R14-6.1.2 *CAT. 4* — Category 4 (according to ISO 13859-1)

R14-6.1.3 *CPU* — Central Processing Unit

R14-6.1.4 *EMO* — Emergency Off

R14-6.1.5 *EUC* — Equipment Under Control

R14-6.1.6 *FD* — Field Device

R14-6.1.7 *FECS* — Fail-to-Safe Equipment Control System

R14-6.1.8 *GUI* — Graphical User Interface

R14-6.1.9 *I/O* — Input/Output

R14-6.1.10 *IFD* — Intelligent Field Device

R14-6.1.11 *ISFD* — Intelligent Safety Field Device

R14-6.1.12 *PLC* — Programmable Logic Controller

R14-6.1.13 *SIL* — Safety Integrity Level (according to IEC 61508)

R14-6.1.14 *SRM* — Safety Relay Module

R14-6.2 *Definitions*

R14-6.2.1 *certified* — Evaluated and approved for use in a particular intended function in conformance with a recognized standard by an accredited testing laboratory (ATL).

NOTE 1: See SEMI S2 for definition of ATL.

R14-6.2.2 *combined I/O* — I/O systems of an FECS in which non-safety-related and safety-related signal modules are combined. (see Figure R14-2).

R14-6.2.3 *common cause failure* — failure, which is the result of one or more events, causing coincident failures of two or more separate channels in a multiple channel system, leading to system failure.

R14-6.2.4 *distributed I/O* — input/output modules for sensors and actuators interfacing to a network.

R14-6.2.5 *electrical/electronic/programmable electronic (adj.)* — based on electrical OR electronic OR programmable electronic technology.

NOTE 6: The term above is intended to cover any and all devices or systems operating on electrical principles.

R14-6.2.6 *Fail-to-safe equipment control system* — A programmable system of control circuits designed and implemented for safety-related functions in accordance with internationally recognized standards such as ISO 13849-1 (EN 954-1) or IEC 61508. These systems (e.g. safety PLC, safety-related 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.

R14-6.2.7 *field device* — sensors and actuators such as valves (electrical or pneumatic), temperature sensors, proximity switches, pumps, motors etc.

R14-6.2.8 *functional safety* — The overall safety design related to the EUC and the EUC control system. Effective functional safety includes the correct functioning of the electrical, electronic, or programmable-electronic safety-related systems; or on other-technology safety-related systems and may include risk reduction measures.

R14-6.2.9 *industrial controller* — general term for controller-technology, which includes PLC and PC-based technology.

R14-6.2.10 *intelligent field device* — sensors and actuators that use local intelligence to perform functions such as communication, diagnosis and interfacing to a network.

R14-6.2.11 *network* — general term for bus technology, which includes field bus technology used in control applications.

R14-6.2.12 *programmable logic controller* — microprocessor based controller for sequential control; the control logic of which can be changed through a programming device connected to the controller, e.g. programming panel, host computer, handheld terminal, either directly or remotely through a network.

R14-6.2.13 *random hardware failure* — failure, occurring at a random time, which results from one or more of the possible degradation mechanisms in the hardware.

R14-6.2.14 *safety function* — function to be implemented by an electrical or electronic or programmable electronic safety-related system, other technology safety-related system or external risk reduction facilities, which is intended to achieve or maintain a safe state for the EUC, in respect of a specific hazardous event.

R14-6.2.15 *safety integrity* — probability of a safety-related system satisfactorily performing the required safety functions under all the stated conditions within a stated period of time.

R14-6.2.16 *safety integrity level (SIL)* — discrete level (one out of a possible four) for specifying the safety integrity requirements of the safety functions to be allocated to the electrical or electronic or programmable electronic safety-related systems, where safety integrity level 4 has the highest level of safety integrity and safety integrity level 1 has the lowest.

R14-6.2.17 *safety network* — a network certified for safety applications *(this can also be a subpart of a standard network).*

R14-6.2.18 *safety PLC* — a programmable logic controller and associated I/O, certified as having the necessary safety integrity to execute the safety-related function.

R14-6.2.19 *safety relay (SR)* —- A positive or force-guided relay, that is used in safety relay modules (SRMs) to achieve a fail-to-safe circuit.

R14-6.2.20 *safety relay module (SRM)* — redundant self monitoring electro-mechanical/ solid state device certified for use in safety applications

R14-6.2.21 *safety-related I/O modules* —I/O modules capable of diagnosing internal and external faults and configured to be redundant. (e.g., a second shutdown path is included for output-circuits).

R14-6.2.22 *safety-related programmable system* — systems designed and implemented for safety functions in accordance with ISO 13849 or IEC 61508. These system types (e.g. safety PLC, safety-related I/O modules) can diagnose internal and external faults and can react upon detected faults in a controlled manner.

R14-6.2.23 *safety requirements specification* — specification containing all the requirements of the safety functions that have to be performed by the safety-related systems.

R14-6.2.24 *solid state electronics* — designation used to describe devices and circuits fabricated from solid materials such as semiconductors, ferrites, or thin films as distinct from devices and circuits making use of electromechanical technology, e.g. solid state relay, micro controller.

R14-6.2.25 *systematic failure* — failure related in a deterministic way to a certain cause, which can only be eliminated by a modification of the design or of the manufacturing process, operational procedures, documentation or other relevant factors.

R14-7 State-of-the-Art Safety Control System — Comprised of Solid State Electronics

R14-7.1 Failure to perform normal function (for example a failure of a computer or its software) may cause economic loss, but is not necessarily a safety issue. However, failure of a safety-related component to perform its safety function could result in a hazardous condition. A fail-to-safe system should be designed in a manner to ensure that failures do not result in a hazardous situation. It is therefore important to perform a system risk assessment to determine safety-related functions and the - safety performance required. The process outlined in following figure should be followed.

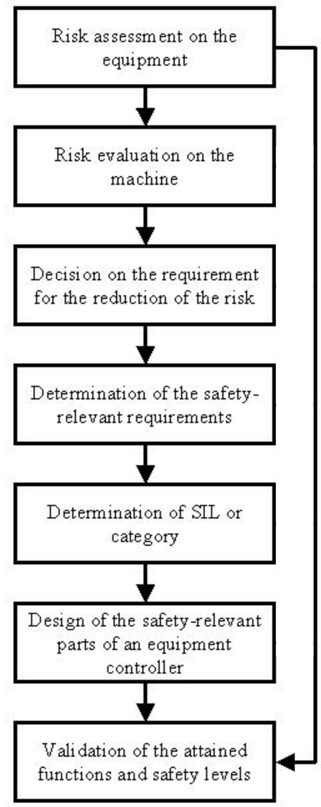

Figure R14-1
Roadmap to Risk Assessment and System Design

R14-7.2 *Safety Interlocks* — Semiconductor manufacturing equipment requires the use of fast, reliable and efficient means of safety interlocking. Important issues concerning complex machine architectures include availability and diagnostic capabilities for quick troubleshooting.

R14-7.2.1 A FECS should, even in the case of failure, maintain a safe state of the EUC. Therefore, a FECS is able to detect faults and cause the system to go to a safe state. A properly designed FECS – using methods such as self-monitoring for fault detection and subsequent well defined reaction – can offer high availability and diagnostics.

R14-7.2.2 Section 11.6 of SEMI S2 (including exceptions and notes) indicates a preference for electromechanical devices and components, and gives guidance on their use. However, non-electromechanical devices and components are permitted and they can provide necessary risk reduction while maintaining safety performance. Section 11.6, Note 26 of SEMI S2, suggests some tools for investigation of suitability for use. Additionally, IEC 61508, ANSI/ISA-SP84.01, and ISO 13849-1 (EN 954-1) provide guidance on the safety system design, assessment and maintenance of suitable control systems.

R14-7.2.3 The usage conditions and safety performance should be determined by the finding of a risk assessment as described in SEMI S10. Risk assessment results can then be used to define appropriate SIL levels and Categories.

NOTE 7:*Emergency Off* — Section 12.2.2 of SEMI S2 states that the EMO system should consist of electromechanical components. The exceptions give guidance to the design of EMO circuits using alternative technologies. Regional, national or industry standards may have additional requirements (e.g., USA: ANSI/NFPA 79, Europe: EN 60204-1).

R14-7.2.4 Any deviation from the risk level of electromechanical devices must be carefully evaluated (see Section 8 of SEMI S2).

R14-7.2.5 Compliance with Section 12 of SEMI S2, emergency shutdown will depend on the risk assessment allowed in Section 8.3.11 of SEMI S2.

R14-7.3 *Software and Programming*

R14-7.3.1 The application software or function blocks have to be verified before being used in an FECS. The automation supplier usually provides a range of approved software blocks.

R14-7.3.2 Access for programming of safety-related functions should be restricted within the FECS to trained people.

R14-7.3.3 To program or modify safety-related programs or parts of it, specially trained or qualified personnel are required. Any changes must be documented and stored within the file history.

R14-8 Philosophy and General Concept

R14-8.1 *Introduction* — An automated machine system mainly comprises components such as industrial controller, drives, I/O etc. The level of safety performance of equipment can differ depending on the particular application of FECS. However, irrespective of the particular application, the FECS always comprises a series of sensors, logic elements and actuators for safe shutdown or a motion into a safe and stable machine state.

R14-8.1.1 The term FECS according to IEC 61508 Part 2, is equivalent to the terms SIS (safety instrumented system) or SRS (safety related system) in other application areas. The examples in this Related Information show some possible architectures of the logic system. Sensors, final elements and software are discussed in this Related Information. Application handbooks from automation suppliers provide users with valuable information on how to use these components in order to achieve a fail-to-safe, equipment control system.

R14-8.1.2 For traditional semiconductor equipment, non-safety-related and safety-related technology, are separated. In many cases non-safety-related and safety-related technology are linked, so that signals representing diagnostics, enable, and feedback can be exchanged.

R14-8.1.3 *Main Characteristics of Architecture Concepts*

1. Fail-to-safe equipment control system with conventional hardwired safety technology.
2. Fail-to-safe equipment control system with separation between fail-to-safe and standard network technology.
3. Fail-to-safe equipment control systems with combined network technology for transmission of fail-to-safe and standard data on a single medium.
4. Redundancy can be used in all concepts to increase availability. Different redundancy concepts are in use (see R14-Section 9).
5. Visualization on the standard control part and on the fail-to-safe part can be realized with various interfaces on the standard part and on the fail-to-safe part.

R14-8.2 *Design of Architecture and Components*

R14-8.2.1 *Possible Application Areas*

1. Semiconductor manufacturing industry
2. Guarding of people, machines, environment and industrial processes

- Emergency stop functions,
- Emergency off functions,
- Emergency shutdown functions,
- Light gates,
- Guard doors,
- Scanners,
- Motion control with safety functions,
- Motor control with safety functions,
- Process valves with safety functions, and
- Process monitoring using safety-related interlocks.

R14-8.2.2 *Safety-related Equipment Control System* — The design of FECS should be carried out in accordance with IEC 61508 and applicable parts of the other referenced standards. The safety controller is used to control (open-loop) processes that can immediately achieve a safe condition. An FECS consists of sensors, logic systems and final elements as shown in Section R14-11. Replacing an existing electromechanical system with a safety controller does not provide a safe system. Sensors and final elements have to be considered as well.

R14-8.2.3 *Safety Requirements* – The FECS should be suitable for SIL1 to SIL3 safety integrity level in compliance with IEC 61508 or control categories 2 to 4 in compliance with ISO 13849-1 (EN 954-1). The required safety performance requirements will be determined in the system safety risk assessment. For application assessment, local authorities and notified bodies should request a safety handbook and certification according to IEC 61508 or ISO 13849. The safety-related system and its components should be validated to ensure it fulfills the safety requirements (SIL, CAT) determined from the risk analysis.

R14-8.2.4 *Principle Of The Safety Functions* — The FECS executes safety functions to bring the equipment into a safe state or to maintain it in a safe condition when a hazardous event occurs. The safety function for a production process can be realized using a user safety function or a fault response function. The safe state can be achieved by de-energizing the output modules.

R14-8.2.5 *Communications* — Non-safety-related and safety-related communications between an industrial controller and I/O modules should pass through a standard network system or a safety network system in sequence or through a combined network system (see Figures R14-2-R14-7). Bridges, routers and repeaters can be used in either standard networks or in safety networks to adapt the network topology to the individual layout of production process and equipment.

R14-8.3 *Basic Topologies* — Sections 7.3.1 through 7.3.3 describe examples of network-based architectures that are capable of achieving a FECS. The suppliers should take into account performance, timing, ease of use, and other factors when selecting an architecture type.

NOTE 8: These examples are not represented to be all-inclusive.

R14-8.3.1 *Use of Fail-to-safe Equipment Control Systems with Conventional Safety Technology* — Equipment manufacturers can achieve functional safety by the use of hardwired circuits. Such hardwired circuits are realized with terminals, electromechanical or electronic safety relays, and contactors. The relays would be certified for use in CAT 4 applications according to ISO 13849. In Figure R14-2, a standard industrial controller is used with standard I/O over a standard network to provide for the non-safety aspects of the machine and to provide diagnostics and visualization of the hardwired safety functions.

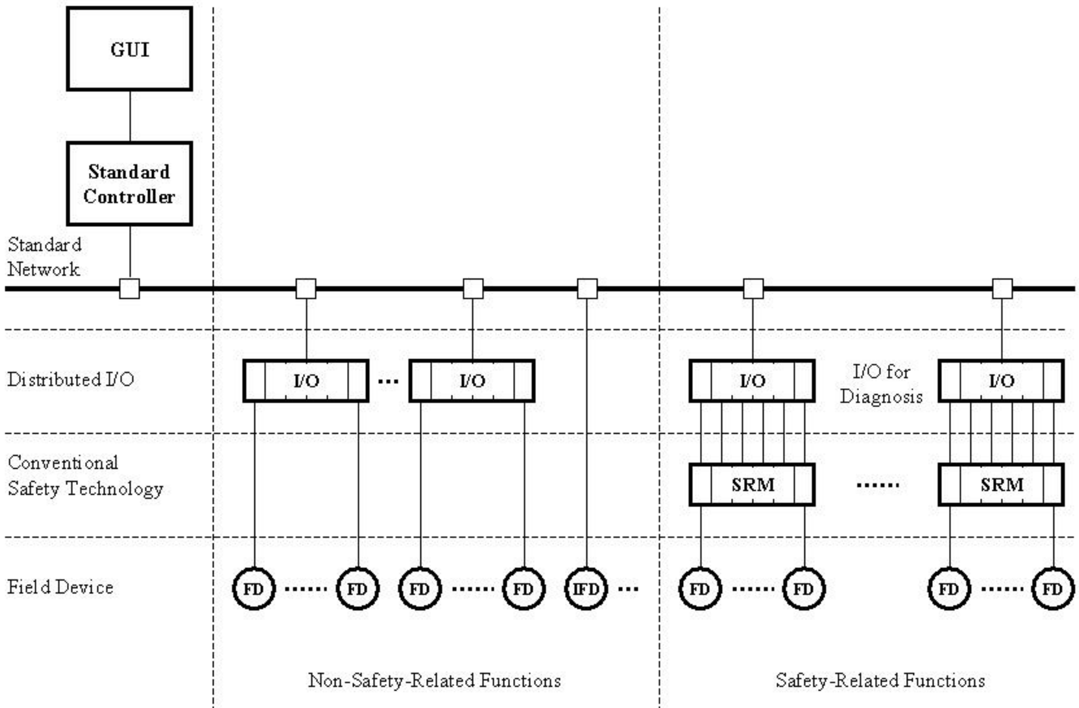

Figure R14-2
Fail-to-safe Equipment Control System with Conventional Safety Technology

R14-8.3.1.1 Use of Fail-to-safe Equipment Control Systems with Dual Networks for Standard and Fail-to-safe Communications and Combined Controllers — Figures R14-3 and R14-4 are dual network systems with control of the non-safety functions remaining the same as in Fail-to-safe Equipment Control Systems with Conventional Safety Technology. Safety functions, however, are achieved using FECS with safety-related information and control managed over a separate dedicated safety network.

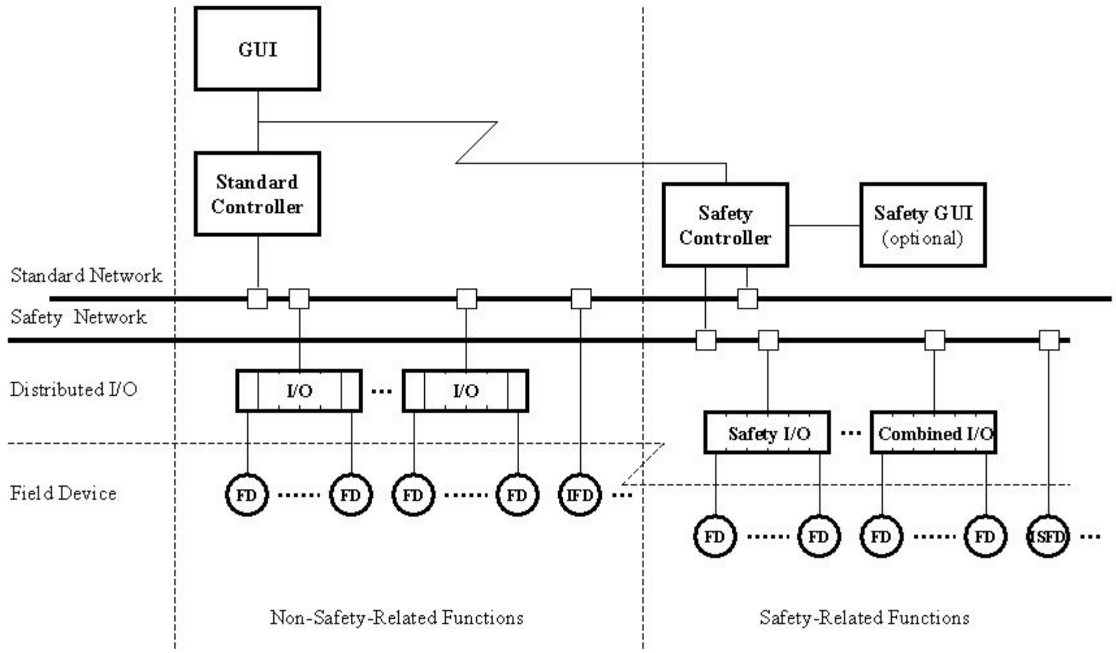

Figure R14-3
Fail-To-Safe Equipment Control System with Dual Network for Standard and Fail-To-Safe Communication and Separated Standard and Safety Controllers

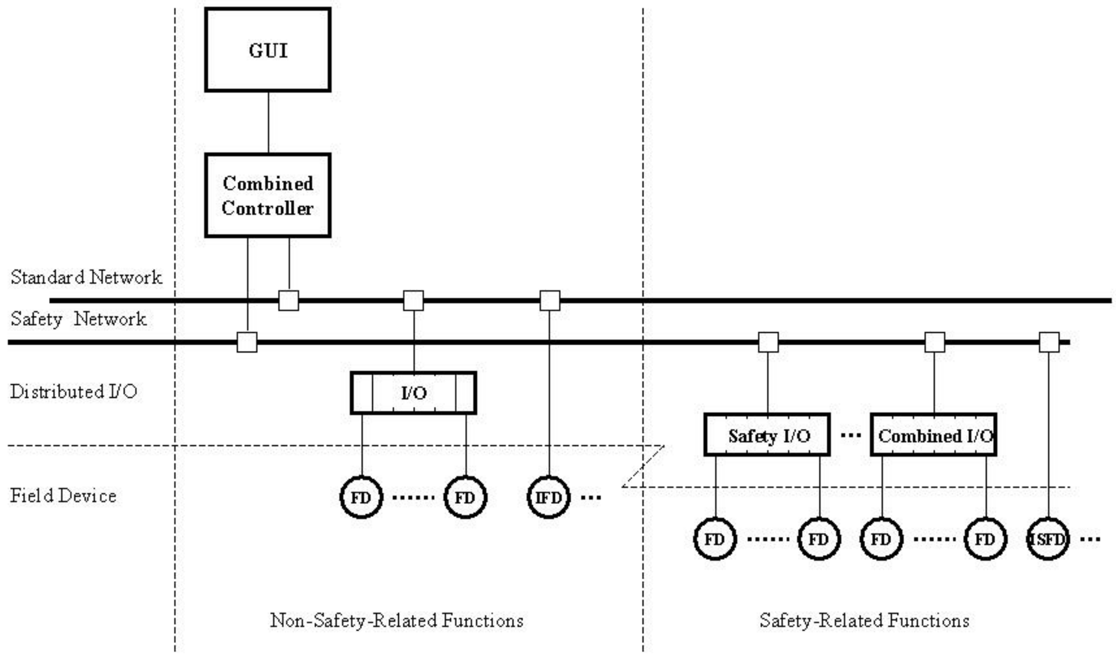

Figure R14-4
Fail-To-Safe Equipment Control System with Dual Network for Standard and Fail-To-Safe Communication and Combined Controller

R14-8.3.2 *Fail-to-safe Equipment Control System With Combined Network For Standard And Fail-to-safe Communication* — In Figures R14-5 and R14-6 the standard network and safety network have been combined into one physical network. The standard controller and the safety controller can physically be consolidated into one single unit. A combined network system is composed of technology that allows the non-safety-related and safety-related communication to function on the same bus cable. Standard I/O, safety I/O and combined standard/safety I/O can all connect to the network.

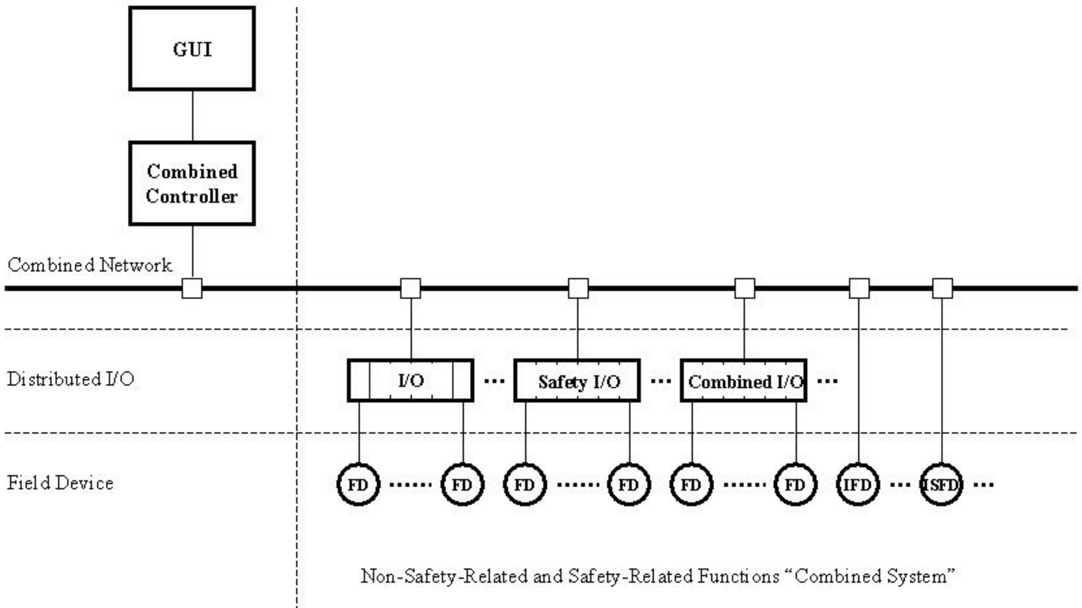

Figure R14-5
Fail-To-Safe Equipment Control System with Combined Network for Standard and Fail-To-Safe Communication and Combined Controller

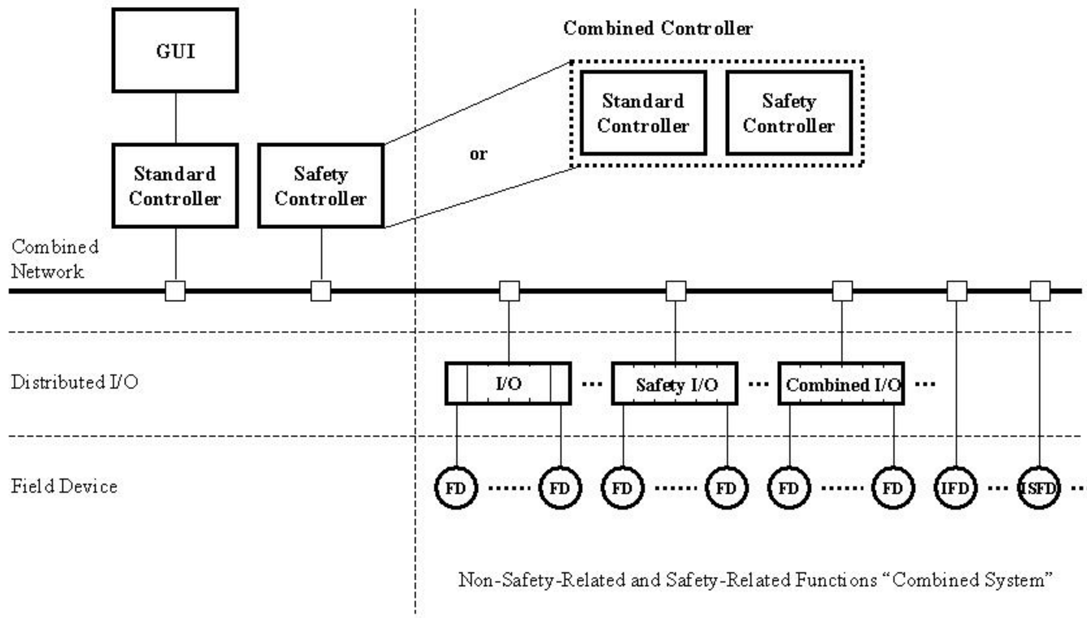

Figure R14-6
Fail-To-Safe Equipment Control System with Combined Network for Standard and Fail-To-Safe Communication and Separated Controller

R14-8.3.3 *Fault Tolerant Equipment Control System With High Availability And Redundant Network* — In Figures R14-2 through R14-6, the FECS enters a safe-state condition if a failure should occur; however, the production process would be interrupted. In order to increase the availability of the automation system and therefore avoid process downtime resulting from control system faults as well as faults and errors of components such as the power supply, the industrial controller, the network connection, and the I/O modules need to be made redundant. Possible architectures (see Figure R14-7) for achieving high availability include 2 oo 2, 2 oo 3, 2 oo 4, etc. (see R14-Section 9). Using fail-to-safe and high availability systems, injury to people or environmental damage can be prevented and the production process can be continued without interruption.

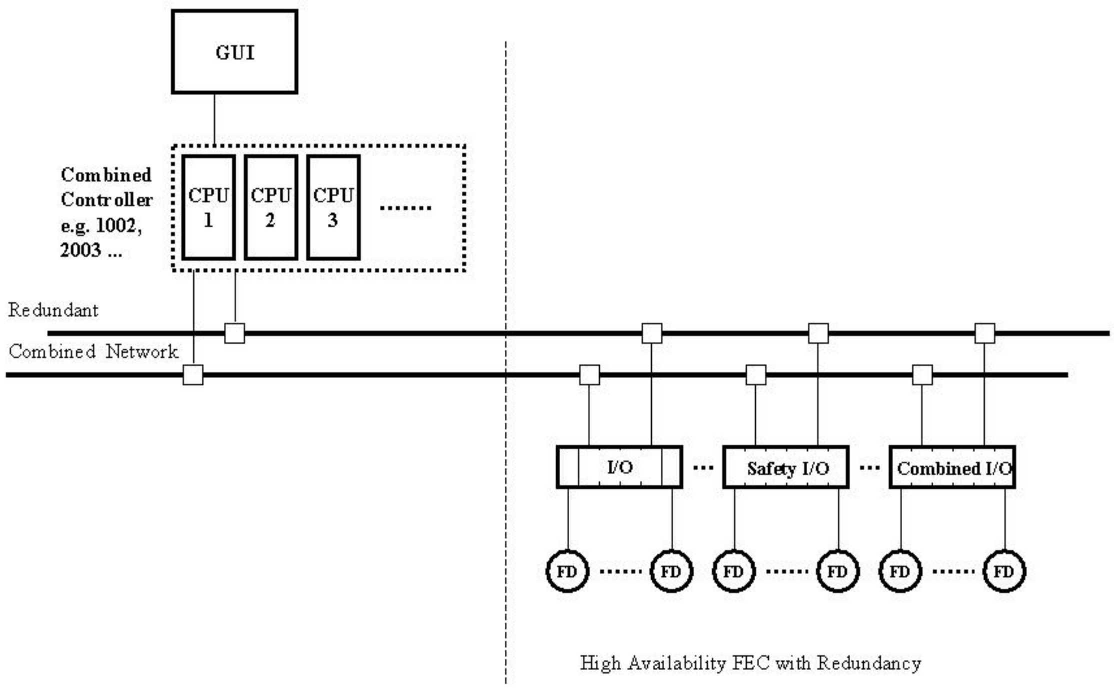

Figure R14-7
Fault-Tolerant Equipment Control System with High Availability FECS and Redundant Network

R14-9 Guide to Assessment and Test Methods

R14-9.1 Assessment and testing of an electronic system (especially programmable systems) for safety integrity levels (SIL) according to IEC 61508/ANSI/ISA-84.01 or risk categories according to ISO 13849-1 (EN 954-1) is a complex and time consuming task, requiring a considerable level of knowledge and expertise. The use of components such as safety PLCs and safety networks, that are certified by third parties for use in systems, and include specific SILs and risk categories, simplifies the process of assessing the whole system.

NOTE 9: Certified (or listed) components need to be certified for functional safety use in safety critical systems. The final integrated system should be fully assessed; using tools such as IEC 61508/ANSI/ISA-84.01 or ISO 13849-1 (EN954-1). Assessments can often simplified by using combinations of certified components or FECS.

R14-9.2 *Commissioning and Site Approval* — Commissioning and site approval as described in IEC 61508 may be confusing and therefore the following criteria are necessary for understanding:

R14-9.2.1 Safety-related components should meet the safety requirements defined during the risk analysis.

NOTE 10: Use of Notified Bodies, ATLs or a Professional Engineer to perform system assessment, type approval/site approval/commissioning of electronic components and for machinery with industrial controllers is defined by the jurisdiction of use.

R14-9.2.2 During control system commissioning, all relevant documentation of the pre-inspection should be available. A pre-inspection usually is the first phase of a control system commissioning.

R14-9.2.3 During pre-inspection, control system commissioning protocols should be prepared.

R14-9.2.4 If a safety analysis or safety case has been prepared for the specific installation, all documents regarding this activity should be made available.

R14-9.2.5 Whether a safety analysis or safety case has been prepared or not, a directory of available documents should be generated.

R14-9.2.5.1 This list should include the titles, dates and number of pages of all documents.

R14-9.2.5.1.1 If possible, all documents should also be available in electronic form.

R14-9.2.5.2 The documentation should include:

a. Safety Specification (if possible as formal specification),

b. Top-level diagram of the application (1 or 2 pages),

c. Technical implementation (e.g. block, flow and timing diagrams),

d. Explanation of separation between safety critical and not safety critical parts of the application,

e. Safety handbooks of the system components (safety handbooks of the safety controllers, sensors and actuators),

f. Description of interfaces,

g. Specification of all safety relevant program parts,

h. I/O documentation,

i. Software program documentation,

j. Wiring documents,

k. Diagram and listing of the interaction between input- and output-data (e.g. safety matrix, cause-effect diagrams or comparable documents),

l. Cross reference listing,

m. Source programs on storage medium, and

n. Description of the procedure to verify, that the documentation, respectively the files on the storage medium, are identical to the programs in the application (upload verify, CRC checksums, or comparable).

R14-10 Safety Performance

R14-10.1 For details on how to achieve the necessary safety system requirements, see ISO 13849.

NOTE 11: An update of document IEC 62061 is currently under preparation, and it should be consulted for further details.

R14-11 Application Examples

R14-11.1 Safety is important in semiconductor equipment (especially in the area of wafer fabrication) where toxic media (e.g. gases or chemicals), high-speed motion, or lasers may be present. The following are examples of some wafer fabrication equipment which could be adapted to a FECS:

a. CVD

b. Cleaning Equipment

c. CMP

d. Diffusion/Oxidation

e. Dry Etch Systems

f. Epitaxy

g. Ion Implantation

h. Lithography

i. Physical Vapor Deposition

j. Vacuum Deposition

k. Wet Etch Systems

R14-12 Related Documents

R14-12.1 DIN V VDE Standards[24]

DIN V VDE 19250 — Control Technology; Functional Safety Aspects to be Considered for Measurement and Control Equipment

24 VDE-Verlag GmbH, Bismarkstrasse 33, 10625 Berlin, Germany, www.vde.de

RELATED INFORMATION 15
ADDITIONAL CONSIDERATIONS FOR FIRE SUPPRESSION SYSTEMS

NOTICE: This related information is not an official part of SEMI S2. It was derived from editorial work by the Fire Protection Task Force. This related information was approved for publication by Technical Ballot and formal adjudication as an Effective date line item on March 18, 2004.

R15-1 Introduction

R15-1.1 Preventing discharges from occurring accidentally and ensuring that systems are able to fulfill their intended function requires attention to detail from the specification of the system, through design, installation and commissioning and then through on-going maintenance.

R15-1.2 The following information is intended to assist stakeholders involved in the process of designing, installing, and maintaining fire protection of semiconductor manufacturing equipment. Further information can be found in the appropriate fire protection codes and standards applicable to the type of fire protection system and in related documents.

NOTE 1: The term “fire suppression” is limited to extinguishing fire, once it has begun. The term “fire protection” incorporates fire suppression and other means of mitigating the risk of fires, including fire detection and materials selection.

R15-1.3 The use of contractors with previous experience in the design and installation of fire protection of cleanrooms and semiconductor manufacturing equipment is desirable.

R15-1.4 Independent third party review of fire protection designs and installations by a fire protection engineer with relevant experience can also help to ensure that systems are correctly designed and installed.

NOTE 2: The material in this Related Information is presented as additional guidance in designing, installing, and maintaining fire protection systems in semiconductor manufacturing equipment. Although this information is believed to be useful in optimizing such systems, the material in this Related Information does not comprise additional criteria for determining conformance to the provisions of SEMI S2 or SEMI S14.

R15-2 Design Review

R15-2.1 Ensure that system proposed uses approved or listed components and that they are used within their listing or approval, e.g., FM Approved wet bench fire suppression systems should be used for open-faced wet bench whereas an enclosed tool can use a system comprising of FM approved & compatible components.

R15-2.2 Detection needs to be selected to suit the working environment and the type of fire/smoke that is anticipated. For example, optical detectors need to have been tested and approved/listed for use with specific flammable liquids or gases. Flames and smoke from burning materials have varying physical characteristics which mean that some detection devices will not always react promptly.

R15-2.3 The location of detection devices in relation to hazards needs to be carefully considered. A detector that is located too close to a heat source may activate when it sees normal process conditions rather than fire conditions.

R15-2.4 Some optical detectors may also be susceptible to accidental activation if they are exposed to welding flashes. Care in detector selection can avoid this, but implementing strict cutting and welding working practices and permissions can also play an important part.

R15-3 Installation Review

R15-3.1 Once completed by the fire protection installer, the fire protection installation should be inspected and reviewed by a competent and experienced fire protection engineer. This review will:

R15-3.1.1 Verify installation against previously working drawings.

R15-3.1.2 Ensure that specified equipment has been installed as indicated on the working drawings and in line with equipment approvals and listings.

R15-3.2 Distribution pipework networks should be complete (including all connections), properly supported using listed and approved equipment. Frequent failures of piped systems, including CO_2 systems, occur due to incorrectly connected pipes or where fittings have not been made or sufficiently tightened.

R15-3.3 Supports for pipework should be able to withstand the expected forces that will be experienced during discharge of the suppression system. This is important to protect personnel and property from moving pipes in high-pressure systems using agents such as carbon dioxide.

R15-3.4 Detection systems should have components installed as per reviewed drawings, however it is not always possible during desktop drawing review to identify that detectors are correctly sited. As a result, the field review should concentrate on ensuring that components are located so that they can see the hazard without obstruction, including clear vision panels, which may prevent detector from "seeing" the flame.

R15-3.5 Similarly, detectors need to be sited so that they will not experience normal process temperatures, radiation or be exposed to chemical, liquid or particles that could result in an accidental activation.

R15-3.6 Where linear heat detection cable is used it should be located where it will not be exposed to levels of ambient or process related heat that could trigger an alarm signal. In addition, the cable should be securely attached to prevent it dislodging and coming into contact with hot surfaces.

R15-3.7 Nozzle locations in many suppression systems can be critical to ensuring functionality, reliability and safety. For example, CO_2 nozzles incorrectly positioned can result in chemical splashing or dislodging product or quartzware. If nozzles are exposed to chemical action including corrosive chemicals, it is important that the materials are resistant to the chemical

R15-3.8 Where automatic sprinkler heads are used, the fusible link should be adequately protected from chemical and mechanical attack.

R15-4 Commissioning Tests

R15-4.1 All installations should undergo a thorough commissioning and acceptance test conducted by the installer and witnessed by the owner or owner's representative.

R15-4.2 Functional Tests are essential, but not sufficient to ensure that system will operate as in tended. The types of problems that can be picked up by functional testing are:

R15-4.2.1 Inability of detection system to detect as intended,

R15-4.2.2 Inability of control system to receive signal from individual detectors, and

R15-4.2.3 Inability of alarm panel to initiate system discharge or send alarm signals to connected devices and safety systems, e.g.,

- local or remote alarm panels,
- sounders & warning devices, and
- interlocks to equipment shutdown and safety systems, EMO.

R15-4.3 Discharge Testing is the only way that we can ensure that that a system will fulfill its intended function. The types of problems that can be picked up by discharge testing are:

R15-4.3.1 Lack of extinguishing agent

R15-4.3.2 Inability to transfer agent from supply to nozzles due to:

- Blockages arising from incorrect equipment,
- Incomplete piping, loose fittings & supports, and
- Installation, design problems (e.g., icing up of CO_2 pipes or nozzles).

R15-4.4 In many cases discharge testing within the cleanroom environment is not considered acceptable or practical. Accordingly, alternatives such as type testing can prove that the design will provide the necessary protection, but may need to be supplemented by a more rigorous commissioning test of the final systems. Type testing would involve the installation and discharge testing of a system on a tool during manufacture or on a mock up of the tool. The aim would be to prove that distribution pipework and nozzles have been correctly designed and that the concentration of agents and distribution patterns from nozzles is acceptable. This would be supplemented by additional tests on each installation, including pressure tests of pipework and "puff" tests to verify pipework integrity.

R15-5 Burn In

R15-5.1 In order to avoid unnecessary discharges, a period of burn-in for the detection system is advisable. This involves the detection system operating, enabling detection of fires and initiation of alarms, but the detection is not interlocked to shut down the process equipment or initiate a discharge.

R15-5.2 A period of days or weeks may be appropriate depending on the effect of an accidental activation of the system in terms of interruption to processing, damage to product or contamination of the environment.

R15-6 Maintenance & Servicing

R15-6.1 Once systems are installed and commissioned it is important that the routine inspection and maintenance procedures recommended by manufacturers and those required by codes and standards, are adequately implemented.

R15-6.2 The inspection frequencies may need to be modified if the ambient conditions can adversely affect the protection systems. For example, sprinkler heads protecting corrosive fume exhaust ducts may need to be inspected weekly or monthly until the appropriate frequency for that particular system can be determined.

R15-6.3 Annual and semi-annual maintenance should be carried out by competent personnel with adequate training for the tasks in hand.

DELAYED REVISIONS SECTION 1 (EFFECTIVE JULY 1, 2006) LASER MODIFICATIONS TO SEMI S2

NOTICE: This Delayed Revisions Section contains material that has been balloted and approved by the SEMI Environmental Health and Safety Committee, but is not immediately effective. The provisions of this material are not an authoritative part of the document until their effective date. The main body of SEMI S2-0703 remains the authoritative version. Some or all of the provisions of revisions not yet in effect may optionally be applied prior to the effective date, providing they do not conflict with portions of the authoritative version other than those that are to be revised or replaced as part of the deferred revision, and are labeled accordingly.

NOTICE: Unless otherwise noted, all material to be added shall be underlined, and all material to be deleted shall be ~~struck through~~.

D1-1 Revisions to Section 4 (Referenced Standards) — OPTIONAL Before Effective Date

D1-1.1 Addition of the following in alphanumeric order to Section 4.5 (IEC Standards):

IEC 60825-1 — Safety of Laser Products, Part 1: Equipment Classification, Requirements, and User's Guide

D1-1.2 Addition of the following in alphanumeric order to Section 4:

4.# *US Code of Federal Regulations*[25]

21CFR 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

D1-2 Revisions to Section 5 (Terminology) — OPTIONAL Before Effective Date

D1-2.1 Addition of the following in alphabetical order to Section 5.1 (Abbreviations & Acronyms):

5.1.# *MPE* — maximum permissible exposure

5.1.# *NOHD* — nominal ocular hazard distance

D1-2.2 Addition of the following in alphabetical order to Section 5.2 (Definitions):

5.2.# *maximum permissible exposure (MPE)* – Level of laser radiation to which, under normal circumstances, persons may be exposed without suffering adverse effects.

5.2.# *nominal ocular hazard distance (NOHD)* – Distance at which the beam irradiance or radiant exposure equals the appropriate corneal maximum permissible exposure (MPE).

D1-3 Revisions to Section 26 (Lasers) — OPTIONAL Before Effective Date

D1-3.1 Revision of the existing Section 26 (Lasers) as shown below:

26 Lasers

26.1 Equipment containing lasers should be properly identified with a laser product classification. This classification should be based on the laser radiation level ~~energy~~ accessible during operation, per the applicable standard or regulation. The laser product classification, applicable standard, and the certification file number (where appropriate) should be documented on a Laser Data Sheet (format in Part 1 of Appendix 7) that is provided to the user.

~~NOTE122: A Class 1 label may be required in some jurisdictions, but is not currently required in the United States.~~

~~26.1.1 The laser energy (or power), wavelength, and temporal mode (continuous wave or pulsed) should be identified in the documentation to the user.~~

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

~~26.1.1.1 If pulsed, the pulse repetition rate, pulse duration and description of the pulse waveform should be identified in the documentation provided to the user.~~

~~26.1.1.2 For Class 3b or 4 embedded laser systems, the above information and the physical location of the laser sources within the product should be identified in the documentation provided to the user and in the maintenance manual.~~

26.1.1 As an alternative to completing a Laser Data Sheet, the equipment manufacturer may provide the information that is specified on the Laser Data Sheet in another format. The information should be organized so the user can easily read and understand it.

26.1.2 Equipment should not exceed the laser product classification of Class 2; however, individual lasers may exceed this classification prior to integration into the final equipment assembly.

26.1.3 Equipment and lasers should be labeled according to the appropriate standards (e.g., IEC 60825-1, 21CFR 1040.10).

NOTE 1: A Class 1 product label may be is required in some jurisdictions. but is not currently required in the United States.

NOTE 2: The laser product classification for some equipment is ~~will be~~ Class 1 or 2, even though an embedded laser is of higher hazard classification.

26.1.4 Equipment suppliers should provide maintenance or service task information in the documents provided to users for equipment that requires access to laser radiation in excess of the maximum permissible exposure (MPE).

26.1.4.1 The information for these tasks should be documented on a Laser Data Sheet (See Appendix 7) in the documents provided to users and should include the accessible laser and beam parameters (A7-2), laser control measures (A7-3) and personal protective equipment (A7-4) for each laser or task requiring this access.

EXCEPTION: In the case of proprietary beam parameters, an acceptable alternative is to provide the nominal ocular hazard distance (NOHD) results (according to IEC 60825 or its equivalent) for each task requiring access above the MPE.

EXCEPTION: If a laser system is a stand-alone laser product delivered as a component or spare for laser equipment, the laser system supplier's responsibility for Laser Data Sheet information is limited to that which applies specifically to the stand-alone laser product and not the integrated laser equipment.

26.1.5 The physical location of the embedded laser sources and access points within the laser product should be identified in the documents provided to users.

26.2 Equipment, including beam diagnostic or alignment tools, should be designed to prevent injury from all lasers during normal operation, and should minimize the risk of injury during maintenance or service. Potential exposures should be controlled in the following order of preference:

26.2.1 Engineering controls (e.g., enclosures, shielding, filters, use of fiber optics to transmit energy, interlocks).

26.2.2 Temporary enclosures or control measures for maintenance, service, and non-routine tasks.

26.2.3 Administrative controls (e.g., written warnings, standard operating procedures, labeling).

26.2.4 Personnel protective equipment.

NOTE 3: Temporary enclosures and personal protective equipment are considered to be administrative controls, because they require human action to implement.

NOTE 4: Certain classes of laser products are regulated around the world. Regulations and licensing requirements may cover activities such as importing, exporting, distributing, demonstrating, installing, servicing, and using these laser products.

26.3 The equipment supplier should provide the following in the operation and maintenance manuals:

- A description of laser related hazards present during operation, maintenance, or service, and methods to minimize the hazard;
- Justification for any procedures that require a laser controlled area and the dimensions of this hazard zone;
- Administrative controls used in maintenance and service activities; and
- A description of the necessary personal protective equipment.

26.4 The following detailed information should be available to an evaluator:

- Justification for when engineering controls are not feasible to limit exposure during operation or maintenance tasks, and how administrative controls provide equivalent protection (See Section 26.2); and
- Documentation showing compliance with an appropriate international laser product safety or industry standard, or the national standard of the country of use.

D1-4 Addition of Appendix 7 (Laser Data Sheet – SEMI S2) — OPTIONAL Before Effective Date

D1-4 Addition of the following as Appendix 7 (Laser Data Sheet – SEMI S2):

APPENDIX 7
Laser Data Sheet – SEMI S2

A7-1 Equipment Information - (All Laser Product Classes)

Laser Equipment Manufacturer ____________________

Equipment Model # ____________________

Date Laser Data Sheet Completed ____________________

Laser Product Classification ____________ (e.g., 1, 1M, 2, 2M, 3A, 3R, 3B, 4)

Classification Standard(s) ____________ (e.g., IEC, FDA/CDRH, JIS)

Certification File Identification Number ____________ (e.g., CDRH accession number, or if CDRH accession number has been applied for, but not yet received, a statement of 'pending' along with the submittal date may be used instead. If self declaring under IEC 60825-1 or if certification is not required, e.g., if class 1 laser product is incorporated without changes, then 'N/A' may be used)

A7-2 Laser Information (Greater than Class 2 & embedded Class 3R (3A), 3B & 4)

Is access to laser radiation above the maximum permissible exposure (MPE) level required during maintenance or service tasks? YES ____ NO ____

If NO, then the information in Parts A7-2, A7-3 and A7-4 need not be provided.

If YES, complete the information in Parts A7-2, A7-3 and A7-4 for each task and laser that requires access.

If there are multiple lasers contained within the laser equipment, provide the following for each task/laser combination that meets the above criteria.

Laser Parameters	**Laser 1**	**2**	**etc.**
Laser Manufacturer			
Laser Model No.			
A7-2.1 Laser Medium Type (HeNe, Nd:YAG, Argon, KrF, Diode, etc.)			
A7-2.2 Wavelength(s) in nanometers (nm)			
A7-2.3 Laser Hazard Classification (individual laser)			

NOTE 3: If a laser is used in both continuous wave and pulsed modes, complete both A7-2.4 and A7-2.5.

A7-2.4 Continuous Wave Lasers			
A. Power in Watts (W)			
B. Irradiance in Watts/square centimeter (W/cm^2 at aperture)			
A7-2.5 Pulsed Laser Characteristics			
A. Pulse Duration in Seconds (s)			
B. Energy per Pulse in Joules (J)			

C. Pulse Repetition Frequency in Hertz (Hz) ____, ____, ____

D. Average Power in Watts (W) ____, ____, ____

E. Radiant Exposure Joules/square centimeter (J/cm^2) ____, ____, ____

F. Q-Switch controlled pulses (Yes/No) ____, ____, ____

A7-2.6 Beam Parameters at maintenance or service access points

Exception: In the case of proprietary information, an acceptable alternative to providing the Beam Parameters is to provide NOHD results for each access point according to IEC 60825 or equivalent.

A. Beam shape Circular (C), Rectangular (R), Elliptical (E) ____, ____, ____

B. Beam size (mm) Major axis (R/E) or diameter (C) ____, ____, ____

Minor axis (R/E) ____, ____, ____

Laser Parameters **Laser 1, 2, etc.**

C. Beam divergence in milliradians (mr)

Major axis (R/E) or diameter (C) ____, ____, ____

Minor axis (R/E) ____, ____, ____

D. Focal length in millimeters (mm) (of the emitting lens)

Major axis (R/E) or diameter (C) ____, ____, ____

Minor axis (R/E) ____, ____, ____

E. Is there a collecting optics hazard? (Yes/No) ____, ____, ____

A7-3 Laser Control Measures

A7-3.1 Specify maintenance/service tasks requiring access to laser radiation in excess of the MPE and recommended laser control measures.

A. Task 1 ____________________

B. Task 2 ____________________

C. Etc. ____________________

Note 1: Suppliers may alternately provide a reference to laser control measures information that is located in a document available to users.

A7-3.2 Of the tasks in A7-3.1, which tasks need a Laser Controlled Area (for Class 3b or 4 lasers)?

____

A7-3.3 If a nominal ocular hazard distance (NOHD) is used as a control measure, then provide the NOHD calculations and assumptions. See IEC 60825-1 for NOHD calculations.

Exception: If specific information required by A7-2.6 is proprietary, suppliers may provide the NOHD results and an explanation of the assumptions made.

A7-3.4 Include a beam path diagram identifying the accessible points.

NOTE 1: A description of the access points from the exterior of the tool can be considered equivalent to a diagram.

A7-4 Personnel Protective Equipment (PPE)

Provide information for accessible laser radiation hazards in excess of the Maximum Permissible Exposure (MPE)

Laser Parameters **Laser 1, 2, etc.**

A. Optical Density (OD) of PPE required during maintenance ____, ____, ____

B. OD of PPE required during service activities ____, ____, ____

C. Other types of PPE (e.g., skin protection) if needed _______, _______, _______

Note 2: Suppliers may alternately provide a reference to PPE information located in a document available to users.

D1-5 Revisions to Related Information 9 (Laser Checklist) — OPTIONAL Before Effective Date

D1-5.1 Revision of the existing Related Information 9 (Laser Checklist) as shown below:

RELATED INFORMATION 9
~~LASER CHECKLIST~~LASER EQUIPMENT SAFETY FEATURES

NOTICE: This related information is not an official part of SEMI S2 and was derived from practical application by task force members. This related information was approved for publication by vote of the responsible committee on ~~October 21, 1999~~ April 22, 2004 with an effective date of July 1, 2006.

~~Laser Manufacturer:~~ ____________________

~~Model #:~~ ____________________

~~Serial #:~~ ____________________

~~Laser Hazard Classification: (During Operation)~~

~~1. Classification Number (e.g. 1, 2, 3a, 3b, 4):~~ ________

~~2. Classification Standard(s) (e.g. FDA/CDRH, IEC, JIS, etc.):~~ ________

~~NOTE R9-1: If any laser contained in the equipment is Class 2, 3a, 3b or 4 laser system or product, the vendor should make available upon request a hazard evaluation to include the following information for each laser in the equipment (where applicable):~~

~~Laser Parameters~~

~~1. Laser medium type (HeNe, Nd:YAG, CO_2, Argon, Excimer, GaAs, etc.):~~ __________

~~Note: For Excimer lasers, specify gases:~~ ______________

~~2. Wavelength(s) in nanometers (nm):~~ ______________

~~3. Continuous Wave~~

~~A. Peak Power in Watts (W):~~ ________

~~B. Available Power in Watts (W):~~ ________

~~C. Irradiance in Watts/square centimeter (W/cm^2):~~ ________

~~4. Pulse Characteristics~~

~~A. Duration of Pulse in Seconds (s):~~ ________

~~B. Energy per Pulse in Joules (J):~~ ________

~~C. Frequency of Pulses (Pulse Repetition Frequency) in Hertz (Hz):~~ ________

~~D. Average Power in Watts (W):~~ ________

~~E. Radiant Exposure in Joules/square centimeter (J/cm^2):~~ ________

~~F. Q-Switch controlled pulses ( ) Yes ( ) No~~

~~5. Beam Parameters~~

~~A. Emerging beam diameter in millimeters (mm):~~ ________

~~B. Expanded beam diameter in millimeters (mm):~~ ________

~~C. Beam divergence in milliradians (mr):~~ ________

~~D. Collecting optics type:~~ ________

~~E. Focal length in millimeters (mm):~~ ________

~~Laser Control Measures~~

~~1. Identify protective measures required during maintenance.~~ ________________

____

~~2. Laser Controlled Area required for Maintenance procedures? ( ) Yes ( ) No~~

~~3. Laser Controlled Area required for Service procedures. ( ) Yes ( ) No~~

~~4. If a Nominal Ocular Hazard Distance (NOHD) is used as a control measure, then provide the NOHD calculations. See IEC 60825-1 for NOHD calculations.~~

~~NOTE R9-2: Attach a diagram of the laser beam path and the irradiance/radiant exposure at each significant point.~~

~~Personnel Protective Equipment (PPE) (for laser radiation hazards in excess of the MPE)~~

~~1. Optical Density (OD) of PPE required during maintenance activities:~~ __________

~~2. OD of PPE required during service activities:~~ __________

~~3. Recommended PPE manufacturer and model #:~~ ____________________

Table R9-1 Equipment Safety Features Reference Table

Reference Number	*Equipment Safety Features (not an inclusive list)*[D]		*USA* *21 CFR 1040.10*[A]	*Europe* *~~EN~~IEC 60825-1*[B]	*Japan* *JIS C 6802*[C]	*Examples*
			~~*Paragraph*~~	~~*Paragraph*~~	~~*Paragraph*~~	~~*Examples*~~
1.	Protective Housing	~~( ) Yes ( ) No~~	(f)(1)	4.2	4.2.1	Aluminum or steel enclosures, windows that provide adequate attenuation, optical fibers or beam tubes.
2.	Safety Interlocks	~~( ) Yes ( ) No~~	(f)(2)	4.3	4.2.2	See Interlock Section ~~11~~ of SEMI S2.
3.	Remote Interlock Connector	~~( ) Yes ( ) No~~	(f)(3)	4.4	4.2.3	Usually a 12 to 24 volt set of contacts available to the user to integrate additional room control measures.
4.	Key Control	~~( ) Yes ( ) No~~	(f)(4)	4.5	4.2.4	A key that is not removable in the operations mode.
5.	Laser Radiation Emission Warning	~~( ) Yes ( ) No~~	(f)(5)	4.6	4.2.5	A light or indicator that warns the user of the emission through the aperture.
6.	Beam Attenuator	~~( ) Yes ( ) No~~	(f)(6)	4.7	4.2.6	Shutters, beam blocks or water-cooled beam dumps
7.	Location of Controls	~~( ) Yes ( ) No~~	(f)(7)	4.8	4.2.7	
8.	Viewing Optics	~~( ) Yes ( ) No~~	(f)(8)	4.9	4.2.8	Must block all hazardous wavelengths to acceptable levels.
9.	Scanning Safeguard	~~( ) Yes ( ) No~~	(f)(9)	4.10	4.2.9	Shuts down if the scanning mechanism (such as a rotating mirror or galvanometer) fails.
10.	Manual Reset Mechanism	~~( ) Yes ( ) No~~	(f)(10)	4.3.1	4.2.2(c)	A button or circuit that must be energized before the equipment resumes its functions.

Reference Number	Equipment Safety Features (not an inclusive list)[D]		USA 21 CFR 1040.10[A]	Europe ~~EN~~IEC 60825-1[B]	Japan JIS C 6802[C]	Examples
11.	Class Designation & Warning Labels	~~( ) Yes~~ ~~( ) No~~	(g)(1)-(g)(4)	5.1-5.6, 5.8-5.11	4.3	Identify which standard was used for each hazard classification.
12.	Aperture Label	~~( ) Yes~~ ~~( ) No~~	(g)(5)	5.7	4.3.7	Identify the aperture.
13.	Positioning of Labels	~~( ) Yes~~ ~~( ) No~~	(g)(9)	5.1	4.3.1	Conspicuous, but size is not specified.
14.	User Information	~~( ) Yes~~ ~~( ) No~~	(h)(1)	6.1	4.4.1	SOPs, instruction manuals
15.	Service Information	~~( ) Yes~~ ~~( ) No~~	(h)(2)	6.2	4.4.2	Accessible laser radiation levels during Service
16.	Measurements	~~( ) Yes~~ ~~( ) No~~	(e)	~~8~~**9**	3.4	
17.	Classification	~~( ) Yes~~ ~~( ) No~~	(c)	~~9~~**8**	3.3.3	
18.	Certification Information		21 CFR	~~TBD by Europe~~	~~TBD by Japan~~	
19.	Certification Label	~~( ) Yes~~ ~~( ) No~~	1010.2			
20.	Identification Label	~~( ) Yes~~ ~~( ) No~~	1010.3			

A. The US FDA/CDRH makes 21 CFR 1040.10 available, so the latest version should be used. The version used to update this table was dated April 1, 2003.

B. The IEC laser products standard used to update this table was 60825-1 © IEC:1993+A1:1997+A2:2001(E)

C. The Japanese Standards Association does not offer the current version of JIS C 6802 in English. However, the current version should be used and the Japanese version is the official version The sections referenced in the table above are from the 1991 English version of C 6802.

D. This requirement applies only to certain classes of lasers.

NOTE 4: Both the IEC and the US FDA/CDRH have published guides to assist manufacturers with laser product conformance.

NOTE 5: The FDA/CDRH has published Laser Notice 50. This laser notice provides guidance to manufacturers relating to the FDA/CDRH acceptance of laser products conforming to the IEC 60825-1 standard. There are conditions and additional requirements, so manufacturers should obtain this laser notice for the details.

R9-2 Referenced Documents

R9-2.1 *IEC Standards*[26]

IEC 60825-1 — Safety of Laser Products, Part 1: Equipment Classification, Requirements, and User's Guide

R9-2.2 *US Code of Federal Regulations*[27]

21CFR 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

26 International Electrotechnical Commission, No. 3, rue de Varembé, Case Postale 131, CH-1211 Geneva 20, Switzerland. Telephone: 41.22.919.02.11; Fax: 41.22.919.03.00. Website: www.iec.ch

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

DELAYED REVISIONS SECTION 2 (EFFECTIVE JULY 1, 2006) SEMI S10 CHANGES TO SEMI S2

NOTICE: This Delayed Revisions Section contains material that has been balloted and approved by the SEMI Environmental Health and Safety Committee, but is not immediately effective. The provisions of this material are not an authoritative part of the document until their effective date. The main body of SEMI S2-0703 remains the authoritative version. Some or all of the provisions of revisions not yet in effect may optionally be applied prior to the effective date, providing they do not conflict with portions of the authoritative version other than those that are to be revised or replaced as part of the deferred revision, and are labeled accordingly.

NOTICE: Unless otherwise noted, all material to be added shall be underlined, and all material to be deleted shall be ~~struck through~~.

D2-1 Revisions to Section 5 (Terminology) — OPTIONAL Before Effective Date

D2-1.1 Addition of the following at the beginning of Section 5.2 (Definitions):

NOTE #: 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 S10-12-96 definitions for the terms hazard, likelihood, mishap, severity, and risk.

D2-1.1 Addition (in alphabetical order), deletion, and revision of the following in Section 5.2 (Definitions):

5.2.# *harm* — physical injury or damage to health of people, or damage to equipment, buildings or environment.

5.2.25 *hazard* ~~— a condition that is a prerequisite to a mishap~~ condition that has the potential to cause harm.

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

~~5.2.44 mishap — an unplanned event or series of events that results in death, injury, occupational illness, damage to or loss of equipment or property, or environmental damage.~~

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

5.2.64 *severity* — ~~the extent of the worst credible loss from a mishap caused by a specific hazard.~~ the extent of potential credible harm.

D2-2 Revisions to Section 6.5 — OPTIONAL Before Effective Date

D2-3.1 Revision of the following in Section 6.5:

NOTE 7 The intent is to control single fault conditions that result in significant risks (i.e., ~~Critical~~ Very High, High, or Medium risks based on the example risk assessment matrix in SEMI S10).

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

D2-3 Revisions to Section 6.8.1 — OPTIONAL Before Effective Date

D2-3.1 Revision of the existing Section 6.8.1 as shown below:

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 ~~a mishap~~ 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 #: The term mishap was replaced with the results of harm in the SEMI S10 1103 revision.

D2-4 Revisions to Section 11.6 — OPTIONAL Before Effective Date

D2-4.1 Revision of the following in Section 11.6:

NOTE 26: Where a safety interlock is provided to safeguard personnel from ~~a~~ severe or catastrophic ~~mishap~~ harm as categorized by SEMI S10, consideration of positive-opening type of switches is recommended.

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.

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

The user's attention is called to the possibility that compliance with this guideline may require use of copyrighted material or of an invention covered by patent rights. By publication of this guideline, SEMI takes no position respecting the validity of any patent rights or copyrights asserted in connection with any item mentioned in this guideline. Users of this guideline are expressly advised that determination of any such patent rights or copyrights, and the risk of infringement of such rights, are entirely their own responsibility.

SEMI S3-91
SAFETY GUIDELINES FOR HEATED CHEMICAL BATHS

NOTICE: These guidelines do not purport to address all of the safety issues associated with their use. It is the responsibility of the users of these guidelines to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

NOTE: As listed or revised, all documents cited shall be the latest publications of adopted standards.

1 Purpose/Scope

This safety guideline pertains to open top heated chemical baths, or “wet stations”, used in the manufacturing of semiconductors. The purpose of this guideline is to provide general safety information for the construction, operation, and maintenance of chemical baths heated by electric immersion, externally bonded or heat exchange type heating devices. This guideline is not intended to provided detailed design information for the individual components of the heating systems, but rather to supply the safety criteria for the design of these systems. (See Figure 1.)

2 Introduction

2.1 Failure to follow the manufacturer’s instructions as to the application or installation of heating systems used for chemical baths can result in accidents and fires in which such systems may be implicated.

2.2 The human element plays a major role in how well the hardware is used. The user of heated chemical bath systems needs to understand the available technology to minimize the risk involved.

2.3 The issue of bath operation and maintenance has been included in this guideline to support the safe use and maintenance of heated baths over their normal service life.

3 Heated Bath Methodology

3.1 *Electric Immersion Heaters* — Electric immersion bath heaters are resistive element heaters. The element itself is typically protected by an outer sheathing which acts as a corrosion and electrical barrier. The element is mounted to the inside of the bath.

3.2 *External Tank Heaters* — External type heaters are normally bonded by a mastic to the outside of a chemical bath. The most common types are manufactured from a thin metal foil material that results in a very low profile configuration.

3.3 *Heat Exchangers* — The most common type of heat exchanger employs a separate heating source that may be remote from the station. This heating source can be electrically powered to generate steam or some other heat transfer fluid. The heat transfer fluid is then delivered by chemically compatible plumbing to the bath and recirculated to the heater.

4 Minimum Heated Bath Safety Requirements

To ensure the safe operation and maintenance of heating systems, the following features are required.

- overcurrent protection
- power interrupt
- manual reset
- automatic temperature controller
- liquid level sensor
- overtemperature protection
- proper grounding and ground fault protection
- compatible construction materials

NOTE: Interlocks should operate as outlined in SEMI S2. These features should be totally compatible with each other.

4.1 *Overcurrent Protection* — A fused disconnect switch or circuit breaker sized for the amperage of the heater.

4.2 *Power Interrupt* — In the event of an overtemperature, low liquid level, or ground fault condition, power to the heater(s) is interrupted upon receiving the respective signal. The interrupt should be separate from any relay incorporated into the automatic temperature controller. The interrupt should be wired in such a manner that any signal from the liquid level sensor, overtemperature sensor, or ground fault condition should shut off power to the heaters and place the system in a “fail safe” condition.

4.3 *Manual Reset* — This reset should be incorporated into the power interrupt device so that when the system shuts off power to the heating element, a manual reset is required to re-energize the system.

4.4 *Automatic Temperature Controller* — An automatic temperature controller maintains the liquid at a set temperature by turning the heating element on and off. The controller is activated by signals from a sensor that is located at the bath. To preserve the integrity of this system, quarterly service/testing and calibration in accordance with the manufacturer's recommendations should be performed.

4.5 *Liquid Level Sensor* — This sensor will act to shut down the heating element if the liquid level falls below a safe operating level. When employing either an immersion or externally mounted type heater, it is recommended that this level be no less than five centimeters (two inches) above the heating element's "hot zone" as established by the manufacturer. This should prevent the element from losing the heat sink created by the liquid.

4.5.1 The selection of a suitable sensor should take into account:

4.5.1.1 The physical properties of the liquids being heated and the environmental conditions to which the sensor(s) will be subjected.

4.5.1.2 The mode of failure, if the sensor fails.

4.5.2 To preserve the integrity of these components, they should be tested on a quarterly basis and serviced following the manufacturer's recommendations.

4.6 *Overtemperature Protection*

4.6.1 *Liquid Overtemperature* — A dedicated liquid overtemperature sensor should typically be set to trip at a temperature below the autoignition temperature of the chemical being used in the bath, and in no case higher than 10°C (18°F) above the normal operating temperature.

4.6.1.1 This temperature setting should compensate for the initial over-shoot often encountered when bringing the liquid from ambient to operating temperature.

4.6.1.2 The sensor should be located in the liquid at an elevation approximating the top of the heating elements "hot zone" and no more than seven centimeters (three inches) away from the heater.

4.6.2 *Heating Element Overtemperature* — When using an electrical immersion type heater, a sensor should be used to shut down the heating element if the surface temperature of the element exceeds a preset value. The sensor is typically placed between the resistance coil and the protective sheath covering.

4.7 *Proper Grounding & Ground Fault Protection* — The amount of insulation surrounding a heater element depends upon the type of heater. This insulation not only provides protection from the corrosive properties of the solution, but also acts as an electrical barrier. If the barrier breaks down, it is possible for the solution to become energized.

4.7.1 The electric heater elements should be equipped with a ground, the construction of which should be approved by a nationally recognized testing laboratory (NRTL).

4.7.2 A ground fault circuit interrupter (GFCI) should be used to preclude worker exposures to potential electrical shock.

4.7.3 The station or equipment in which the heated bath will be used needs to be reviewed to ensure that all National Electrical Code requirements have been addressed.

4.8 *Compatible Construction Materials* — All portions of the station that could come in contact with process chemicals should be constructed from materials compatible with these chemicals. It is recommended that metal materials be used in the station's construction when using combustible or flammable solutions.

5 Operation and Maintenance

5.1 Before heated baths are put into service, a detailed review of the wet station operation and maintenance should be conducted for all employees operating or servicing the station. New employees should receive the same information prior to work assignment.

5.1.1 All safety features included with the station's heating system should be user tested, and the frequency of testing should be noted in the user's periodic maintenance procedures.

NOTE: Recommended minimum frequency of testing is quarterly and after any station maintenance.

5.1.2 Vendor-supplied information on the bath operation and limitations that may apply should be reviewed and appropriate employee training conducted.

5.1.3 When the user plans to install the baths and to perform maintenance, the suppliers should provide guidance to ensure that all aspects of the system, such as the controller and the heated bath safety systems, are integrated properly.

5.1.4 Review the process requirements to ensure that operating temperatures are within the range and capability of the safety controls. For flammable and combustible liquids, operating temperatures should be below the ignition temperature.

5.1.5 Limit the interchanging of parts that were not included in the original design unless so advised by the supplier. Alternate parts can lead to failures resulting in a fire or physical injury.

6 Related Documents

6.1 UFC 1988 edition.

6.2 OSHA Safety & Health Standards (29 CFR 1910).

6.3 Joseph Lotti, "Electric Immersion Heater Redundant Control System", presented to Semiconductor Safety Association Annual Conference, May 1986.

6.4 Factory Mutual Insurance Corporation, "Plastics and Plastic-Lined Tanks with Electric Immersion Heaters," 7-6.

6.5 National Electrical Code, "Articles 500, 501, Hazardous Locations," latest edition.

6.6 National Electrical Code, "Articles 250, 422, 427, and 516, Grounding, Appliances, Fixed Electrical Heating for Pipe Lines and Vessels and Spray Application, Dipping and Coating Processes."

6.7 SEMI S2, Safety Guidelines for Semiconductor Manufacturing Equipment.

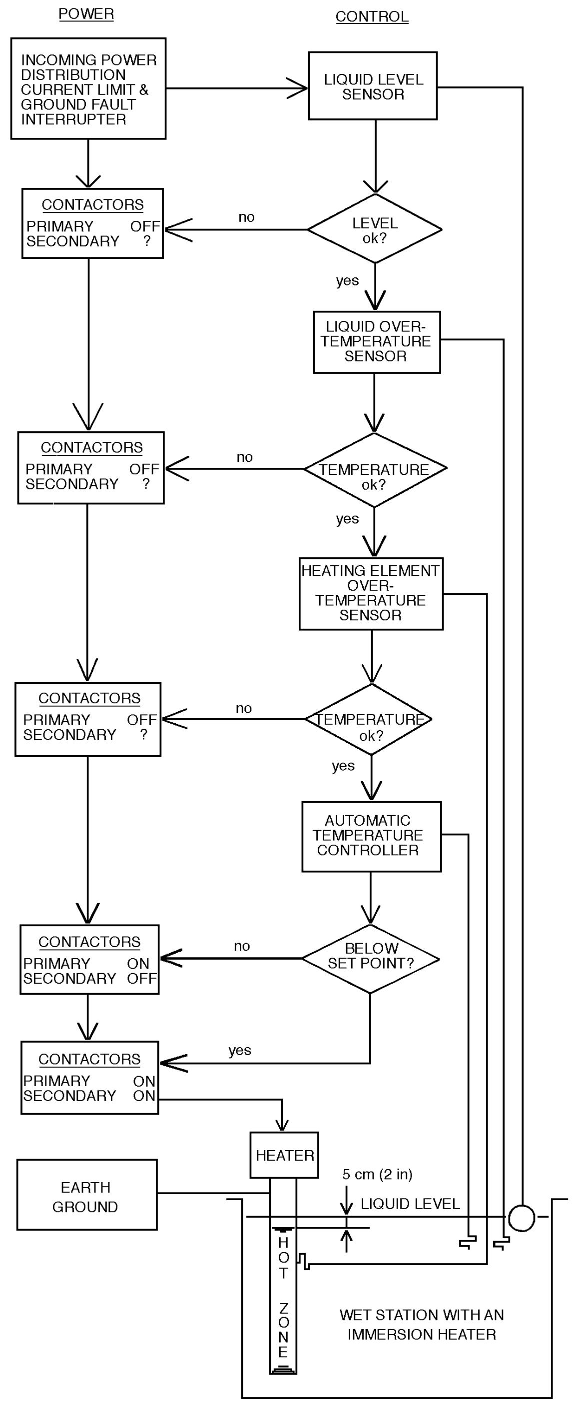
POWER
CONTROL
INCOMING POWER DISTRIBUTION CURRENT LIMIT & GROUND FAULT INTERRUPTER
LIQUID LEVEL SENSOR
CONTACTORS
PRIMARY OFF
SECONDARY ?
no
LEVEL ok?
yes
LIQUID OVER-TEMPERATURE SENSOR
CONTACTORS
PRIMARY OFF
SECONDARY ?
no
TEMPERATURE ok?
yes
HEATING ELEMENT OVER-TEMPERATURE SENSOR
CONTACTORS
PRIMARY OFF
SECONDARY ?
no
TEMPERATURE ok?
yes
AUTOMATIC TEMPERATURE CONTROLLER
CONTACTORS
PRIMARY ON
SECONDARY OFF
no
BELOW SET POINT?
CONTACTORS
PRIMARY ON
SECONDARY ON
yes
HEATER
EARTH GROUND
5 cm (2 in)
LIQUID LEVEL
HOT ZONE
WET STATION WITH AN IMMERSION HEATER

Figure 1

NOTICE: These guidelines do not purport to address all of the safety issues associated with their use. It is the responsibility of the users of these guidelines to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use. SEMI makes no warranties or representations as to the suitability of the guidelines set forth herein for any particular application. The determination of the suitability of these guidelines is solely the responsibility of the user. Users are cautioned to refer to manufacturer's instructions, product labels, product data sheets, and other relevant literature respecting any materials mentioned herein. These guidelines are subject to change without notice.

The user's attention is called to the possibility that compliance with this standard may require use of copyrighted material or of an invention covered by patent rights. By publication of this standard, SEMI takes no position respecting the validity of any patent rights or copyrights asserted in connection with any item mentioned in this standard. Users of this standard are expressly advised that determination of any such patent rights or copyrights, and the risk of infringement of such rights, are entirely their own responsibility.

SEMI S4-0304
SAFETY GUIDELINE FOR THE SEPARATION OF CHEMICAL CYLINDERS CONTAINED IN DISPENSING CABINETS

This safety guideline was technically approved by the Global Environmental, Health, and Safety Committee and is the direct responsibility of the North American Environmental, Health, and Safety Committee. Current edition approved by the North American Regional Standards Committee on December 4, 2003. Initially available at www.semi.org February 2004; to be published March 2004. Originally published in 1992.

NOTICE: This safety guideline was completely rewritten in 2003.

NOTICE: Paragraphs entitled "NOTE" are not an official part of this document and are not intended to modify or supersede the official Safety Guideline. These have been supplied by the Task Force to enhance usage of the Safety Guideline.

NOTICE: The intent of the task force that produced this document is that conformance to the "should" provisions of this guideline comprises conformance with this guideline.

1 Purpose

1.1 This safety guideline provides a method for determining cylinders of which types of chemicals should be in separate gas cabinets and which cylinders may be in gas cabinets with each other.

1.2 The safety guideline is intended to be used by those working or doing research in semiconductor-related technology.

2 Scope

2.1 This safety guideline refers to chemicals, which includes gases and liquids, contained in cylinders, that are used in gaseous form because of their vapor pressure or because they may be transported as a vapor by a carrier gas.

2.2 It also pertains to all types of cylinders, up to and including an internal volume of 1000 liters.

2.3 The primary intent of this guideline is directed to a cylinder gas in use in, or being dispensed in, the research and manufacturing processes.

2.4 This safety guideline addresses purge gases supplied in cylinders and used to purge process chemical lines.

2.5 This safety guideline addresses process chemicals in cylinders which are designed to provide them at pressures less than 101.3 kPa (one atmosphere).

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

3 Limitations

3.1 This safety guideline does not pertain to those cases where chemical cylinders are incorporated within a piece of process equipment.

NOTE 1: Guidance regarding other aspects of the safety and management of gas cylinders is contained in several of the documents listed in the Related Documents section of this safety guideline.

3.2 This safety guideline does not pertain to chemicals used in fabrication facilities for ancillary purposes, such as welding.

4 Referenced Standards

4.1 *United States Code of Federal Regulations*

16 CFR 1500.41 — Method of testing primary irritant substances[1]

49 CFR 173 — Shippers – General Requirements for Shipment and Packaging[2]

4.2 *National Fire Protection Association*[3]

NFPA 49 — Hazardous Chemicals Data

NOTE 2: NFPA 49 is no longer part of the NFPA codes in either the compact disc or hard copy version. It is now part of the NFPA Fire Protection Guide to Hazardous Materials and must be purchased separately from NFPA.

NFPA 704 — Identification of Fire Hazards of Materials

1 The Office of the Federal Register, Washington, D.C. 20037 http://www.access.gpo.gov/nara/cfr/waisidx_00/16cfr1500_00.html

2 The Office of the Federal Register, Washington, D.C. 20037 http://www.access.gpo.gov/nara/cfr/waisidx_00/49cfr173_00.html

3 National Fire Protection Association, 1 Batterymarch Park, Quincy, MA 02269, Website: www.nfpa.org

4.3 *Compressed Gas Association* [4]

P20 — Standard for the Classification of Toxic Gas Mixtures

P23 — Standard for Categorizing Gas Mixtures Containing Flammable and Nonflammable Components

4.4 *International Organization for Standardization (ISO)* [5]

10156:1996 — Gases and gas mixtures - Determination of fire potential and oxidizing ability for the selection of cylinder valve outlets

4.5 *European Directives* [6]

67/548/EEC — On The Approximation Of The Laws, Regulations And Administrative Provisions Relating To The Classification, Packaging And Labeling Of Dangerous Substances Including Its Amendments And Adaptations To Technical Progress

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

5 Terminology

5.1 *Abbreviations and Acronyms*

5.1.1 *CGA* — Compressed Gas Association

5.1.2 *CFR* — Code of Federal Regulations (United States)

5.1.3 *HPM*— Hazardous Production Material

5.1.4 *ISO* — International Organization for Standardization

5.1.5 LC_{50} — median lethal concentration in air

5.1.6 *NFPA* — National Fire Protection Association

5.2 *Definitions*

5.2.1 *acid* — a corrosive chemical whose chemical reaction characteristic is that of an electron acceptor.

5.2.2 *base* — a corrosive chemical whose chemical reaction characteristic is that of an electron donor.

5.2.3 *chemical* — a liquid or gas used in a process for its ability to react with or displace other substances.

5.2.4 *combustible material* — a material that, in the form in which it is used and under the conditions anticipated, may ignite, burn, or release flammable vapors when subjected to fire or heat.

5.2.5 *corrosive* — a chemical that causes visible destruction of, or irreversible alterations in, living tissue by chemical action at the site of contact. A chemical is considered to be corrosive if, when tested on the intact skin of albino rabbits by the method described in the U. S. Department of Transportation in Appendix A to 49 CFR 173, it destroys or changes irreversibly the structure of the tissue at the site of contact following an exposure period of four hours. This term shall not refer to action on inanimate surfaces.

5.2.6 *cylinder* — a pressure vessel designed for containing chemicals at positive gauge pressure and having a circular cross section. The definition of "cylinder" does not include a portable tank, multiunit tank car tank, cargo tank, or tank car.

5.2.7 *flammable gas* — any gas that forms an ignitable mixture with air at 20 ° C (68 ° F) and 101.3 kPa (14.7 psia). [SEMI S2, S18]

5.2.8 *gas* — the fluid form of a substance in which it can expand indefinitely and completely fill its container; form that is neither liquid or solid. [SEMI F78]

5.2.9 *gas cabinet* — a metal enclosure which is intended to provide local exhaust ventilation, protection for the gas cylinder from fire from outside the cabinet, and protection for the surroundings from fire from inside the cabinet.

5.2.10 *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 which have as their end product materials which are not hazardous. [SEMI S2]

5.2.11 *highly toxic chemical* — a chemical that has a median lethal concentration (LC_{50}) in air of 200 parts per million by volume or less of gas or vapor, or 2 milligrams per liter or less of mist, fume, or dust, when administered by continuous inhalation for one hour (or less if death occurs within one hour) to albino rats weighing between 200 and 300 grams each.

5.2.12 *inert gas* — a gas which at ambient conditions does not react chemically with other chemicals.

5.2.13 *irritant* — A chemical is considered to be an irritant if:

a) It is classified as a "primary skin irritant" per 16 CFR 1500, or

4 Compressed Gas Association, 4221 Walney Road, 5th Floor, Chantilly VA 20151-2923., Phone: 703-788-2700, Fax: 703-961-1831, Email: cga@cganet.com , www.cganet.com

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, Website: /www.iso.ch

6 http://europa.eu.int/comm/environment/dansub/main67_548/index-_en.htm

b) It is designated as an irritant according to European Directive 67/548/EEC, on the approximation of the laws, regulations and administrative provisions relating to the classification, packaging and labeling of dangerous substances including its amendments and adaptations to technical progress.

5.2.14 *liquid* — having its molecules moving freely with respect to each other so as to flow readily, unlike a solid, but because of cohesive forces not expanding infinitely like a gas. [SEMI F78]

5.2.15 *other health hazard* —A chemical for which there is statistically significant evidence based on at least one study conducted in accordance with established scientific principles that acute or chronic health effects may occur in exposed employees, other than those for which a separate classification is defined. The term “other health hazard” includes chemicals which are carcinogens, reproductive toxins, sensitizers, hepatotoxins, nephrotoxins, neurotoxins, mutagens, agents which act on the hematopoietic system, and agents which damage the lungs, skin, eyes, or mucous membranes.

5.2.16 *oxidizer chemical* — a chemical which will support combustion or increase the burning rate of a combustible or flammable material with which it may come in contact.

5.2.17 *pyrophoric chemical* — a chemical which upon contact with air will ignite spontaneously at or below a temperature of 54°C (130°F).

5.2.18 *separation* — the condition of having the risks of mixing of chemicals and of exposure of cylinders to chemicals other than those they contain managed by the cylinders being in different gas cabinets.

5.2.19 *toxic chemical* — A chemical is considered to be toxic if:

a) It that has a median lethal concentration (LC_{50}) in air of more than 200 parts per million but not more than 2,000 parts per million by volume of gas or vapor, or more than 20 milligrams per liter of mist, fume, or dust, when administered by continuous inhalation for one hour (or less if death occurs within one hour) to albino rats weighing between 200 and 300 grams each, or

b) It is designated as “Toxic” according to European Directive 67/548/EEC on the approximation of the laws, regulations and administrative provisions relating to the classification, packaging and labeling of dangerous substances including its amendments and adaptations to technical progress.

5.2.20 *unstable (reactive)* — a chemical which in the pure state, or as produced or transported, will vigorously polymerize, decompose, condense, or will become self-reactive under conditions of shock, pressure, or temperature.

5.2.21 *water reactive* — a chemical that reacts with water to release a chemical that is either flammable or presents a health hazard.

6 Classification

6.1 Chemicals should be classified according to the categories and associated symbols as shown in Table 1.

6.2 Information on the properties of chemicals (other than mixtures) should be obtained through measurement or from literature, such as MSDSs.

Table 1 Classifications and Symbols

Classification	*Symbol*
Flammable	F
Pyrophoric	P
Corrosive Acid	CA
Corrosive Base	CB
Toxic	T
Highly Toxic	HT
Oxidizer	O
Inert	I
Irritant	IRR
Water Reactive	WR
Unstable (Reactive)	UR
Other Health Hazard	OHH

6.3 A chemical should be assigned more than one classification if it possesses more than one of the characteristics listed in the table.

6.4 The properties of mixtures of two or more chemicals should be determined experimentally or estimated using accepted principles, such as those in ISO 10156, CGA P20 and P23.

NOTE 3: The experimentation or estimation may be performed by the user, or the user may rely on experimental results or estimations by accepted principles performed by others and reported in a document, such as an MSDS.

NOTE 4: A list of some chemicals used in the semiconductor industry and their classification symbols appears in Related Information 1.

7 Separation

7.1 Where practical, each chemical (except for inert gases) should be contained in a separate cabinet.

7.2 *Containing Different Chemicals in a Cabinet*

7.2.1 Except as described below, chemicals should be contained in different gas cabinets if they do not possess exactly the same classification symbols.

7.2.2 An inert (I) gas does not have to be separated from any other chemical.

7.2.3 An irritant (IRR) chemical may be contained in a gas cabinet with a chemical that is not an irritant, if the remaining classification symbols are exactly the same.

7.2.4 A toxic (T) chemical may be contained in a gas cabinet with a highly toxic (HT) chemical, if the remaining classification symbols are exactly the same.

NOTE 5: Related Information 2 contains additional information and references on the separation of chemicals, as practiced or regulated in specific geographical regions.

8 Related Documents

8.1 *SEMI Standards*

F13 — Guide for Gas Source Control Equipment

F14 — Guide for the Design of Gas Source Equipment Enclosures

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

S18 — Environmental, Health, and Safety Guideline for Silane Family Gases Handling

8.2 *Building Officials and Code Administrators* [7]

BOCA National Fire Prevention Code

8.3 *Compressed Gas Association* [8]

P-1 — Safe Handling of Compressed Gas in Containers

8.4 *International Conference of Building Officials and Western Fire Chiefs Association* [9]

Uniform Fire Code

8.5 *Southern Building Code Conference International, Inc* [10]

SBCCI Standard Fire Prevention Code

8.6 *United States Code of Federal Regulations*[11]

29 CFR 1910.1200 — Hazard Communication

49 CFR 172.101 — Hazardous Materials Regulations and Procedures

8.7 *Dangerous Properties of Industrial Materials* — N. Irving Sax, Seventh Edition, 1988.

8.8 *Matheson Gas Data Book* — 7th Edition[12]

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

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7 Building Officials & Code Administrators International, Inc. , 4051 West Flossmor Road, Country Club Hills, IL 60477

8 Compressed Gas Association, 4221 Walney Road, 5th Floor, Chantilly VA 20151-2923., Phone: 703-788-2700, Fax: 703-961-1831, Email: cga@cganet.com, www.cganet.com

9 International Fire Code Institute, 5360 Workman Mill Road, Whittier, California 90601-2298, USA, www.ifci.org

10 Southern Building Code Congress International (SBCCI), 900 Montclair Road, Birmingham, AL 35213

11 The Office of the Federal Register, Washington, D.C. 20037

12 Available from www.mathesontrigas.com

RELATED INFORMATION 1
CLASSIFICATIONS OF CHEMICALS

NOTICE: This related information is not an official part of SEMI S4 and was derived from task force members' knowledge, S4-92, and various references. This related information was approved for publication by letter ballot on December 4, 2003.

R1-1 Classifications of chemicals

R1-1.1 Table R1-1 provides the classifications of some chemicals in common use in the semiconductor and flat panel industries. This table is sorted alphabetically by name of the chemical. (See Table 1 for the definitions of the symbols.)

NOTE 1: The classifications are presented in alphabetical order for each chemical so that classifications can be compared, and the second table could be created, more easily. There is no technical significance to the order in which the classifications are listed.

R1-1.2 Table R1-2 contains the same information as Table R1-1, but it is sorted by classification to be a more convenient way to identify chemicals that may be contained in the same gas cabinet.

Table R1-1 Classifications, sorted by chemical name

Chemicals	*Classifications*
Ammonia (NH_3)	CB-F
Argon (Ar)	I
Arsenic Pentafluoride (AsF_5)	CA-HT-OHH-WR
Arsine (AsH_3)	F-HT-OHH
Boron Trichloride (BCl_3)	CA-WR
Boron Trifluoride (BF_3)	CA-T-WR
Carbon Dioxide (CO_2)	I
Carbon Tetrachloride (CCl_4)	OHH
Chlorine (Cl_2)	CA-O-T
Diborane (B_2H_6)	HT-IRR-P-WR
Dichlorosilane ($SiCl_2H_2$)	CA-P-T-WR
Diethyl Telluride ($(C_2H_5)_2Te$)	P-IRR
Diethyl Zinc ($(C_2H_5)_2Zn$)	CA-P-UR-WR
Dimethyl Zinc ($(CH_3)_2Zn$)	CA-P-UR-WR
Germane (GeH_4)	F-IRR-T-UR
Halocarbon 11 (trichlorofluoromethane, CCl_3F)	I
Halocarbon 115 (chloropentafluoroethane, C_2ClF_5)	I
Halocarbon 116 (hexafluoroethane, C_2F_6)	I
Halocarbon 12 (dichlorodifluoromethane, CCl_2F_2)	I
Halocarbon 13 (chlorotrifluoromethane, $CClF_3$)	I
Halocarbon 13B1 (bromotrifluoromethane, $CBrF_3$)	I
Halocarbon 14 (tetrafluoromethane, CF_4)	I
Halocarbon 23 (fluoroform, CHF_3)	I
Helium (He)	I
Hydrogen (H_2)	F
Hydrogen Chloride (HCl)	CA
Hydrogen Fluoride (HF)	CA-T
Hydrogen Sulfide (H_2S)	T-F-IRR
Methyl Chloride (CH_3Cl)	F-IRR
Methyl Fluoride (CH_3F)	F-IRR
Nitric Oxide (NO)	IRR-O-T
Nitrogen (N_2)	I
Nitrogen Trifluoride (NF_3)	IRR-O
Nitrous Oxide (N_2O)	O
Oxygen (O_2)	O
Perfluoropropane (C_3F_8)	I
Phosphine (PH_3)	HT-P
Phosphorous Pentafluoride (PF_5)	CA-T-WR
Silane (SiH_4)	P
Silicon Tetrachloride ($SiCl_4$)	CA-WR
Silicon Tetrafluoride (SiF_4)	CA-T-WR
Sulfur Hexafluoride (SF_6)	I
Trichlorosilane ($SiCl_3H$)	CA-F-UR
Triethyl Aluminum ($(C_2H_5)_3Al$)	P
Trimethyl Aluminum ($(CH_3)_3Al$)	P
Trimethyl Antimony ($(CH_3)_3Sb$)	F-T
Trimethyl Arsine ($(CH_3)_3As$)	F-T
Trimethyl Gallium ($(CH_3)_3Ga$)	P
Trimethyl Indium ($(CH_3)_3In$)	P
Trimethyl Phosphine ($(CH_3)_3P$)	F-T
Tungsten Hexafluoride (WF_6)	CA-T-WR

Note 1: Additional chemicals may be used at the present time or may be suggested in the future. Any new chemical should be categorized in a way that chemicals of similar chemical characteristics are treated. If detailed chemical data are not available, the chemical should be considered to present unkown hazards and should be stored with only inert chemicals.

Table R1-2 Classifications, sorted by Classifications

Classifications	*Chemicals*
CA	Hydrogen Chloride
CA-F-UR	Trichlorosilane
CA-HT-OHH-WR	Arsenic Pentafluoride
CA-O-T	Chlorine
CA-P-T-WR	Dichlorosilane
CA-P-UR-WR	Diethyl Zinc
CA-P-UR-WR	Dimethyl Zinc
CA-T	Hydrogen Fluoride
CA-T-WR	Boron Trifluoride
CA-T-WR	Phosphorous Pentafluoride
CA-T-WR	Silicon Tetrafluoride
CA-T-WR	Tungsten Hexafluoride
CA-WR	Boron Trichloride
CA-WR	Silicon Tetrachloride
CB-F	Ammonia
F	Hydrogen
F-HT-OHH	Arsine
F-IRR	Methyl Chloride
F-IRR	Methyl Fluoride
F-IRR-T-UR	Germane
F-T	Trimethyl Antimony
F-T	Trimethyl Arsine
F-T	Trimethyl Phosphine
HT-IRR-P-WR	Diborane
HT-P	Phosphine
I	Argon
I	Carbon Dioxide
I	Halocarbon 14 (tetrafluoromethane)
I	Halocarbon 116 (hexafluoroethane)
I	Helium
I	Nitrogen
I	Perfluoropropane
I	Sulfur Hexafluoride
I	Halocarbon 11 (trichlorofluoromethane)
I	Halocarbon 12 (dichlorodifluoromethane)
I	Halocarbon 13 (chlorotrifluoromethane)
I	Halocarbon 13B1 (bromotrifluoromethane)
I	Halocarbon 23 (fluoroform)
I	Halocarbon 115 (chloropentafluoroethane)
IRR-O	Nitrogen Trifluoride
IRR-O-T	Nitric Oxide
O	Nitrous Oxide
O	Oxygen
OHH	Carbon Tetrachloride
P	Silane
P	Triethyl Aluminum
P	Trimethyl Aluminum
P	Trimethyl Gallium
P	Trimethyl Indium
P-IRR	Diethyl Telluride
T-F-IRR	Hydrogen Sulfide

RELATED INFORMATION 2
REGIONAL INFORMATION

NOTICE: This related information is not an official part of SEMI S4 and was derived from task force members' knowledge and various references. This related information was approved for publication by letter ballot on December 4, 2003.

R2-1 Purpose of this Related Information

R2-1.1 This Related Information was intended, at the time of original publication, by the EHS Committee to provide additional information and references on the separation of chemicals, as practiced or regulated in specific geographical regions.

R2-1.2 It is envisioned that the EHS Committee in each Region of the SEMI Standards Program will provide the appropriate text for its geographical region.

R2-2 North America

R2-2.1 Requirements for the separation of chemicals can be found, for example, in both the International Building Code (IBC) and the International Fire Code (IFC). These requirements deal with the segregation of incompatible chemicals in separate cabinets and separation by barriers/distance in storage rooms. These requirements can be found in the 2000 IBC section 415.9.5.9 and Table 415.9.5.9 and in the 2000 IFC sections 2703.8.5 and 2703.9.8.

R2-3 Japan

R2-3.1 In Japan, requirements for the separation of incompatible gases can be found in the High Pressure Gas Safety law and related notifications from Ministry of Economy and Industry, such as in section 11 of “Notification regarding technical standards for Location, Construction, and Facility of Manufacturing Plant”.

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

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SEMI S5-0703
SAFETY GUIDELINE FOR SIZING AND IDENTIFYING FLOW LIMITING DEVICES FOR GAS CYLINDER VALVES

This safety guideline was technically approved by the Global Gases Committee and is the direct responsibility of the North American Gases Committee. Current edition approved by the North American Regional Standards Committee on April 11, 2003. Initially available at www.semi.org June 2003; to be published July 2003. Originally published in 1993.

NOTICE: This document was completely rewritten in 2003.

1 Purpose

1.1 The purpose of this safety guideline is to provide a method to size and identify flow limiting devices that limit the rate of release of hazardous gases from the gas cylinder valve during transportation, storage, and use.

2 Scope

2.1 This safety guideline provides a method to identify flow limiting devices by size, and to calculate maximum and minimum flow rates so that the size required can be determined. Specific SAFETY WARNINGS are contained in Section 3.

2.2 This safety guideline pertains to flow limiting devices for valves on cylinders containing hazardous gases. These devices are intended to limit the flow rate of uncontrolled releases of gases at or downstream of the valve outlet. This guideline does not pertain to gas releases caused by failure of the cylinder, the valve connection to the cylinder, actuation of the cylinder pressure relief device, or some failures of the valve.

2.3 This safety guideline pertains to flow limiting devices operating at critical flow rates that result from cylinder pressures greater than 103 kPa (15 psig). Generally, flow limiting devices are not used for cylinders pressurized less than 103 kPa (15psig) because the size required to provide adequate flow for the process is so large that flow reduction resulting from the flow limiting device would be minimal.

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

3 SAFETY WARNINGS

3.1 *Installation* — Only the gas supplier or cylinder owner should install, remove, or otherwise service the flow limiting device. Special equipment and procedures may be required to perform any installation or service operation safely. No other person should install, remove, replace, clean, adjust, or otherwise alter the flow limiting device unless authorized by the cylinder owner.

3.2 *Verification* — When a flow limiting device is required, the user should always verify that the size is identified by tag, label or marking on the cylinder or cylinder valve exterior, and that the device size indicated matches the requirement. If a required flow limiting device is missing, the cylinder should be rejected prior to use.

3.3 *Purging* — The addition of a flow limiting device in the cylinder valve may restrict gas flow during purging. The user should assure that adequate purging methods are used to prevent plugging the flow limiting device. As a minimum, the operator should purge the valve outlet after use with the same procedure used for purging the valve outlet just after installation of the cylinder. This is important to prevent contamination in the valve outlet and reduce the probability of creating a hazard at the cylinder supplier's plant.

3.4 *Blockage* — Under certain conditions, some hydrides such as diborane can polymerize and cause obstruction or total blockage of flow limiting devices. Care should be taken with cylinders that seem to be empty, but may contain product.

4 Referenced Standards

4.1 *SEMI Standard*

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

4.2 *NFPA Document*[1]

NFPA 704 — Standard System for the Identification of Fire Hazards of Materials

NOTICE: As listed or revised, all documents cited shall be the latest publications of adopted standards. Regional standards may be substituted provided they are equivalent. Equivalent international standards if adopted, will be referenced in the next revision of this guideline.

1 National Fire Protection Association, Batterymarch Park, Quincy, MA 02269 Website: www.nfpa.org

5 Terminology

5.1 *Definitions*

5.1.1 *equivalent orifice* — a passage that will allow fluid flow equivalent to a round hole at 80% efficiency. The efficiency, known as the orifice coefficient, will typically vary from 65% (.65) for a sharp entrance to 95% (.95) for a well-rounded entrance. A flow rate tolerance of ± 20% is used in Table 1 to allow for variations in the entrance geometry and passage size. Figure 1 illustrates the flow rate variation resulting from this tolerance for different equivalent orifice sizes.

5.1.2 *flow limiting device* — a device installed in a gas cylinder valve that will reduce maximum flow from the valve under full flow conditions.

5.1.3 *flow rate* — flow rates in this guideline are given in standard liters per minute (slm) at the standard conditions of 0°C (32°F) and 101 kPa absolute (14.7 psia). This corresponds to the standard conditions used for calibration of mass flow controllers used in semiconductor processing systems.

5.1.4 *hazardous gases* — gases that have a degree of hazard rating in health, flammability, or reactivity of class 3 or 4 in accordance with NFPA 704, or equivalent rating by a regional standard.

5.1.5 *mixing gas* — an inert gas used to dilute another gas.

6 Flow Limiting Device Criteria

6.1 *Where Used* — Flow limiting devices should be installed or incorporated into cylinder valves that are used for gas cylinders containing the hazardous gases listed in Table 2. Table 2 lists hazardous gases for which devices are known to be feasible by reason of testing and experience. SEMI encourages testing by its members of hazardous gases not listed in Table 2 so that new information can be added.

6.2 *Materials* — The flow limiting device should be made of materials that are compatible with the gas in the cylinder.

6.3 *Installation* — The flow limiting device should be installed by the gas supplier or cylinder owner. See Safety Warnings.

6.4 *Identification* — The preferred method of identifying flow limiting devices is by equivalent orifice size as shown in Table 1. Other means of identification, requiring identification by the supplier as to the device installed, may be used if unambiguous.

6.5 *Service Life* — Removable flow limiting devices may be reused, but should be tested by the gas supplier or cylinder owner before each use to assure that the flow rate is as listed in Table 1.

6.6 *Sizing* — A flow limiting device that will not allow nitrogen flows out of the valve outlet to exceed the flow rates listed for its equivalent orifice size in Table 1. The flow limiting device should be the smallest size that satisfies the process requirements. The user should make the choice of flow rate based on safety philosophy contained in SEMI S2.

NOTE 1: Flow rates determined by the calculations in this safety guideline are based on critical flow where the cylinder pressure is equal or greater than 2 atmospheres and pressure at the outlet of the flow limiting device is 1 atmosphere. Consult the flow limiting device supplier to determine the minimum size that will provide the required process flow rate when cylinder absolute pressure is less than 2 times outlet absolute pressure.

7 Flow Rate Calculations

7.1 The flow rates in Table 1 are specified for critical flow of nitrogen through the flow limiting device at several cylinder pressure levels. Densities are given in Table 2 for some hazardous gases. First determine the critical flow of nitrogen through the flow limiting device from Table 1, or calculate using the method specified in Section 7.2. Then, using the method specified in Section 7.3, calculate the gas and pressure-corrected flow rates to determine the proper flow limiting device size for the application. For gas mixtures, the density can be calculated using the method specified in Section 7.4.

7.2 *Nitrogen Flow Rate*— Nitrogen flow rate correction for cylinder pressures not listed in Table 1 follows:

NOTE 2: This equation is only valid for ideal gases, and critical flow that results for most gases when $P_{cyl}/P_{atm} \geq 2$. It is necessary to multiply the equation by a compressibility factor (Z) for better accuracy, however for nitrogen at temperatures between -54 to +60°C (-65 to +140°F) and at cylinder pressures less than 21,000 kPa gauge (3045 psig), the result will be accurate within a few percent.

$$\mathbf{Q_N = Q_{NT} \; x} \; \frac{P_{cyl} + P_{atm}}{P_{NT} + P_{atm}} \quad \textbf{Equation 1.}$$

$\mathbf{Q_N}$ is the critical flow rate in slm of nitrogen at pressures not listed in Table 1.

$\mathbf{Q_{NT}}$ is the critical flow rate in slm of nitrogen from Table 1 that corresponds to a given equivalent orifice size at pressure.

$\mathbf{P_{cyl}}$ is the gauge pressure kPa gauge (psig) in the gas cylinder for which the flow rate is being calculated.

$\mathbf{P_{atm}}$ is standard atmospheric pressure 101 kPa absolute (14.7 psia) at sea level.

$\mathbf{P_{NT}}$ is the pressure in kPa gauge (psig) from Table 1 that produces critical flow rate Q_{NT} for a given equivalent orifice size.

EXAMPLE 1: What is the minimum flow rate of nitrogen through a 0.25 mm (0.01 inch) equivalent orifice at 862 kPa gauge (125 psig)?

$Q_N = 2.90 \times \frac{862+101}{700+101} = 3.5$ slm nitrogen (Q_{NT}= 2.90 is the minimum flow rate at 700 kPa gauge, the minimum flow rate for a 0.25 mm orifice at any pressure listed in Table 1 will provide the same result.)

EXAMPLE 2: What is the maximum flow rate of nitrogen through a 0.25 mm (0.01 inch) equivalent orifice at 12,414 kPa gauge (1,800 psig)?

$Q_N = 4.35 \times \frac{12414+101}{700+101} = 68$ slm nitrogen (Q_{NT}= 4.35 is the maximum flow rate at 700 kPa gauge.)

7.3 *Hazardous Gas Flow Rate*— Flow rate correction for gases listed in Table 2 other than nitrogen follows:

NOTE 3: This formula is only valid for critical flow, typically where $P_{\mathbf{cyl}} / P_{\mathbf{atm}} > 2$

$\mathbf{Q_g = Q_N} \times \sqrt{\frac{1.25}{(Z)D_g}}$ **Equation 2.** (Use $\mathbf{Q_{NT}}$ in place of $\mathbf{Q_N}$ when the applicable cylinder pressure is listed in Table 2.)

$\mathbf{Q_g}$ is the critical flow rate in slm of the gas listed in Table 2.

$\mathbf{D_g}$ is the standard density of the gas in kg/m^3 at one atmosphere and 0°C (32°F) listed in Table 2.

Z is the compressibility factor at P_{cyl} for the gas listed in Table 2. For pressures not listed, interpolation of Z with Z assumed proportional to pressure and equal to 1.0 at zero pressure should provide adequate accuracy in the pressure and temperature ranges found in this document. For gas mixtures with the mixing gas 95% by volume or greater, use of Z for the mixing gas should provide adequate accuracy, for lower percentages consult the gas supplier.

NOTE 4: Density is the reciprocal of specific volume. Density or specific volume is frequently given at a temperature of 21.1°C (70°F). To convert 21.1°C (70°F) to 0°C (32°F) standard density, multiply by 1.077.

EXAMPLE 3: What is the minimum flow for Nitrogen Trifluoride through a 0.75 mm (0.03 inch) equivalent orifice at 700 kPa gauge?

$Q = 26.1 \times \sqrt{\frac{1.25}{(0.97)(3.20)}} = 16.6$ slm Nitrogen Trifluoride (Z is interpolated at 700 kPa)

7.4 *Density For Gas Mixtures* — Density correction for mixtures of gases listed in Table 2, or Table 2 and Table 3 follows:

$\mathbf{D_{mix} = \Sigma\ V_g \times D_g}$ **Equation 3.** (For gas mixtures, use D_{mix} in place of D_g in Equation 2.)

$\mathbf{V_g}$ is the volume fraction of each gas in the mixture.

EXAMPLE 4: What is the density for a mixture of 5% arsine and 95% nitrogen?

$D_{mix} = (.05 \times 3.45) + (.95 \times 1.25) = 1.36$ kg/m^3

8 Related Documents

8.1 *CGA Standard*[2]

CGA V-9 — Compressed Gas Association Standard for Compressed Gas Cylinder Valves

2 Compressed Gas Association, Inc., 1725 Jefferson Davis Highway, Suite 1004, Arlington, VA 22202

Table 1 Critical Nitrogen Flow Rates (Q_{NT}) For Flow Limiting Devices

Equivalent Orifice Size		*Critical Flow Rate (slm) of nitrogen at the following cylinder pressures:*											
		700 kPa gauge (102 psig)			*2100 kPa gauge (305 psig)*			*7000 kPa gauge (1015 psig)*			*21000 kPa gauge (3045 psig)*		
mm	inch	min. −20%	nom.	max. +20%	min. −20%	nom.	max. +20%	min. −20%	nom.	max. +20%	min. −20%	nom.	max. +20%
0.15	**0.006**	1.04	**1.31**	1.57	2.86	**3.57**	4.29	9.21	**11.5**	13.8	27.4	**34.2**	41.0
0.25	**0.01**	2.90	**3.62**	4.35	7.94	**9.93**	11.9	25.6	**31.0**	38.4	76.0	**95.0**	114
0.50	**0.02**	11.6	**14.5**	17.4	31.8	**39.7**	47.7	102	**128**	153	304	**380**	456
0.75	**0.03**	26.1	**32.6**	39.1	71.5	**89.4**	107	230	**288**	345	684	**855**	1026
1.00	**0.04**	46.4	**58.0**	69.6	127	**159**	191	409	**512**	614	1216	**1520**	1824
1.25	**0.05**	72.5	**90.6**	108	199	**248**	298	640	**799**	959	1900	**2375**	2850
1.50	**0.06**	104	**130**	157	286	**357**	429	921	**1151**	1381	2736	**3421**	4105

Table 2 Hazardous Gases for Which Flow Limiting Devices May be Used

Hazardous Gas Type	*Standard Density (D), 1 atm., 0°C [kg/m^3 (lbs/ft^3)]*	*Cylinder Pressure (P_{cyl}) Typical Max. @ Room Temp. [kPa_gauge (psig)] (See Note 1.)*	*Compressibility Factor (Z) @ Typ. Max.Cylinder Pressure (See Note 2.)*	*Compressibility Factor (z) @ 10% Typ. Max.Cylinder Pressure (See Note 2.)*	*Max. Flow Rate (q) 0.25 mm (0.01 in.) Equiv.Orifice (slm)*
Arsine, AsH3	3.45 (0.216)	1,410 (205)	0.81	0.98	5.5
Carbon Monoxide, CO	1.250 (0.078)	11,385 (1,650)	0.97	1.0	63
Diborane, B2H6	1.250 (0.078)	1% in N2 12,410 (1,800)	0.29 @ 7,000 (1,015)	0.93 @ 700 (103)	1% in N2 68
Germane, GeH4	3.415 (0.213)	607 (88)	0.94	0.99	2.4
Hydrogen, H2	.090 (0.0056)	15,180 (2,200)	1.03	1.0	303
Nitrogen Trifluoride, NF3	3.200 (0.199)	10,000 (1,450)	0.64	0.96	43
Phosphine, PH3	1.519 (0.095)	4,095 (594)	0.52	0.95	29
Silane, SiH4	1.433 (0.090)	8,280 (1,200)	0.36	0.94	70
Stibine, SbH3	1.444 (0.090)	---	---	---	---

NOTE 1: Cylinder pressures will vary, consult gas supplier to verify the actual cylinder pressure.

NOTE 2: Compressibility factors are interpolated from available data, consult gas supplier for alternate pressures.

Table 3 Mixing Gases

Mixing Gas Type	*Standard Density (D), 1 atm., 0°C [kg/m^3 (lbs/ft^3)]*	*Cylinder Pressure* (P_{cyl}) Typical Max. @ Room Temp [kPa_gauge (psig)]*	*Compressibility Factor (Z) @ Typ. Max. Cylinder Pressure*	*Compressibility Factor (Z) @ 10% Typ. Max.Cylinder Pressure*	*Max. Flow Rate (Q) thru 0.25 mm (0.01 in.) Equivalent Orifice (slm)*
Argon, Ar	1.788 (0.111)	17,180 (2,490)	0.93	0.99	81
Helium, He	0.179 (0.011)	17,180 (2,490)	1.1	1.0	235
Nitrogen, N_2	1.250 (0.078)	17,180 (2,490)	1.0	1.0	93

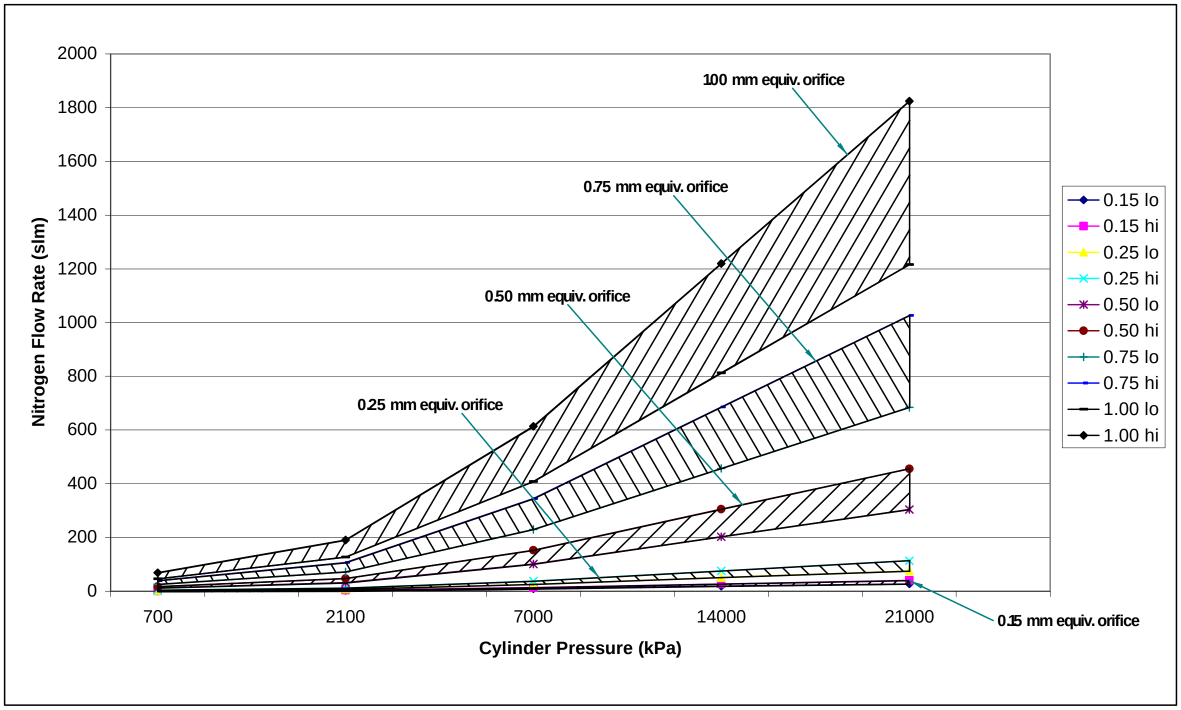

Figure 1
Nitrogen Flow Rate

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

The user's attention is called to the possibility that compliance with this standard may require use of copyrighted material or of an invention covered by patent rights. By publication of this standard, SEMI takes no position respecting the validity of any patent rights or copyrights asserted in connection with any item mentioned in this standard. Users of this standard are expressly advised that determination of any such patent rights or copyrights, and the risk of infringement of such rights, is entirely their own responsibility.

SEMI S6-93
SAFETY GUIDELINE FOR VENTILATION

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

NOTE: As listed or revised, all documents cited shall be the latest publications of adopted standards.

1 Introduction

The equipment supplier should design an internal equipment exhaust system that is efficient when connected to potential users' exhaust systems. Seldom, if ever, are users' systems designed for a specific piece of process equipment or set of process equipment. Most users' exhaust systems are designed and installed to industry-accepted exhaust principles.

2 Purpose

This document is intended to help the semiconductor equipment supplier design equipment exhaust systems to a common set of performance criteria as well as to provide assistance to both users and suppliers in the understanding of exhaust requirements for equipment systems. It is not intended to establish design specifications. The supplier will still own, and be responsible for, the information it specifies. This guideline has six concurrent performance-related objectives.

2.1 Ensure hazardous gases, fumes, and vapors are controlled (during normal operations of equipment and facilities services) such that concentrations present in the work room air should be less than 1.0% of the Threshold Limit Value (TLV), as established by the American Conference of Governmental Industrial Hygienists (ACGIH) or Permissible Exposure Limit (PEL) as published by the appropriate regulatory agency, whichever is lower.

2.2 Ensure exhaust is provided within specifications to support the proper operation of equipment.

2.3 Optimize the user's exhaust system(s).

2.4 Use the most cost effective methods to interface with user's exhaust systems.

2.5 Provide a platform for communicating "special case" exhaust requirements.

2.6 Establish guidelines for measurement and communication of equipment exhaust requirements.

3 Scope

This guideline applies to all semiconductor equipment that incorporates exhausted enclosures that are intended to be connected to user facilities' exhaust system(s). This document is written with the assumption that the users' exhaust distribution systems will be designed with central fans, ducting, and, where applicable, abatement equipment. Where users use other types of exhaust systems, equipment suppliers should acquire exhaust specifications from the users. Whether equipment is connected to a central exhaust system or to one which serves only that piece of equipment, this guideline should be applied.

4 Referenced Documents (see Appendix 2)

5 Terminology

5.1 *balancing* — Adjustments made after the ventilated equipment and the ventilation system are installed to assure that airflow to each piece of ventilated equipment is within design specifications.

5.2 *capture* — To entrain undesirable elements (gases, fumes, vapor, and particles) in the exhaust stream for removal.

5.3 *dilute* — To reduce the concentration of undesirable elements to acceptable levels. Dilution is a function of flow volume.

5.4 *flow velocity (V)* — The average speed at which the effluent stream travels through the exhaust duct. It is measured in meters per second (m/s) or feet per minute (fpm).

5.5 *flow volume (Q)* — The volumetric flow rate of the effluent stream passing a given location in the exhaust system per unit of time. It is measured in cubic meters per second (m^3/s) or cubic feet per minute (cfm).

5.6 *initiate motion* — To use an exhaust stream to start contaminants (or machine parts) moving from a rest position.

5.7 *long radius elbow* — An exhaust duct elbow that has a center line radius 1.5 or more times the duct diameter.

5.8 *set point tolerance* — The range (+/-) of static pressure within which an exhaust enclosure will perform efficiently and effectively.

5.9 *static pressure (SP)* — The measure of differential pressure across the duct wall to the ambient pressure (inside the duct). The unit of measure is pascals (Pa, Newtons per square meter (N/m^2)) or inches of water.

5.10 *traverse measurements* — Multiple air flow measurements taken at points of equal separation, in a matrix pattern, along the face plane of an exhaust duct or opening in an exhaust enclosure.

5.11 *vena contracta* — A point in a duct where the diameter of the air stream is smaller than the diameter of the duct.

6 Attributes of Typical Semiconductor Facilities' Exhaust Systems

6.1 A typical semiconductor facility's exhaust system has three measurable working elements: (1) flow velocity, (2) flow volume, and (3) pressure.

6.1.1 Flow Volume is related to the Flow Velocity by the equation Q = VA. In this equation, Q = volumetric flow rate, V = average velocity, and A = duct cross sectional area (m^2 or ft^2).

6.2 There are three duct pressure measurements possible: (1) static pressure, (2) velocity pressure, and (3) total pressure.

6.2.1 In exhaust distribution systems with central fans and abatement equipment (typical of semiconductor facilities), exhaust duct pressure (static) upstream of the fan is less than the ambient pressure outside of the duct.

6.2.2 While Velocity Pressure (VP) and Total Pressure (TP) provide a more reliable measure of Flow than Static Pressure, VP and TP are normally not specified for semiconductor facilities' exhaust systems; therefore, they will not be discussed in these guidelines. If more information is desired on VP or TP, it can be found in "Industrial Ventilation" (Appendix 2, Reference 1).

7 Exhaust Usage Typical of Semiconductor Operations

Semiconductor equipment typically uses exhaust to perform one or more of the following tasks:

7.1 *Capture* — Capture should occur as close to the source as practical to prevent exposure of personnel or products to the undesirable elements.

7.1.1 Capture is a function of Flow Velocity. Chapter 3 of "Industrial Ventilation," A Manual of Recommended Practice, 20th Edition, (Appendix 2, Reference 1) outlines the design principles and required velocity calculations for proper capture of process emissions.

7.2 *Moving* is also a function of Flow Velocity. The exhaust requirements specified by the equipment supplier should be adequate to maintain motion of undesirable elements once they are captured in the exhaust stream.

7.3 *Dilution* is a function of Flow Volume. Dilution may also provide reactive elements to undesirable elements entrained in the exhaust stream (for example, air and silane).

7.4 *Holding* — The movement of the exhaust stream is often used to activate and hold safety control devices, such as vane switches or differential pressure gauges in the active state. Such safety control devices should be used to sense adequate exhaust pressure or flow to ensure safe operation of the process equipment.

7.5 *Initiation of Motion* — The use of exhaust to intiate motion in the semiconductor industry is a special case application and should be resolved at the time of purchase. Most semiconductor-related gases, vapors, fumes, and fine particles (less than 20 microns in diameter) move with the air in which they are mixed.

8 Key Elements of Exhaust Specifications

8.1 SEMI S2 establishes specific requirements for exhaust enclosures of equipment that use hazardous materials. Access to enclosures serving hazardous materials requires special design. If there is a potential for exposure of personnel to hazardous materials when the access hatch is open, an average face velocity (measured at the hatch opening) sufficient to capture the hazardous materials should be maintained in the hatch opening. (SEMI S2 also has recommendations for exhaust monitoring and alarms. S2 should be fully understood before designing exhaust systems for hazardous materials.)

8.2 Properties of chemicals (density, vapor pressure, boiling point, flammability, etc.), the state of the materials within the exhausted enclosure (solid, liquid, or gas), and conditions such as temperature and concentration will determine the final design and exhaust specifications of the equipment enclosure. Equipment suppliers should use available reference books and Material Safety Data Sheets (MSDS) to obtain information on chemical properties. The equipment's process requirements will dictate the state and condition of the material.

8.3 When developing specifications for equipment exhaust systems to be given to the equipment user, equipment suppliers should incorporate all of the key elements that will provide clear and accurate information. These key elements are:

1. Point of measurement.

2. Duct size at the point of measurement.

3. Flow through the duct.

4. Air density.
5. Temperature of the exhaust stream when it enters the exhaust system.
6. Static pressure at the point of measurement.
7. Physical condition of the process equipment at the time of measurement.
8. Peak, normal, and special exhaust requirements.
9. Equipment environmental conditions anticipated (installed).
10. Stability and tolerance requirements of the specifications.
11. Priority of exhaust attributes when the system is balanced. (What is the primary intent of the exhaust, secondary, etc.?)
12. Instruments and practices used (and recommended) for taking measurements.
13. Design information on the complete equipment exhaust system (including materials of construction).
14. Constituents of the exhaust stream.

Each of these key elements is discussed in detail in Sections 8.3.1 through 8.3.14.

8.3.1 The point of measurement for the equipment exhaust duct should be clearly defined. Information given to locate the point of measurement should include a diagram of the exhaust connection with locations of the traverse points used.

8.3.1.1 Turbulence in the duct at the point of measurement should be minimized. The measurement point should be in a straight section of duct. It should be downstream in the connecting duct past the vena contracta from the last transition made in the equipment. It should be far enough from fittings, dampers, or sprinkler heads to minimize their interference with the measurements. Normal recommended practice is 7.5 duct diameters from any point of connection or fitting. See “HVAC Systems Testing, Adjusting, and Balancing,” (Appendix 2, Reference 3).

8.3.1.2 Equipment users typically use a throttling damper for exhaust balancing where the equipment drop connects to the rest of the exhaust system. Balancing measurements should be taken on the equipment side of these balancing dampers. The supplier may elect to provide a damper, at or near the equipment connection point, to be used only as a trimming device over a narrow performance band around the equipment flow and pressure specifications. Features of this damper should be designed to prevent complete blockage of exhaust flow.

8.3.2 Duct size is the inside diameter of the exhaust connection from the equipment. The supplier should provide any other dimensions needed to design the connection of the exhaust system to the equipment.

8.3.2.1 The duct size of the equipment connection should fall in the low flow velocity range of the duct friction table. See “HVAC Systems Duct Design” (Appendix 2, Reference 2). Low flow velocity ducts will promote flexibility and ease of interface to exhaust systems serving multiple equipment. When particles are to be captured and removed, design the system for the minimum flow velocity that will ensure capture.

NOTE: Exhaust system designers should always keep in mind the difficulty that can be experienced in flow velocity measurements in unduly large ducts. Tool connections should be sized for accurate flow measurements.

8.3.2.2 The design of the equipment exhaust connection should allow for long radius connecting elbows at the point of connection. This will reduce friction losses. Additionally, the equipment supplier should avoid configurations that would require an angle of entrance into the user’s branch ducts of greater than 30 degrees.

8.3.2.3 Duct connection configuration should be such that liquid spills or releases within the equipment enclosures will not enter the facility’s exhaust system.

8.3.3 Flow through the equipment enclosure, and the duct at the point of connection, can be specified in velocity or volume. Normally, the balancing engineer will measure Flow Velocity and convert velocity to Flow Volume using the equation $Q = VA$. (See Section 6.1.1.)

8.3.3.1 Section 8.3.6 of this document shows the pressure guidelines for semiconductor exhaust systems. The equipment supplier should establish, through testing, the Flow Velocity and Volume required for efficient operation of its equipment’s exhaust system. The user and the supplier should agree, before the purchase of the equipment, on the safety control devices to be used. Any safety control device requiring flows or pressures outside these ranges is a special case and should be resolved at the time of purchase.

8.3.4 Exhaust specifications should be stated in Standard Air Density (kg/m^3 or lb/ft^3), as defined in “Industrial Ventilation,” (Appendix 2, Reference 1). If the measurements are of non-standard air, state the correction factor for density. Users should correct field balancing measurements taken above 600 meters (2000 feet) elevation before comparing them to suppliers' specified data. Additionally, the supplier-specified data must be corrected to sea level if it was measured above 600 meters elevation.

8.3.4.1 Flow measurements taken at other than standard air temperatures (21.1°C (70°F)) should be corrected to standard conditions.

8.3.4.2 Corrections for altitude and temperature should use the following relationship:

$M^3/s = (m^3/s)(294.3/T_K)(D)$

$CFM = (cfm)(530/T_R)(D)$

M^3/s = Standard cubic meters per second

m^3/s = Measured cubic meters per second

CFM = Standard cubic feet per minute

cfm = Measured cubic feet per minute

T_K = Measured temperature in degrees K ($T_K = T_C + 273.2$)

T_C = Measured temperature in degrees C

T_R = Measured temperature in degrees R ($T_R = T_F + 459.7$)

T_F = Measured temperature in degrees F

D = Altitude density correction factor

Altitude	*Density Correction Factor*
sea level	1.00
300 m (1000 ft)	0.96
600 m (2000 ft)	0.93
900 m (3000 ft)	0.89
1200 m (4000 ft)	0.86
1500 m (5000 ft)	0.83

8.3.5 The expected temperature of the exhaust stream (from the supplier's equipment) at the connection to the user's exhaust system should be included in the specifications. The connecting duct material should be compatible with this temperature. The normal operating and maximum high and minimum low temperatures should be specified.

8.3.6 Static pressure is measured at the same traverse point as discussed in Section 8.3.1. The equipment specifications should define the minimum Static Pressure, at the point of connection, required for proper equipment operation.

8.3.6.1 The target Static Pressure range at the point of connection to equipment is -125 to -250 Pa (-0.5 inches to -1.0 inches of water). This permits flexibility of equipment placement with minimal need for pressure boosting devices, such as booster fans.

8.3.6.2 For exhaust Static Pressure requirements lower than -1.0 inches of water, the equipment supplier must establish, with the user's concurrence, the specifications for a safe booster add-on device. A larger negative number is a lower exhaust pressure. Normally, users will install boosters only when their exhaust distribution system cannot reach the specified static pressure. As each user's facility is unique, booster add-on devices should be separate from the equipment's functional design and used only as a last resort.

8.3.7 The physical settings and configuration of the process equipment when specified flow and pressure measurements are made is critical to the repeatability of the measurements.

8.3.7.1 Exhaust enclosures, capture zones, and entry points in the equipment should isolate the area to be exhausted from adjacent areas. Internal ducts, partitions, and guide plates in the equipment should be leak tight to prevent the release of contamination from the exhaust stream.

8.3.7.2 To capture, move, or dilute contaminants effectively within the equipment's exhaust enclosure, there must be a continuous supply of make-up air. The enclosure should be designed such that the make-up air is drawn from a selected area through designed openings in the enclosure walls. Care should be taken to ensure the make-up air does not contain, or potentially contain, vapors or fumes that could be incompatible with the exhaust enclosures material of construction, components, or target materials being exhausted.

8.3.7.3 Minimize the volume of the enclosures where possible to reduce the load on the exhaust system and on its companion make-up air system.

8.3.7.4 Enclosures supplied with, or as part of, equipment should be designed so that exhaust properly sweeps all potential emission release points.

8.3.7.5 Aerodynamic "dead spots" inside the enclosure should be minimized.

8.3.7.6 Components that have no potential for release should be located outside the enclosure, when possible. Additionally, the handles for any valves located inside the exhausted enclosure should be positioned outside of the enclosure to reduce the need to open the enclosure.

8.3.7.7 Verification that the exhaust enclosure provides the desired capture of contaminants can be accomplished by using Sulfur Hexafluoride as a tracer gas (see SEMI F15). Verification that aerodynamic "dead spots" have been eliminated can be accomplished by use of “clean smoke” generated from a deionized water vapor generating system.

8.3.7.8 Once capture has been verified, measurements should be taken at specific openings (make-up air slots, access ports, or windows, etc.) to establish the minimum flow velocity necessary at these specific openings to achieve capture.

8.3.7.9 Record the position of covers, doors, dampers, valved openings, etc., and flow restrictions (such as fluid levels in vessels which exhaust air serves or flows through) at the time of the ventilation tests so that the test can be duplicated.

8.3.7.10 The supplier should specify how to duplicate these conditions at the time of field adjustment and balance. If the original conditions are not duplicated, the exhaust losses through the equipment may vary. The major risk is that the equipment exhaust level will be set as close to the suppliers’ specifications as possible and may not provide the safety level intended during actual equipment operation.

8.3.8 The equipment may require different exhaust flow or pressure during the process cycle than in standby or maintenance modes. The supplier should provide specifications for normal operating mode demands, peak demand, and any other demand level required for employee safety. The normal, peak, and other critical safety condition demands should be compensated for in both the system design and the field balance.

8.3.9 Equipment data used to establish exhaust specifications should reflect the equipment’s environmental conditions anticipated when installed (e.g., bulkhead mounted equipment is supplied with data for a bulkhead installation).

8.3.9.1 Typical user clean rooms are designed using the “bay” and “chase” concept. The bay is served with 100% ceiling-supplied, HEPA-filtered air. Vertical air flow below the ceiling is typically 0.5 m/s (100 FPM) across the entire bay. The chase section is the return air plenum for the bay air supply system. The typical pressure differential across the bay wall is 2.5 to 7.5 Pa (0.01 to 0.03 inches of water), with the lower pressure on the chase side.

8.3.9.2 Bulkhead or through-the-wall mounted equipment should tolerate this pressure differential.

8.3.9.3 Cabinet or enclosure exhaust applications should be designed so that back streaming into the clean bay or chase is prevented.

8.3.10 The set point tolerance at time of initial installation should be included in the specification. Performance stability over time for the exhaust flow and pressure requirements, needed to support equipment operations and safe working conditions, should also be specified.

8.3.10.1 The users’ exhaust distribution systems typically hold a balance setting ±10% of the set point(s) over time. Equipment which integrates high or low exhaust level alarms, requiring tighter stability control, are special cases and should be identified at the time of purchase.

8.3.10.2 The supplier-specified set points for Exhaust Flow, Volume, and Pressure should include a tolerance of -0% +10%. (This is the common acceptance range established for exhaust distribution system balance.)

8.3.11 The five methods of exhaust use discussed in Section 7 drive different priorities when establishing exhaust specifications.

8.3.11.1 The “initiate motion” and “hold” functions are either pressure or velocity driven, depending on the safety equipment selected by the supplier.

8.3.11.2 “Capturing” and “moving” are typically velocity-dependent.

8.3.11.3 “Dilution” is flow volume dependent.

8.3.11.4 The equipment exhaust specification should focus on the exhaust attribute (see Section 6) associated with the exhaust use (see Section 7). If multiple uses are being met, the supplier should prioritize Pressure, Flow, and Flow Volume for balancing.

8.3.12 The instruments and practices used for taking measurements to establish equipment specifications should be recommended in the specifications and used in field balance operations.

8.3.12.1 A hot wire anemometer is acceptable for velocities less than 150 m/s (500 FPM). A low range differential pressure gauge (0 to 60 Pa or 0.0 to 0.25 inches of water) is acceptable for velocities over 150 m/s (500 FPM).

8.3.12.2 An inclined/vertical manometer or high range differential pressure gauge is acceptable for measuring static pressure.

8.3.12.3 Conversion charts should be developed to indicate what flow volume is present at various points on the inclined/vertical manometer or differential pressure gauge.

8.3.12.4 Equipment suppliers should include recommendations in the equipment specifications for the proper selection of the pitot tube, static tip, etc., to use when measuring exhaust flow and pressure.

8.3.12.5 The description, operation, maintenance, and limitations of these and alternate instruments is covered

8.3.12.6 in Chapter 9 of "Industrial Ventilation," A Manual of Recommended Practice, 20th Edition, (Appendix 2, Reference 1). A companion reference is Chapter 5 of HVAC Systems Testing, Adjusting, and Balancing, (Appendix 2, Reference 3).

8.3.12.7 As with any test performed to establish or verify specifications, the measuring instruments used should be in good working condition and current calibration.

8.3.12.8 If an air balancing contractor is used, it should be certified by the Associated Air Balance Council (AABC) or the National Environmental Balancing Bureau (NEBB) as meeting their technical standards for membership.

8.3.12.9 For additional information, see National Standards for Field Measurement and Instrumentation - Total System Balance, Volume Two, No. 12173, (Appendix 2, Reference 6). Also see Procedural Standards for Testing of Cleanrooms, (Appendix 2, Reference 4).

8.3.13 The exhaust specification provided to the user by the supplier should include design information on the complete equipment exhaust system. A prototype exhaust data worksheet is shown in Appendix 1. The supplier should also provide:

8.3.13.1 A scaled drawing of the equipment exhaust system showing all connections, dampers, monitoring devices, etc.

8.3.13.2 A diagram of the exhaust connection with critical dimensions, established set point, and the location of the traverse point used to develop the specifications.

8.3.13.3 Any special case exceptions.

8.3.13.4 A list of materials used in the construction of the exhaust enclosure and materials for components of the exhaust system.

8.3.14 The supplier should provide the user with a list of constituents that could be expected in the exhaust stream when the equipment and the users' exhaust system are operating within design specifications. Information typically required is:

8.3.14.1 Percent by volume.

8.3.14.2 Percent by weight.

8.3.14.3 State of constituent (liquid, gas, or solid).

8.3.14.4 Temperature of the composite exhaust stream under normal operations.

8.3.14.5 Information should be based on a continuous twenty-four hour operation of the equipment. (Extrapolation is generally acceptable if the method used is well-documented and can be duplicated.)

APPENDIX 1
PROCESS EQUIPMENT EXHAUST REQUIREMENT SUMMARY

Page 1 of 2

Manufacturer____

Equipment Name_______________________________________ Model_________________

Supplier Representative________________________________ Date___________________

Demand Status ____________Normal ___________Peak ____________Other (Explain)____________

Doors, Hatches & Covers ____________Closed ___________% Open _________Removed

Chemical Location	Chemical Contents	Condition
1. ____________________	_____________________	______Empty ______Full
2. ____________________	_____________________	______Empty ______Full
3. ____________________	_____________________	______Empty ______Full
4. ____________________	_____________________	______Empty ______Full
5. ____________________	_____________________	______Empty ______Full
6. ____________________	_____________________	______Empty ______Full

Electrical Power	______On ______Off _______Disconnected
Equipment at Operating Temperature	______Yes ______No
Other Utilities	______On ______Off _______Disconnected
Process Material Positions	______Occupied ________Empty

Equipment Status at Time of Measurement

_______Up and at Idle _______Up and Ready to Start Cycle

_______Specific Point in the Process Cycle

(Explain)____

____

_______Down for Installation/Modification _______Down for Cleaning

_______Down for Preventive Maintenance _______Down for Repair semi

PROCESS EQUIPMENT EXHAUST REQUIREMENT SUMMARY (continued)

NOTE: Repeat this sheet for each exhaust connection to the machine.

Manufacturer ______________________________

Equipment Name ______________________________ Model ______________

Demand Status ______________Normal ___________Peak ___________Other (Explain)__________

Duct Connection Identity ______________________________

Connection Inside Diameter ______________________________centimeters (inches)

Connection Outside Diameter ______________________________centimeters (inches)

	*Priority	Target	Tolerance	Stability
Flow Volume m/s (CFM)	_______	______	-0% +______%	±_______%
Flow Velocity m/s (FPM)	_______	______	-0% +______%	±_______%
Static Pressure pascals (inches of water)	_______	______	-0% +______%	±_______%

Data Corrected to Sea Level ______Yes ______No

Data Corrected to Std Air Density ______Yes ______No

Exhaust Stream Temperature ______°C (°F) ______°C (°F) ______°C (°F)

Min Normal Max

Measurement Location

Altitude___________m (ft) ambient temperature___________°C (°F) Humidity_____________

Chemical Make-up of Expected Effluent Stream

Element	State	% Concentration	Volume	Weight
___________	________	________________	________	______
___________	________	________________	________	______
___________	________	________________	________	______
___________	________	________________	________	______
___________	________	________________	________	______

Exhaust Schematic Diagram Included _______Yes _______No

* Priority is the rank order importance (from one to four) of the indicated value in proper operation of the equipment. The balance will adjust to priority one values at the expense of other values in this sheet.

APPENDIX 2
REFERENCED DOCUMENTS

A2-1 Industrial Ventilation

A Manual of Recommended Practice
20th EditionCopyright 1988
Library of Congress Catalog Card Number: 62-12929

Published by: ACGIH (American Conference of Government Industrial Hygienists)
6500 Glenway Ave., Building D-7
Cincinnati, OH 45211-4438
Telephone: 513-661-7881

A2-2 HVAC Systems Duct Design

1981 Second Edition

Published by: SMACNA (Sheet Metal and Air Conditioning Contractors' National Association, Inc.)
8224 Old Courthouse RoadTyson's Corner
Vienna, VA 22183
Telephone: 703-790-9890

A2-3 HVAC Systems

Testing, Adjusting, and Balancing
Third Printing - June 1986

Published by: SMACNA (Sheet Metal and Air Conditioning Contractors' National Association, Inc.)

A2-4 Procedural Standards for Certified Testing of Cleanrooms

First Edition — October 1988

Published by: NEBB (National Environmental Balancing Bureau) 8224 Old Courthouse Road Tyson's Corner Vienna, VA 22180

A2-5 Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices

Published by: ACGIH

A2-6 AABC National Standards for Field Measurement and Instrumentation — Total System Balance

Volume Two, No. 12173

Published by: AABC (Associated Air Balance Council)
1518 K Street Northwest
Suite 503
Washington, D.C. 20005
Telephone: 202-737-0202

A2-7 ASHRAE 1981 Fundamentals Handbook

Chapter 33 Duct Design

Published by: ASHRAE (American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc.)
1791 Tullie Circle, N.E.Atlanta, GA 30329
Telephone: 404-636-8400

A2-8 SEMI S2, Safety Guidelines for Semiconductor Manufacturing Equipment

Published by: SEMI (Semiconductor Equipment and Materials International)
3081 Zanker Road
San Jose, CA 95134
Telephone: 408-428-9600

A2-9 SEMI F15, Test Method for Enclosures Using Sulfur Hexafluoride Tracer Gas and Gas Chromatography

Published by: SEMI

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