are constructed as part of the SME and are intended to support and lift nothing other than their associated hinged loads should conform to each applicable criterion of § 18.6.

EXCEPTION: Hinged loads having a total mass not more than 5 kg (11 lb).

18.6.1.2 Other lifting equipment used for maintenance and service of SME and used to lift hinged loads should conform to each applicable criterion of § 18.5.

18.6.2 There are multiple ways by which the energy for movement of a hinged load can be provided:

18.6.2.1 *Direct Human Power* — Energy for lifting is supplied by a human and at a rate no greater than that at which it is provided by the human. This type includes simple machines (e.g., a handle mounted opposite a hinge) and complex machines (e.g., a winch driven by a human turning a crank handle which drives, through a series of gears, a drum which retracts a cable which, through a series of pulleys, lifts a load).

18.6.2.2 *Stored Energy* — At least some of the energy for lifting is supplied from a part of the mechanism in which it was stored, such as a spring (including a "gas spring") or a counterweight.

18.6.2.3 *External Power* — Energy for lifting is supplied by an external source, such as an electric motor or pneumatic drive cylinder.

18.6.2.4 Combination of direct human power and stored energy.

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18.6.2.5 Combination of external power and stored energy.

18.6.3 *Design Criteria for Mechanisms Supporting and Moving Hinged Loads*

18.6.3.1 *Mechanical Strength* — Mechanisms supporting hinged loads (including hinges) should be designed such that they have a minimum factor of safety of 3, where the factor of safety is the ratio of yield strength to stress on each component, in the least favorable condition. For the purposes of § 18.6, "least favorable condition" is the position and orientation of fixed or moveable elements that places the greatest stress on the components of the support mechanism.

NOTE 98: Mechanisms supporting hinged loads include hinges; support hardware such as springs, gas-filled shocks, and spring dampeners; mounting hardware; and counterbalance mechanisms. This does not mean for example, a gas-filled shock must be "sized" to hold 3 times the mass of the hinged component if it is used only as an ergonomic assist.

NOTE 99: The "least favorable condition" may differ from component to component. Therefore, more than one position may need to be considered in designing and testing to meet this criterion.

NOTE 100: Failure to follow procedural controls (e.g., not venting chamber or removing hardware) may have a significant affect on these structures. It is recommended that such conditions be fully explored using analysis methods listed in ¶ 18.6.4.2 or other similar methods designed to identify critical deficiencies within a design or process.

18.6.3.2 Materials should be appropriate for their intended uses. Materials should be chosen with particular consideration to the effects of corrosion, abrasion, impact, and aging.

18.6.4 *Design Verification* — The conformance to these criteria should be demonstrated for each mechanism supporting a hinged load, or a representative sample of each such design.

18.6.4.1 *Ergonomic Considerations* — Means of moving hinged loads that use "direct human power" (with or without "stored energy") should be assessed to the applicable sections of Appendix 1 (SESC) of SEMI S8.

18.6.4.2 Mechanisms supporting and moving hinged loads should undergo verification and testing that includes:

- classical engineering calculations;
- risk assessment, such as failure modes and effects analysis (FMEA), and
- physical testing under static and dynamic load.

NOTE 101: "Classical engineering calculations" are calculations based on: dimensions and masses of the components of the mechanism, dimensions and mass of the load, and typical characteristics of the materials of which they are constructed.

NOTE 102: Several standards and directives (e.g., ISO 2415 (forged shackles) and 98/37/EC (Machinery Directive)) require keeping records for 10 years or more beyond the time the last unit was produced, tested and shipped.

18.6.4.3 *Static Load Testing*

18.6.4.3.1 Static load testing should be conducted on mechanisms supporting and moving hinged loads at 150% of the manufacturer's intended configured load and with the mechanical elements of the structure in their least favorable conditions. This may be done prior to full integration, such as by using a test fixture, or after full integration.

NOTE 103: The term "full integration" refers to the level of assembly where the moveable part of the hinge is attached to its static hinge portion as required to complete the SME assembly.

18.6.4.3.2 See ¶ 18.6.3.1 for guidance as to determining the "least favorable condition."

18.6.4.3.3 The static test should be conducted for a minimum of 2 minutes beyond the time that the test load has stabilized (stopped moving).

18.6.4.3.4 A static test should be considered acceptable if no permanent deformation or other physical damage is found once the test load has been removed and equipment examined. A static test resulting in damage or abnormality should be considered to be a failed test.

NOTE 104: Static load test (proof load testing) of a new design is part of the process of validating the design's maximum working load.

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18.6.4.4 *Dynamic Load Testing*

18.6.4.4.1 Dynamic load testing should be conducted on hinged loads at 100 percent of the manufacturer's intended configured load.

NOTE 105: Dynamic load testing is conducted to confirm that equipment has been properly assembled and that all operational features, including mechanical stops, limit switches, brakes (if fitted) and all safety related features are fully adjusted and operational.

18.6.4.4.2 Dynamic load testing should be conducted for a minimum of five complete cycles at maximum operational speed of each axis of motion.

NOTE 106: Dynamic testing of a hinged load at 100 percent of the manufacturer's intended configured load is a different test than that specified in § 18.5 for lifting equipment. The latter has a more severe load condition than that stated for hinged loads and as such, may likely highlight areas of concern within two cycles of operation. For testing of hinged loads, it was felt that additional operational cycles should be performed, allowing more opportunity for the mechanism to be exercised and areas of concern amply reviewed.

18.6.4.4.3 Dynamic testing using human power should be performed at speeds that do not put the human at unacceptable risk.

18.6.4.4.4 *Acceptance Criteria*

18.6.4.4.4.1 There should be no noticeable signs of improper assembly.

18.6.4.4.4.2 There should be no noticeable signs of excessive wear.

18.6.4.4.4.3 There should be no noticeable signs of improper operation or incorrect adjustment of operational features, including mechanical stops, limit switches, and brakes (if fitted).

18.6.4.4.4.4 There should be no noises that indicate a problem other than that a simple adjustment is required.

18.6.4.4.4.5 All safety features should be operational and perform their intended function.

18.6.4.4.4.6 There should be no permanent set (yielding) of any mechanical or structural member.

18.6.4.5 *Documentation of Testing*

18.6.4.5.1 A written report should be prepared and should include:

- written test specifications,
- photographs or drawings of how the testing was conducted, and
- results of all tests.

18.6.4.5.2 Documentation, including the elements in §§ 18.6.3–18.6.4.5.1, and § 9.6.3 (user documentation), should be prepared and kept for sufficient time to support the equipment while in service and for sufficient time (typically a minimum of ten years) after the equipment is placed on the market. Conformance with this criterion may be demonstrated by making the documentation from design verification available to the assessor and providing the assessor evidence that the equipment supplier has a program that will retain the records for an appropriate period.

18.6.5 *Subsequently Produced Lifting Equipment* — Each hinged load assembly supporting and moving a hinged load should be tested in accordance with § 18.6.4.4 and have records kept in accordance with § 18.6.4.5. Test certificates should accompany each unit upon delivery. The supplier should retain a copy of test records for at least 10 years from the date of shipment.

18.7 *Extreme Temperatures* — Surfaces that are accessible to personnel, and that are at high (per temperature limits in Table 1) or very cold temperatures (below −10°C [14°F]), should be fitted with guards or designed out.

18.7.1 Where it is not feasible to protect or design out the exposures to extreme temperature, temperatures exceeding the limits are permitted, provided that either of the following conditions is met:

- unintentional contact with such a surface is unlikely; or
- the part has a warning indicating that the surface is at a hazardous temperature.

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