SEMI S6-0707
EHS GUIDELINE FOR EXHAUST VENTILATION OF SEMICONDUCTOR MANUFACTURING EQUIPMENT

This safety guideline was technically approved by the global Environmental, Health & Safety Committee. This edition was approved for publication by the global Audits and Reviews Subcommittee on April 25, 2007. It was available at www.semi.org in June 2007 and on CD-ROM in July 2007. Originally published in 1993.

NOTICE: This document was completely rewritten in 2007.

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

1 Purpose

1.1 This safety guideline provides safety performance criteria for exhaust ventilation of semiconductor manufacturing equipment (SME) and test methods for assessing conformance to those criteria.

1.2 The optimization of exhaust ventilation is becoming more important as energy efficiency and the physical constraints of exhaust ventilation utilities in user facilities become more pronounced. Efficiently designed exhaust ventilation should be provided to protect personnel, property, and the environment from health and safety risks. The purpose of this safety guideline is to provide performance and design principles and test methods and criteria for exhaust ventilation.

2 Scope

2.1 This guideline applies to semiconductor manufacturing equipment that incorporates exhaust ventilation intended to be connected to user facilities' exhaust ventilation system(s).

2.2 The criteria of this document should be applied to exhaust ventilation systems provided for the purposes (in whole or in part) of personnel protection, equipment protection, and fire risk reduction.

2.3 The performance and assessment criteria in this document apply to all of the equipment provided by a supplier to a user or to another supplier to be provided as part of equipment the latter supplier provides to a user.

2.4 This document is intended to help the semiconductor equipment supplier design equipment exhaust ventilation systems to a common set of performance criteria as well as to provide assistance to both users and suppliers in the understanding of exhaust ventilation requirements for equipment systems. It is not intended to establish design specifications.

NOTE 1: Design suggestions for several applications of exhaust ventilation are provided as Related Information.

2.5 Test methods are provided in § 8 and several appendices.

2.6 This document is not intended to limit hazard evaluation methods or control strategies (e.g., design principles) employed by suppliers or users. Many different methods may be employed if they provide a sufficient level of protection.

2.7 *Contents*

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Appendix 1 — Determination of Gas and Vapor Generation and Release Rates

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Appendix 4 — Test Method for Air Pattern Assessment For Flammable Gas And Vapor Sources

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NOTE 2: At the time of publication, SEMI S6-0707 contained the following Related Information sections:

- Related Information 1 — Example Exhaust Ventilation Parameters
- Related Information 2 — Relationship to Facility Exhaust Ventilation Systems
- Related Information 3 — General Design Recommendations
- Related Information 4 — Controlling Objectionable Odors from Process Equipment
- Related Information 5 — Recommended Form for Reporting Exhaust Ventilation
- Related Information 6 — General Equation Relating Process Gas Flow Rate to Tracer Gas Injection Rate
- Related Information 7 — Exhaust Ventilation as Smoke Control

3 Limitations

3.1 This document does not provide criteria for determining whether exhaust ventilation is to be used to mitigate the risks of the use of a substance within SME. It provides criteria for exhaust ventilation features of SME when exhaust ventilation has been selected as a means of mitigating such risks.

3.2 Effluent sampling for environmental criteria is not covered in this document. Mass balance sampling for environmental characterization is not covered in this document.

NOTE 3: Guidelines for Environmental Characterization of Semiconductor Equipment, TT# 01104197A-XRF [1] contains information on environmental characterizations.

3.3 Ventilation for particle control for product quality (i.e., other than for safety) is outside the scope of this safety guideline.

3.4 Ventilation for control of smoke is outside the scope of this safety guideline.

NOTE 4: Ventilation for control of smoke is discussed in Related Information 8 of this document and in a Related Information of SEMI S14.

3.5 Ventilation for removal of heat is outside the scope of this safety guideline.

NOTE 5: Because of the cost of conditioning air, particularly for cleanrooms, using exhaust ventilation to remove heat may add substantially to the capital and operating costs.

3.6 This document is written with the assumption that the users' exhaust ventilation distribution systems will be designed with central fans, ducting, and, where applicable, abatement equipment. Suppliers should be aware that other types of exhaust ventilation systems may be encountered. End users should communicate relevant details of their exhaust ventilation systems to their suppliers, particularly if the systems deviate from the assumed model.

3.7 Existing models and subsystems should continue to meet the provisions of SEMI S6-93. Models with redesigns that significantly affect the EHS aspects of the equipment ventilation should conform to the latest version of SEMI S6. This safety guideline is not intended to be applied retroactively.

NOTE 6: EHS aspects of equipment ventilation may be affected by changes to ventilation and by changes to the hazards the risks of which are mitigated by ventilation.

NOTICE: International System of Units (SI) units of measure, symbols and abbreviations (as expressed in standards such as IEEE/ASTM SI-10 or National Institute of Standards and Technology (NIST) Special Publication 330 (SP 330), "The International System of Units (SI)") appear in this document as the official units of SEMI

1 SEMATECH, 2706 Montopolis Drive, Austin, TX 78741, USA. Telephone: 512.356.3500; http://www.sematech.org; URL for this document: http://www.sematech.org/public/docubase/abstracts/4197axfr.htm

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Standards publications. They may be followed (in parentheses) by US Customary units of measure for convenience, but the SI units define the criteria.

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.

4 Referenced Standards and Documents

4.1 *SEMI Standards and Safety Guidelines*

SEMI F5 — Guide for Gaseous Effluent Handling

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

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

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

4.2 *ACGIH®*[2]

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

4.3 *ASHRAE*[3]

Standard 110-1995 — Method of Testing Performance of Laboratory Fume Hoods

4.4 *ASTM Standards*[4]

ASTM E 697 — Practice for Use of Electron Capture Detectors in Gas Chromatography

IEEE/ASTM SI 10 — American National Standard for Use of the International System of Units (SI): The Modern Metric System

4.5 *CGA Standards*[5]

CGA P20 — Standard for the Classification of Toxic Gas Mixtures

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

4.6 *European Standards*[6]

EN1127-1 — Explosive atmospheres – Explosion prevention and protection. Part 1. Basic concepts and methodology

4.7 *European Directives*[7]

94/9/EC — Directive 94/9/EC Of The European Parliament and The Council of 23 March 1994 on the approximation of the laws of the Member States concerning equipment and protective Systems for use in potentially explosive atmospheres

4.8 *NFPA Standards*[8]

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

3 ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.) 1791 Tullie Circle, N.E., Atlanta, GA 30329 USA. Telephone: (404)636-8400; Fax: (404)321-5478; http://www.ashrae.org

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

5 CGA (Compressed Gas Association) 4221 Walney Rd., 5th Floor, Chantilly, VA 20151, USA. Telephone: 703.788.2700; Fax: 703.961.1831; http://www.cganet.com

6 European Committee for Standardization (CEN), Central Secretariat, rue de Stassart 35, B-1050 Brussels, Belgium

7 http://europa.eu.int/smartapi/cgi/sga_doc?smartapi!celexplus!prod!CELEXnumdoc&lg=en&numdoc=31994L0009

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

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NFPA 1 — Uniform Fire Code

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

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

4.9 *National Institute of Standards and Technology*[9]

Special Publication 330 (SP 330), "The International System of Units (SI)"

5 Terminology

5.1 *Abbreviations and Acronyms*

5.1.1 *AEV* — additional exhaust ventilation

5.1.2 *ATL* — accredited testing laboratory

5.1.3 *C* — ceiling limit

5.1.4 *ERC* — equivalent release concentration

5.1.5 *FEV* — facility exhaust ventilation

5.1.6 *HEI* — hazardous energy isolation

5.1.7 *IDLH* — Immediately Dangerous to Life and Health

5.1.8 *LFL* — lower flammable limit

5.1.9 *OEL* — occupational exposure limit

5.1.10 *PEV*— primary exhaust ventilation

5.1.11 *SEV* — secondary exhaust ventilation

5.1.12 *SME* — semiconductor manufacturing equipment

5.1.13 *SOC* — substance of concern

5.1.14 *STEL* — Short Term Exposure Limit

5.1.15 *TWA* — Time Weighted Average exposure limit

5.1.16 *UFL* — upper flammable limit

5.2 *Definitions*

5.2.1 *access* — the means of inserting a tool or any part of the body into an enclosure.

5.2.2 *accessway* — a feature of the equipment that allows access. The term includes both openings that are provided with a means of closure (e.g., a door or removable cover) and those that are not.

5.2.3 *additional exhaust ventilation (AEV)* — airflow that is not present during normal operation but is provided to extract substances of concern during maintenance or in the case of an abnormal release from primary containment.

NOTE 7: Additional exhaust ventilation may be turned on either automatically (e.g., in response to leak detection) or manually, and it may be provided through the ducting used for primary or secondary exhaust ventilation (by increasing the volumetric flow rate) or through separate ducting (e.g., a flexible duct ("elephant trunk") used for process chamber cleaning).

5.2.4 *balancing* — adjustments made to airflow rate (e.g., by setting positions of dampers) after the ventilated equipment and the exhaust ventilation system are installed to assure that airflow to each piece of ventilated equipment is within design specifications.

5.2.5 *capture* — entrainment of undesirable elements (gases, fumes, vapor, and particles) in the exhaust ventilation stream for removal.

9 National Institute of Standards and Technology, 100 Bureau Drive, Stop 3460, Gaithersburg, MD 20899-3460, USA. Telephone: 301.975.6478; http://www.nist.gov; URL for this publication: http://physics.nist.gov/Pubs/SP330/sp330.pdf

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5.2.6 *ceiling limit (C)* — an occupational exposure limit (OEL) for the maximum concentration to which a worker may be exposed at any time.

5.2.7 *closed processing equipment* — equipment in which the process and chemical handling take place inside of components the interiors of which are not in communication with ambient air. Components inside the ventilated enclosures may include sealed mixing or measurement vessels and holding tanks, enclosed plumbing, and process chambers. In this type of equipment it is not normal operation for the inside of the ventilated enclosure or the secondary containment to be exposed to chemicals.

5.2.8 *continuous air sampling* — performing instantaneous air sampling at a frequency of at least once each fifteen minutes.

5.2.9 *dilute* — to reduce the concentration of a substance by addition of materials that are not substances of concern.

5.2.10 *effluent* — the air removed from SME by exhaust ventilation, including any material mixed with or suspended in it.

5.2.11 *enclosure* — a physical structure that separates a space in which exhaust ventilation is provided from another such space or from a space in which ventilation is not provided.

5.2.12 *equivalent release concentration (ERC)* — the theoretical concentration of a substance of concern that would be measured in air inside or outside an enclosure in the event of a primary containment failure. The ERC is calculated from the measured concentration of the gas that is released to perform the test. The ERC can be expressed as a percentage of the OEL or LFL of the substance of concern.

5.2.13 *exhaust ventilation* — any of primary, secondary, or additional exhaust ventilation (i.e., PEV, SEV, or AEV), as defined herein.

5.2.14 *facility exhaust ventilation (FEV)* — removal of air and the contaminants, if any, contained therein, from SME or its immediate proximity. FEV is a service provided by a facility, usually through a duct.

5.2.15 *flammable gas* — any gas that forms an ignitable mixture in air at 20°C (68°F) and 101.3 kPa (14.7 psia). This includes, by definition, any pyrophoric gas. (As used in this definition, “an ignitable mixture with air” is a mixture that can be ignited.)

NOTE 8: Within some regulations, pyrophoric materials are considered differently than are other flammable materials.

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

5.2.17 *flammable range* — the range of concentrations of the dispersed chemical species in air through which a flame will propagate if a source of ignition is supplied. This range is bounded by the lower flammable limit (LFL) and the upper flammable limit (UFL).

NOTE 9: The following pairs of terms are commonly used interchangeably:

- "lower explosive limit (LEL)" and "lower flammable limit (LFL)";
- "upper explosive limit (UEL)" and "upper flammable limit (UFL)"; and
- "explosive range" and "flammable range".

Some literature uses "LEL", "UEL", or "explosive range" to designate concentrations to which a more specific criterion (e.g., a certain pressure rise or flame front speed) than the ability to propagate flame pertains. This document uses the "flammable range" terminology to avoid the ambiguity that accompanies the "explosive range" terminology.

5.2.18 *flash point* — the minimum temperature at which a liquid gives off sufficient vapor to form an ignitable mixture with air near the surface of the liquid or within the test vessel used. (As used in this definition, “an ignitable mixture with air” is a mixture that can be ignited.)

5.2.19 *flow sensor* — a device which measures the movement of a fluid. Flow sensors may measure by comparison of pressures or by other means.

5.2.20 *flow velocity,* V — the average speed at which an effluent stream travels through an exhaust ventilation duct. It is commonly expressed in meters per second (m/s). The US Customary unit is feet per minute (fpm).

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5.2.21 *flow volume,* Q — the volumetric flow rate of an effluent stream passing a given location in the ventilation system per unit of time. It is commonly expressed in cubic meters per hour (m^3/hr). The US Customary unit is cubic feet per minute (cfm).

5.2.22 *fugitive, adj.* — escaping, from the ventilated enclosure that was intended for its control, into the work area.

5.2.23 *gas* — the fluid form of a substance in which it can expand indefinitely and completely fill its container; form that is neither liquid nor solid. [SEMI S4, SEMI F78, SEMI F81]

5.2.24 *hood* — a shaped inlet designed to capture air and conduct it into a facility exhaust ventilation duct system.

5.2.25 *Immediately Dangerous to Life or Health (IDLH)* — an atmosphere that poses an immediate threat to life, would cause irreversible adverse health effects, or would impair an individual's ability to escape from a dangerous atmosphere. [29CFR1910.134b]

5.2.26 *inch of water gauge ("w.g., in. w.g.*, or *i.w.g.)* — the pressure that supports a column of water one inch tall. It is a common US, not SI, unit for pressure. (See also the definition for static pressure.)

5.2.27 *integrated air sampling* — moving potentially contaminated air at a known rate for a known sampling period through a medium suitable for collecting and retaining the contaminants of interest for subsequent chemical analysis. Integrated sampling provides a means of measuring the time average airborne concentrations of the contaminants during the sampling period.

5.2.28 *instantaneous air sampling* — collecting potentially contaminated air for chemical analysis as rapidly as the collection method permits. Typically, the collection time is less than one minute per sample. Instantaneous sampling provides a means of measuring airborne concentrations of the contaminants during a brief period.

5.2.29 *lower flammable limit* — the minimum concentration of a flammable substance in air through which a flame will propagate. (See also the definition for flammable range.)

5.2.30 *long radius elbow* — a ventilation duct elbow that has a center line radius 1.5 or more times the duct diameter.

5.2.31 *maintenance* — planned or unplanned activities intended to keep equipment in good working order. (See also the definition for *service*.) [SEMI S2]

NOTE 10: "Unplanned" means that the activity had not been scheduled, i.e., that the activity is performed in response to an observed condition. "Unplanned" does not mean that the activity had not been foreseen or that the equipment supplier had not provided instructions for performing the activity.

5.2.32 *millimeter of water gauge, mm. w.g.* — the pressure that supports a column of water one millimeter tall. It is a common, not SI, unit for pressure. (It is also called mm Aq.) See definition for static pressure.

5.2.33 *non-combustible material* — a material that, in the form in which it is used and under the conditions anticipated, does not ignite, burn, or release flammable vapors when subjected to fire or heat.

5.2.34 *occupational exposure limit (OEL)* — the maximum airborne concentration of a substance to which a worker may be exposed for the specified time. OELs include TWAs, STELs, and Ceiling limits, which differ in the time period for which they specify concentrations. Various terms are used to refer to OELs, such as permissible exposure levels, Threshold Limit Values®, maximum acceptable concentrations, maximum exposure limits, and occupational exposure standards. The criteria used in determining OELs can differ among the countries that have established values. (Threshold Limit Value is a registered trademark of the American Conference of Governmental Industrial Hygienists.)

5.2.35 *open processing equipment* — equipment in which at least some of the process and chemical handling take place inside of components the interiors of which are in communication with ambient air. In equipment of this type, such areas of the primary containment are ventilated.

5.2.36 *pocketting* — accumulation in a portion of a ventilated enclosure of a released SOC at a concentration greater than the ratio of the rate of release to the volumetric airflow through the enclosure. Pocketting may result if the linear velocity and mixing of airflow within the enclosure is not uniform.

5.2.37 *primary containment* — the first level of containment (i.e., the container, piping, or other component) that is intended to come into immediate contact on its inner surface with the material being contained during normal

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operation, maintenance and service. Primary containment does not include exhaust handling components (e.g., ducting and exhausted enclosures).

5.2.38 *primary exhaust ventilation* (PEV) — airflow that, in normal operation, extracts substances of concern from the equipment.

NOTE 11: For example, the exhaust ventilation provided to collect and extract the vapor that leaves the liquid surface in an open processing vessel is considered primary exhaust ventilation because evaporation of substances of concern from the liquid surface is expected during normal operation.

5.2.39 *process vessel* — primary containment in which substrates are exposed to chemicals, heat, radiation, or vibration.

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

5.2.41 *safe condition* — a condition in which the equipment does not present an unacceptable risk to personnel, itself or the facility. A safe condition is determined by the designer of the equipment and is based on the risks in the design.

5.2.42 *secondary containment* — the second level of containment, the purpose of which is to contain substances of concern should they be released from their primary containment due to failure or to maintenance or service operations. This pertains to both liquids and gases.

5.2.43 *secondary exhaust ventilation* (SEV) — airflow that, in normal operation of the equipment, does not extract substances of concern, but operates continuously to extract substances of concern should they be released from their primary containment due to failure or to maintenance or service operations.

NOTE 12: For example, the exhaust ventilation through gas panels is considered SEV, because in normal operation, the hazardous gases are within their piping and only under failure, maintenance, or service are hazardous gases removed by the exhaust ventilation.

5.2.44 *semiconductor manufacturing equipment (SME)* — equipment used to manufacture, measure, assemble, or test semiconductor products. It includes the equipment that processes substrates (e.g., silicon wafers, reticles), its component parts, and its auxiliary, support or peripheral equipment (e.g., chemical controllers, chemical delivery systems, vacuum pumps). SME also includes other items (e.g., structures, piping, ductwork, effluent treatment systems, valve manifold boxes, filtration, and heaters) specific to and provided with the aforementioned equipment, but does not include such an item if the item is part of a facility and can support more than one piece of SME. [SEMI S3]

5.2.45 *service* — unplanned activities intended to return equipment that has failed to good working order. (See also the definition for *maintenance*.) [SEMI S2]

5.2.46 *short term exposure limit (STEL)* — an occupational exposure limit (OEL) for an exposure period much less than a work shift, typically fifteen minutes. The time period is specified as part of the STEL.

5.2.47 *static pressure, SP* — the measure of differential pressure across a duct or enclosure wall. That is, the difference between the ambient (pressure of the room in which the duct is located) and the pressure inside the duct. This is usually expressed in pascals (Pa) or inches of water.

NOTE 13: One inch of water gauge ("w.g.) equals 249 Pa. One pascal equals one newton per square meter (N/m^2).

5.2.48 *static pressure sensor* — a device which measures static pressure.

5.2.49 *substance of concern (SOC), n.* — a substance for which the equipment relies on exhaust ventilation to protect personnel from exposure above the limits established in SEMI S2 or to prevent formation of a mixture with air at above 25% of the LFL of the substance during normal operation, during maintenance, or in the case of failure. This includes substances meeting the criteria in the definition that are to be used in processes, those that are products or byproducts of intended or foreseeable reactions, those that are not intended to be directly involved in the processes (e.g., coolants) and those that are used only in maintenance or service (e.g., solutions used to clean process chambers).

NOTE 14: Whether a solution or mixture is a substance of concern depends on the properties of the solution or mixture, as it is supplied to the SME, not on the properties of the constituents, unless it is reasonably foreseeable that the solution or mixture will

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separate into its constituents. For example, a mixture of 5% H_2 in N_2 is not a flammable gas, although H_2 itself and a 5% H_2 in He mixture are flammable gases. CGA P23 and P20, respectively, provide guidance on determining the properties of gas mixtures containing flammable and toxic components.

5.2.50 *substance-of-concern, adj. or adv.* — pertaining to a substance of concern.

5.2.51 *supply ventilation* — the delivery of air to SME or a workplace.

5.2.52 *time weighted average (TWA)* — an occupational exposure limit (OEL) for an exposure period on one work shift, typically eight hours. The time period is specified as part of the TWA.

5.2.53 *traverse measurements* — multiple airflow measurements taken at points of equal separation, by area, in a matrix pattern, along the cross-section of a ventilation duct or face plane of an opening in a ventilated enclosure.

5.2.54 *upper flammable limit* — the maximum concentration of a flammable substance in air through which a flame will propagate. (See also the definition for flammable range.)

5.2.55 *vapor* — the gas phase of a substance that is usually considered to be a liquid.

5.2.56 *vena contracta* — a location downstream of an orifice (e.g., the opening of a duct) where the static pressure falls to a minimum and the velocity pressure reaches a maximum.

5.3 *Symbols*

5.3.1 ¶ — a character used to identify a particular paragraph of the document. The identified portion includes the numbered paragraph identified by the number following the symbol and the Exceptions and lists (bulleted or numbered) embedded therein. It does not, however, include the subordinate headers and paragraphs. When duplicated, as ¶¶, it refers to more than one paragraph. For example, ¶ 8.5.3 refers to the text immediately following that number, the bulleted list, and the Exception. Contrarily, ¶ 8.5.1 refers to only that paragraph, but not to ¶ 8.5.1.1, 8.5.1.2, or 8.5.1.2.1.

5.3.2 § — a character used to identify a particular section or subsection of the document. The identified portion includes the numbered paragraph or header identified by the number following the symbol and all subordinate headers and paragraphs as well as the Exceptions and lists (bulleted or numbered) embedded therein. When duplicated, as §§, it refers to more than one section or subsection. For example, § 8.5 refers to ¶¶ 8.5, 8.5.1, 8.5.1.1, 8.5.1.2, 8.5.1.2.1, 8.5.2, and 8.5.3 (including the bulleted items and the Exception).

6 Design Criteria

6.1 The material in § 6 of this document should be used to determine conformance to this document.

6.2 Components should be rated and suitable for their intended use (including consideration of at least: pressure, temperature, and chemical compatibility).

NOTE 15: SEMI S2 includes additional criteria on suitability and application of components.

NOTE 16: Related Information 3 contains recommendations on equipment ventilation design.

6.3 *Materials and Components Compatibility*

6.3.1 All primary and secondary containment components and exhaust ventilation system components, including enclosures and connecting duct material, should be compatible with the process chemicals specified by the SME supplier and all reasonably foreseeable process byproducts they may contact. For equipment in which different exhaust ventilation systems may convey different chemicals, the appropriate materials should be used in each location within the equipment.

6.3.2 The materials of construction for ducts and other components that come in contact with effluent should be resistant to the effects (e.g., corrosion, softening, or embrittlement) of that effluent.

NOTE 17: The combustibility criteria of SEMI S2 may limit the choice of duct material. Refer to ¶ 7.5.4 for additional information.

6.4 *Setup and Balancing*

6.4.1 The provisions of § 6.4 do not apply to automated dampers.

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6.4.2 The supplier may provide a damper, at or near the equipment connection point, to be used only as a trimming device to meet the equipment flow and pressure specifications.

NOTE 18: Dampers that are balanced in the nearly closed position are more prone to plugging when the effluent contains materials that are likely to deposit on surfaces in the exhaust ventilation system.

6.4.3 Gates and dampers should be securable with a tool or lock to prevent inadvertent or unauthorized adjustment.

6.5 Exhaust ventilation for maintenance procedures should either be incorporated in the system design or AEV criteria should be specified separately from the system PEV and SEV. Where exhaust ventilation for maintenance procedures is incorporated into the equipment, the flow and static pressure required to be provided by the facility are part of the requirements specified for the SME. When AEV is needed, the equipment supplier should specify the:

- inlet size and shape,
- minimum and maximum flow, and
- minimum and maximum static pressure.

NOTE 19: Both static pressure and flow must be specified to ensure that the pressure drop in the AEV equipment does not reduce the flow below that which is needed to capture the SOC.

NOTE 20: It is recommended that capture occur as close to the source as practical to manage exposure of personnel or products to the SOC.

NOTE 21: This criterion is intended to describe how exhaust ventilation for maintenance is to be provided. It is not intended to state that such ventilation is appropriate for all SME or all tasks.

6.6 The SME should not require that the facility provide a static pressure more negative than -375 Pa (-38mm H_2O or -1.5 i.w.g) at the point of connection to the facility to meet the other performance criteria in this document.

EXCEPTION: If the equipment (e.g., coater) design requires pressure more negative than -375 Pa, a technical rationale for the additional static pressure demand should be provided to the end user. Additionally, methods should be described for achieving the necessary static pressure and means (e.g., interlocks) should be described that will prevent any portion of the exhaust line from reaching a positive pressure. This information should be supplied in the documentation provided to the end user.

6.7 Points of connection to facility exhaust ventilation system should be of a size, shape and material that are compatible with commonly available duct materials.

7 Performance Criteria

7.1 The material in § 7 of this document should be used to determine conformance to this document. These criteria pertain only when the acceptability of the risk depends on the performance of the ventilation.

NOTE 22: As there were no criteria for exposure during service specified in SEMI S2 at the time this version of SEMI S6 was developed, no criteria for exhaust ventilation performance for service are included in this document. However, the same methods used to determine the adequacy of exhaust ventilation for maintenance could be used for service, if exposure criteria were established. In the absence of criteria, concentrations and potential exposures at the time of service need to be assessed and appropriate protection needs to be provided for personnel who are to perform service.

7.2 *Release and Generation Rates*

7.2.1 To test the adequacy of the exhaust ventilation by simulating a release, one must establish the mass or volumetric flow rate and velocity at which gases (including vapors) and aerosols of the substances of concern are reasonably foreseen to be released or generated in normal operation, during maintenance, and during failures (e.g., overtemperature of a bath or leak of primary containment). The determining factors include the physical state of the substance of concern (i.e., solid, liquid, or gas) and the conditions (e.g., temperature and pressure) under which it is handled and used in the SME.

7.2.2 Liquid sources that require equipment exhaust ventilation can be grouped several ways. They can be grouped by whether the liquid is exposed to the atmosphere under normal operating conditions (e.g., in an open-tank wet station), or only under maintenance conditions (e.g., wet cleaning a CVD process chamber), or only under abnormal conditions (e.g., a leak in a liquid supply line to a CVD process chamber). Liquids can also be grouped by the hazards they present: toxicity, flammability, or both.

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7.2.2.1 As the management of the liquids themselves is outside the scope of this document and the only differences between liquid and gas releases are the rate and location of the release and, in the case of liquids, of the conversion to vapor, the methods described for gas releases may be used.

7.2.3 *Closed Processing Equipment*

7.2.3.1 In normal operation, no substances of concern are released to, or generated in, ventilated enclosures of the equipment or work environment.

7.2.3.2 The release or generation rate during maintenance depends on the equipment, its use, and the maintenance activity. For maintenance activities that involve opening the primary containment of the substances of concern, see the discussion below (§ 7.2.4) regarding open processing equipment. In maintenance activities in which primary containment is not opened, there is no substance of concern released to, or generated in, the ventilated enclosure.

7.2.3.3 All reasonably foreseeable, single fault conditions (e.g., overheating, overpressurization) should be considered. Additionally, for liquid and gas piping systems, the disconnection of each non-welded connection should be considered, whether or not it is "reasonably foreseeable". Releases from failure should be estimated as follows:

NOTE 23: It is recommended that SME manufacturers specify the maximum inlet pressure under facility fault conditions for which the SME is suitable.

7.2.3.3.1 For foreseen failure points in gas and liquid piping systems (including each non-welded connection), the release rate specified herein is the rate at which the substance of concern would flow if the primary containment were disconnected at the point of failure. This depends on the substance of concern, its pressure, and the flow limitation (deliberate, e.g., by flow limiting devices or incidental, e.g., by filters) imposed by the engineering controls in the fluid source and the primary containment system. Appendix 1 provides conservative models for estimating the release of a gas from a disconnected line and for estimating the vapor generation rate from release of liquids. These models should be used if the release or vapor generation rate has not been measured.

7.2.3.3.2 The engineering controls may be incorporated in the SME or the equipment supplier may specify, in documentation provided to the user, that the flow of a substance of concern from a facility to the SME be limited, by an engineering control, to a particular value. The release rate used in determining conformance to this safety guideline should not depend on administrative controls, such as assembly and leak checking procedures.

NOTE 24: The task force that developed this document could not reach consensus on a generally valid, but less conservative, release rate other than the total available flow of substance of concern. Exhaust ventilation requirements may depend on supplier or user choices as to how much flow to make available. Engineering controls, such as excess flow valves, flow switches and flow restrictors can be used to limit the available flow and, thereby, reduce the exhaust ventilation required.

7.2.3.3.3 For foreseen failure points in vessels, the release rate depends on the failure mode.

NOTE 25: Vessel failures range from the development of pinholes, which might release fluids at rates of less than one liter per hour, to rupture, which might release the entire liquid volume in less than one second.

7.2.3.3.4 The quantity or duration of a release is limited by the available substance of concern. This is limited by the amount of the substance of concern in the equipment, if there is no external supply of the substance of concern.

7.2.3.3.5 The quantity or duration of release may also be limited by automated interruption of the substance-of-concern supply to the failure point, if both of the following conditions are met:

- The means of detection of release has been found by an ATL to conform to a relevant performance standard (e.g., FM6320, ANSI-ISA 12.13.01 or CSA 22.9 No. 152 for combustible gas sensors). For the purpose of this criterion, a "performance standard" is one that specifies the ability of the detector to detect the SOC.
- The means by which the signal from the detector results in stopping flow meets the SEMI S2 criteria for safety interlocks.

7.2.3.3.6 For substances of concern that are released as liquids or aerosols, see Appendix 1 for the means of determining the vapor generation rate.

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7.2.4 *Open Processing Equipment*

7.2.4.1 *In Normal Operation*

7.2.4.1.1 The rate at which open portions of the system (i.e., those portions in which the substances of concern are exposed to the ventilated space) release or generate substances of concern into the ventilated space depends on the substances of concern and physical conditions of the exposure. If the adequacy of the exhaust ventilation is to be tested by simulating a release, the methods in Appendix 1 should be used to determine the vapor generation rate.

7.2.4.1.2 No substances of concern are released from closed portions of the primary containment to the ventilated enclosure or work environment.

7.2.4.2 *During Maintenance*

7.2.4.2.1 The release or generation rate during maintenance depends on the equipment, its use, and the maintenance activity.

7.2.4.2.2 For maintenance activities that involve open portions of the system, release or generation of substances of concern into the ventilated space depends on the substances of concern and physical conditions of the exposure. If the adequacy of the exhaust ventilation is to be tested by simulating a release, the methods in Appendix 1 should be used to determine the vapor generation rate.

NOTE 26: Opening accessways may cause changes in the exhaust ventilation conditions, including the velocity and flow volume of air past the exposed substances of concern.

NOTE 27: In many equipment configurations, personnel performing maintenance may occupy locations that are not occupied by personnel during normal operation.

7.2.4.2.3 For maintenance activities that involve opening the primary containment of the substances of concern in closed portions of the system, the release or generation rate should be determined as if the involved portion of the system were open.

7.2.4.2.4 In maintenance activities that involve closed portions of the system but in which primary containment is not opened, there is no substance of concern released to, or generated in, the ventilated enclosure.

7.2.4.3 *During Fault Conditions*

7.2.4.3.1 All reasonably foreseeable, single fault conditions should be considered. Releases from failure should be estimated as follows:

7.2.4.3.2 The release resulting from failure of primary containment should be determined as is described above for closed processing systems.

7.2.4.3.3 The release rate during other failures (e.g., abnormally high temperature of an open container of liquid) is determined by using the methods for normal operation, substituting the failure conditions for the normal operating conditions.

7.3 *General Criteria*

7.3.1 SME design should include means of mitigating the risks associated with the total loss of facility exhaust ventilation or with loss of facility exhaust ventilation to below the levels that enable the equipment exhaust ventilation to perform the functions described in this safety guideline. Selection of such means should be based on the result of hazard analysis and risk assessment and provide automatic actions (e.g., drain chemicals, shut off source, cover open vessels) to place the equipment in a safe condition. Different means of risk mitigation may be required for different equipment configurations (e.g., minienvironment or not) or facility configurations (e.g., laminar flow variations among facilities).

7.3.2 Where the equipment supplier provides written procedures for maintenance functions (such as closing manual valves or adjusting regulators) to be performed without isolating the supply of substance of concern to the enclosure, an accessway should be designed in a way that will not result in inadequate exhaust ventilation performance. This criterion pertains only when the acceptability of the risk of performing those maintenance functions depends on the performance of the ventilation.

NOTE 28: Procedures of this nature may need to be evaluated to ensure that they do not violate regulations regarding hazardous energy control.

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7.3.2.1 Access to a secondary containment enclosure to perform a maintenance task is considered maintenance only if there is no release to that enclosure at the time of access, i.e., no release is ongoing at time of access and no release begins during access. Access to secondary containment enclosures in which releases are occurring is not maintenance; it is service, because the release is a failure condition, not a condition of normal operation.

NOTE 29: For example, access to a gas panel enclosure to perform HEI is "maintenance" if the concentration of SOC in the enclosure is below the limit for exposure for maintenance personnel. (By definition, in normal operation, the concentration is immeasurably small.) If, however, there is a leak within the enclosure that would result in exposure above that limit if the accessway were opened, opening the accessway would be outside the scope of "maintenance", because the leak is a fault condition.

NOTE 30: It may be appropriate to consider the risk of a maintenance function causing a release (e.g., a valve being broken as it is used to perform HEI) in the assessment of conformance to SEMI S2. It may be appropriate to mitigate that risk by ventilation design, primary containment design, or other means.

7.4 *Management of Exposure to Personnel*

7.4.1 Exhaust ventilation designs for substances of concern should ensure hazardous gases, particles, and vapors are controlled during normal operations such that concentrations present in the work room air meet the breathing zone criteria for normal operations in SEMI S2.

7.4.2 Exhaust ventilation designs for substances of concern should ensure hazardous gases, particles, and vapors are controlled during maintenance operations such that concentrations present in the breathing zone of the maintenance worker meet the breathing zone criteria in SEMI S2. Exposure risks during maintenance should be described and recommendations made about the exhaust ventilation volumetric flow and potential methods for providing exhaust ventilation during maintenance periods.

7.4.3 Exhaust ventilation designs for substances of concern should ensure hazardous gases, particles, and vapors are controlled during failures such that concentrations present in the work room air meet the breathing zone criteria for failures in SEMI S2.

7.4.4 If the reasonably foreseeable breathing zone of personnel during operation, maintenance or service includes a volume within an enclosure, the ventilation should preclude pocketing within those portions of the enclosure.

NOTE 31: If the protection of personnel performing service (i.e., working on equipment after a failure) depends on exhaust ventilation, it is recommended that the exhaust ventilation design ensure that no reasonably foreseeable breathing zone within an enclosure has a concentration in excess of one half of the IDLH. This can be achieved by any of several means, including having sufficient airflow to dilute to that level or precluding access to an enclosure until after the release has been stopped and sufficient time has passed to allow the exhaust ventilation to reduce the concentration to below the limit.

NOTE 32: Protection of personnel that is provided by controls other than exhaust ventilation (e.g., other engineering controls, administrative controls, personal protective equipment (PPE)) is outside the scope of this document.

7.5 *Management of Fire Risk*

7.5.1 There are two common means of reducing the risk of ignition of atmospheres: reducing the risk of the presence of such atmospheres and reducing the risk of there being ignition sources in such atmospheres. The equipment supplier may choose which of these to use for each location within the equipment. It is not the intention of this safety guideline to imply a preference between these methods.

NOTE 33: The risks presented by the coincidence of air containing an SOC at 25% of its LFL, oxidizers, and potential ignition sources can be addressed by controlling any of those elements. Control of oxidizers and potential ignition sources, however, is outside the scope of this document.

NOTE 34: Ignition sources may not affect the design and operation of pyrophoric substance enclosures, as the nature of a pyrophoric material is that it may ignite on contact with air. However, as the autoignition temperature of a pyrophoric material may be as high as 54.4°C (130°F), not all releases of pyrophoric material into enclosures will autoignite. For reasons that are not well understood, some releases of pyrophoric gases above the autoignition temperature result in accumulation and delayed ignition. For some materials, the LFL is lower than the minimum concentration for autoignition, so there is a concentration range in which an ignition source is of concern. Also, stronger ignition sources can increase the pressure rise in explosions.

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NOTE 35: Higher than normal (up to 1 m/s (200 fpm)) air velocities have been specified to ensure that pyrophoric gases do not collect and reach explosive levels. Research[10] has shown that air velocity does not affect probability of ignition at the point of release for silane. The task force which prepared this version of SEMI S6 is not aware of any experimental proof that air velocity affects probability of ignition for any pyrophoric gas. Silane pressure at the point of release appears to be the dominant factor in determining its ignition behavior.

NOTE 36: User and jurisdictional requirements may be part of the design criteria for pyrophoric exhaust ventilation systems.

7.5.2 During normal operation, maintenance, and all release conditions described in § 7.2, equipment exhaust ventilation design should prevent accumulation of 25% of the LFL at potential ignition sources within an enclosure if an oxidizer is present.

7.5.2.1 Exhaust ventilation may be used for capture and removal of flammable gas or vapor.

7.5.2.2 Exhaust ventilation may also be used to provide dilution with uncontaminated air, which can be used to keep the concentration of flammable gas or vapor below 25% of its LFL at potential ignition sources.

7.5.2.2.1 Enclosures for flammable SOCs should be designed to ensure adequate dilution throughout the enclosures by exhaust ventilation (i.e., prevent "pocketing").

NOTE 37: Electrical components located within an enclosure that potentially contains 25% of the LFL may be subject to regulatory requirements to provide classified electrical components (such as for Class I, Division 2 in the NFPA Electrical Code or the Uniform Fire Code). The requirements in these codes for Classified or Hazardous Locations pertain only to electrical sources of ignition. If there is no electrical equipment in the Location, then these requirements do not pertain. Detailed information as to whether special electrical designs are necessary is included in such documents as EN1127, NFPA 497 and 94/9/EC. NFPA 497 includes, as areas "it is not usually necessary to classify", i.e., that do not usually require special electrical design:

- those with adequate exhaust ventilation and combustible materials "contained within suitable, well-maintained closed piping systems",
- those without adequate exhaust ventilation, but piping without accessories that are leak-prone, and
- those used for storage of combustible materials in "suitable containers".

7.5.3 The volumetric flow should be sufficient to provide dilution of flammable SOCs to less than 25% of the LFL (in maintenance or fault conditions (as described in § 7.2)) at the point of connection of the equipment to the facility, where dilution is the primary means of limiting flammable SOCs to less than 25% of the LFL.

7.5.4 Ducting within the equipment should be constructed of non-combustible material (e.g., ferrous and nickel alloys) when normal operation or maintenance results in either:

- flammable gases (including vapors of flammable liquids) above 25% of their LFLs, or
- flammable or combustible residues deposited in duct work.

EXCEPTION: If the ducting is reasonably foreseen to contain >25% of the LFL of vapor, but not foreseen to contain solid or liquid flammable or combustible residues, combustible ducts, ducting components, or materials found by an ATL to conform to appropriate standards (e.g., UL 181 — Standard for Safety of Factory-Made Air Ducts and Air Connectors, FM 4922 — Fume Exhaust Ducts or Fume and Smoke Exhaust Ducts) may be used.

NOTE 38: Some jurisdictions require fire protection sprinklers in ducts with cross section dimensions above certain sizes. Fire protection sprinklers may be required in either combustible ducts or in ducts that may contain 25% of the LFL.

NOTE 39: Some jurisdictions prohibit, or impose additional requirements on, ducts foreseen to contain flammable materials above 10% of LFL.

7.6 *Efficiency/Optimization*

7.6.1 Demand on the facility's exhaust ventilation system(s) should be as low as is consistent with meeting safety and process requirements including minimizing nuisance alarms. Equipment suppliers should design the equipment to require the least exhaust ventilation feasible to meet health and safety objectives (control of exposure and reduction of the risk of fire).

10 Tamanini,F., Chaffee J., "Ignition Charactoristics of Releases of 100% Silane, FMRC J.I.0Z0R7.RK, December 14,1995 ,Factory Mutual Research Corporation, 1151 Providence Hwy., Norwood, MA 0262

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7.6.1.1 This criterion is considered to be met if the airflow does not exceed the greater of:

- two times the flow necessary to provide dilution of flammable substances of concern to less than 25% of the LFL (in maintenance or fault conditions (as described in § 7.2)) at the point of connection of the equipment to the facility, or
- the flow necessary to provide ten times the volume of the enclosure(s) each minute.

NOTE 40: Five air exchanges per minute is generally considered sufficient to provide good mixing within an enclosure. However, this does not relieve one of the obligation to assess performance within enclosures. Furthermore, there are regulatory requirements for higher air exchange rates in some jurisdictions.

7.6.1.2 If the flow required to meet the health and safety objectives exceeds that described in ¶ 7.6.1.1 the equipment supplier should provide users a written explanation of why the criteria cannot be met.

7.6.2 As the exhaust ventilation flow requirements depend strongly on the potential release, the equipment supplier should consider limiting the available flow of substances of concern, such as with flow restrictors or excess flow valves, as a means of reducing the required exhaust ventilation flow.

NOTE 41: In much of the equipment in use today, the available flow within primary containment is much larger than the flow required for the intended and foreseeable processes. It is the available flow(s) of substance(s) of concern, however, than can be released during failure of primary containment.

7.7 *Interlocks and Monitoring*

7.7.1 *Detection of Substances of Concern*

7.7.1.1 Equipment that uses substances of concern or odorous or irritant chemicals should be provided with sensors to detect releases from primary containment. Alternatively, the equipment supplier may specify the location and performance of detectors, but not provide them, so that the user may better integrate the detection in the equipment with that in the facility. This alternative should be negotiated explicitly by supplier and user.

NOTE 42: This does not necessitate one detector for each chemical species, just that all species be detected. For example, a float switch could be use to detect a leak of any of several liquid reagents and a hydride gas detector could be used to detect phosphine, arsine and diborane.

7.7.1.2 The means of detection should be one that has been found by an ATL to conform to a relevant performance standard (e.g., FM6320, ANSI-ISA 12.13.01 or CSA 22.9 No. 152 for combustible gas sensors). For the purpose of this criterion, a "performance standard" is one that specifies the ability of the detector to detect the SOC.

7.7.1.3 Gas sensors should be located so that they will detect and respond to a release from primary containment such that it will not result in concentrations present in the work room air exceeding the breathing zone criteria in SEMI S2 or concentration of a flammable gas inside or outside enclosures above 25% of LFL at a potential ignition source.

7.7.1.4 The sensitivity of leak detection sensors and systems required should be determined during controls design and should be based on the hazard characteristics of the potentially leaking materials.

7.7.1.5 Gas and vapor sensors should be located so that they measure the concentration in the airflow from only those enclosures in which there can be a release of the specific materials.

EXCEPTION: Sensors may be located so that they measure concentration in airflows manifolded together from more than one enclosure within a single piece of SME, only if sensitivity of the sensors used in such a manner is sufficient to meet the criteria of ¶ 7.7.1.3.

7.7.1.6 Liquid sensors may be used instead of gas sensors if they are capable of detecting liquid leaks that could result in vapors of substances of concern. Liquid sensors should be located so that they will detect and respond to a leak such that it will not result in exposure above the permissible level (as defined in SEMI S2) or concentration of a flammable gas above 25% of LFL at a potential ignition source, if an oxidizer is present.

7.7.2 *Monitoring of Exhaust Ventilation (Exhaust Ventilation Interlocks)*

7.7.2.1 SME incorporating PEV and AEV systems that are used for safety should be provided with safety interlocks to shut down the flow of chemicals to and within the equipment and any other exhaust-ventilation-related hazard when the exhaust ventilation falls below the levels needed to perform as prescribed within this document.

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7.7.2.2 *SME Incorporating SEV that is Used for Safety Where Detectors for the SOCs are Not Provided in Accordance with § 7.7.1* — Safety interlocks should be provided to shut down the flow of chemicals to and within the equipment and any other exhaust-ventilation-related hazard when the exhaust ventilation falls below the levels needed to perform as prescribed within this document.

7.7.2.3 SME incorporating SEV that is used for safety where detectors for the SOCs are provided in accordance with § 7.7.1.

7.7.2.3.1 If the exhaust ventilation rate falls below the levels needed to perform as prescribed within this document, but the detectors for the SOCs do not indicate that SOCs are being released from primary containment and the detectors for the SOCs are installed in such a manner that they will detect a leak when no exhaust ventilation is present, the SME may continue to process the product that it has begun processing. Starting processing of additional product should be precluded, however, until sufficient exhaust flow and pressure are detected. Software may be used to preclude starting processing of additional product.

7.7.2.3.2 If the exhaust ventilation falls below the levels prescribed within this document, and the detectors for the SOCs indicate that SOCs are being released from primary containment, the SME should, through the action of safety interlocks, shut down the flow of chemicals to and within the equipment and any other exhaust-ventilation-related hazard.

NOTE 43: The intent is that the equipment include the sensors for the interlocks and that the interlock signal close the first (in order of process flow) valve in the equipment that can be operated automatically. If the substance of concern is supplied to the equipment through piping, the interlock should also send a signal to the external supply system (e.g., bulk refill system) to stop supplying the substance of concern.

7.7.2.4 Exhaust ventilation monitoring should be capable of detecting the total loss of exhaust ventilation or loss of exhaust ventilation to below the levels that enable the equipment exhaust ventilation to perform the functions described in this safety guideline. Upon detection of such a loss of exhaust ventilation, the equipment should automatically place itself in a safe condition, as described above. (See ¶ 7.7.2.2 and § 7.7.2.3).

NOTE 44: Optional responses may be necessary to align with user and regulatory requirements.

7.7.2.5 Exhaust ventilation monitoring and interlock components should be identified as safety critical parts for the purposes of SEMI S2 assessments.

NOTE 45: SEMI S2 contains criteria for safety critical parts and describes how they are to be considered during assessments.

7.7.2.6 It is recommended that flow sensors, rather than static pressure sensors, be used where volumetric airflow is the characteristic of the exhaust ventilation that controls the risk, such as by dilution of flammable gas.

NOTE 46: Flow sensors are less prone to activation by opening the enclosure and they do activate if the intake is blocked.

7.7.2.7 Where static pressure sensing is used to monitor both pressure and flow, the sensors should detect, and activate interlocks in response to, both excessive and insufficient static pressure.

NOTE 47: If air inlets are obstructed (i.e., airflow is reduced), the sensors will indicate a more negative (higher absolute value) static pressure. If only insufficient static pressure is monitored, the sensor will not activate an interlock when the air inlets are obstructed.

7.7.2.8 Static pressure sensors should be used when static pressure is the characteristic of the exhaust ventilation that controls the risk, such as by preventing emission of a released toxic gas from a SEV enclosure.

7.7.2.9 A single sensor that measures both flow and pressure may be used if both flow and pressure need to be monitored.

7.7.2.10 Static pressure or flow sensors used for safety interlocks should have sufficient performance to detect exhaust ventilation flow rate or static pressure conditions outside the ranges for which the exhaust ventilation has been shown to be effective. The performance characteristics considered should include:

- sensitivity
- accuracy
- repeatability
- hysterisis

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- deadband
- response time

7.7.2.11 Static pressure and flow sensors should measure conditions upstream (i.e., on the equipment side) of dampers.

NOTE 48: Some flow sensing devices require certain duct characteristics (e.g., a straight portion of duct) in order to function. The exhaust ventilation sensing device used as an interlock should be appropriate for the facilitization of the equipment. If a flow sensing device cannot be found to suit the exhaust ventilation configuration, then a static pressure sensing device which detects excessive and insufficient static pressure is recommended.

7.7.2.12 A time delay in triggering shutdown may be included to enable the equipment to continue to operate during transient facility static pressure and flow variations. The devices used to delay the shutdown should conform to the SEMI S2 criteria for safety interlocks.

7.7.2.12.1 This is permissible for PEV and AEV only if testing validates that the delay will not result in exposure above the permissible level or concentration of a flammable gas above 25% of LFL at a potential ignition source.

7.7.2.12.2 This is permissible for SEV only if:

- testing validates that the delay will not result, during a release into secondary containment, in exposure above the permissible level or concentration of a flammable gas above 25% of LFL at a potential ignition source, or
- risk assessment considering the expected severity of the consequences of and frequencies of releases into secondary containment and of inadequate exhaust ventilation and whether there are common causes for these events indicates that the risk presented by the time delay is acceptable.

7.7.3 *Alarms and Remote Signaling*

7.7.3.1 Local (at or within the equipment) visible alarms should be provided for all the SOC detection and exhaust ventilation sensors and monitors. This criterion may be satisfied by the use of alerting devices (e.g., strobes) or by a message displayed on the equipment operation console. The alarms should be located so that the personnel in locations which may present an unacceptable risk of exposure because of the detected condition, are alerted.

7.7.3.2 Local audible alarms should be provided for the detection of the loss or insufficiency of PEV or AEV flow or pressure.

7.7.3.3 Local audible alarms should be provided for the detection of releases from closed processing systems which occur at the same time as the loss or insufficiency of SEV flow or pressure.

7.7.3.4 The equipment should have the capability to provide signals from the SOC detection and exhaust ventilation sensors and monitors to the facility alarm system.

7.7.3.4.1 The signals from SOC detectors should identify the SOC (or type of SOC if the detector detects more than one SOC) and the location in which it is detected. The signal may report the detected concentration. If the signal does not report the detected concentration, then the equipment supplier should include, in the documentation provided to the user, the minimum concentration at which the detector will report. If the minimum concentration to be reported is intended to be adjusted by the user, then the equipment supplier should include instructions for making that adjustment and the highest minimum reporting concentration at which the detector can be set to meet the exposure criteria of SEMI S2.

7.7.3.4.2 The signals from exhaust ventilation sensors and monitors should report the location at which insufficient exhaust is detected. If static pressure and flow are sensed or monitored separately, the signal should report which condition was detected.

7.7.4 *Equipment Responses* — The equipment should shut down the delivery of chemical (e.g., by closing internal valves, stopping internal pumps, and relieving pressure in pressure-driven systems) to the appropriate portion of the primary containment when a release from a closed processing system or inadequate PEV or AEV is detected.

8 Validation Methods and Reporting

8.1 *Purposes of this Section*

8.1.1 The material in § 8 of this document should be used to determine conformance to this document.

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8.1.2 The appropriate validation tests in this section should be used by the equipment supplier or its agent to demonstrate that the exhaust ventilation meets the performance criteria described in § 7 in normal operating conditions, during maintenance tasks, and in the event of failure. The validation tests in this Section should also be used by the equipment supplier or its agent to establish the values of characteristics (e.g., static pressure) that are used to verify that the exhaust ventilation of installed equipment is operating properly.

8.1.3 The validation tests in this Section may be used by others, including users, for the same purposes or for such purposes as validation of the performance of equipment after installation.

8.1.4 If the installation or facility exhaust ventilation services provided by the user's facility are not as specified by the equipment supplier, the validation tests in this Section should be used by the user or its agent to demonstrate that the exhaust ventilation meets the performance criteria described in § 7 in normal operating conditions, during maintenance tasks, and in the event of failure. The validation tests in this Section should also be used (for such installations) by the user or its agent to establish the values of characteristics (e.g., static pressure) that are used to verify that the exhaust ventilation of installed equipment is operating properly.

8.2 *Test Conditions and Locations*

8.2.1 As SEMI S2 has different toxic material exposure criteria for different tasks and states of the equipment, it may be necessary to test the performance of the exhaust ventilation at different release rates against different criteria. For example, it may be necessary to test a wet station with the liquids at the specified operating temperature against the exposure criteria for normal operation and at the maximum temperature under single-fault conditions against the exposure criteria for fault conditions.

8.2.2 Measurements should be performed after equipment components are assembled.

8.2.3 *Hierarchy for Selecting Test Substances*

8.2.3.1 Where feasible, testing should be performed using the intended substances of concern and processes in a representative sample of the equipment.

8.2.3.2 If such testing presents unacceptable risk, testing may be performed as described below, in order of decreasing preferability:

- For gaseous substances of concern, a tracer gas in a representative sample of the equipment at the intended operating conditions, released at a rate determined by engineering analysis of the available gas flow at the point of release. (See Appendix 1.)
- For liquid substances of concern, a substitute liquid, with an evaporation rate at the relevant temperature no less than that of the substance of concern, in a representative sample of the equipment at the intended operating conditions. (See Appendix 1 for the method of determining the evaporation rate.)
- For liquid substances of concern, a tracer gas in a representative sample of the equipment at the intended operating conditions, released at a rate determined using the method described in Appendix 1 for determining the evaporation rate.
- For liquid substances of concern, a tracer gas in a representative sample of the equipment at the intended operating conditions, released at a rate determined using the method described in Appendix 1 for calculating an estimated vapor generation rate from the properties of the substance of concern.

8.2.3.3 Tracer gas fugitive emission testing (see Appendix 2) may be used when instrumentation for the substances of concern does not have adequate sensitivity, or when an instrument is not available for the substances of concern. Tracer gas testing should be used where testing with the substance of concern would present an unacceptable risk (e.g., system failure simulation with potential release of hazardous gas to atmosphere). See Appendix 1 for the means of determining the tracer gas release rate.

8.2.4 *Sampling Time for Measuring Airborne Concentrations* — Sampling for a time period consistent with the OEL, should be performed under operating, maintenance, or simulated failure conditions.

8.2.4.1 For TWAs and STELs, integrated sampling for the OEL exposure period is preferred. Alternatively, continuous sampling for the exposure period may be performed and the average concentration calculated from the data. The average concentration should be compared directly to the performance criteria in § 7 to determine conformance to this document.

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EXCEPTION: If the SME has a process cycle that is less than the exposure period of the TWA, sampling may be performed for a complete process cycle and the average value during the cycle compared to the TWA to determine conformance.

8.2.4.2 For Ceiling and IDLH limits, continuous sampling should be performed for the duration of the task. The highest measured concentration should be compared directly to the performance criteria in § 7 to demonstrate conformance to this document.

NOTE 49: Each OEL is specified for an exposure period. For example, ACGIH specifies Time Weighted Average (TWA) limits for an eight hour exposure period and Short Term Exposure Limits for a fifteen minute exposure period. When comparing measured concentrations to OELs, the measurement period must be consistent with the period specified for the OEL. For example, if an air sample for HCl is taken, an instantaneous air sampling method or a direct reading instrument should be used to determine if there are peak emissions that exceed 25% of the TLV Ceiling level. For chemicals that have time weighted average and short term exposure limits, sampling methods should be selected that will provide data allowing a comparison to those OEL values.

NOTE 50: For substances for which a TWA, but not STEL or Ceiling limit, is specified, it is generally accepted that excursions should be limited to five times the TWA as an instantaneous peak and three times the TWA for a maximum of thirty minutes per shift.

8.2.4.3 Integrated sampling methods may be used when instantaneous sampling methods do not have adequate sensitivity, or are not available for the substance(s) of concern. Where integrated air sampling is used, the sample duration and locations(s) should be representative of the worst-case, realistic, anticipated exposure time and locations.

8.2.4.4 The resulting concentrations are directly compared to the performance criteria in § 7 to demonstrate conformance to this document.

8.2.5 *Identification of Critical Exhaust Ventilation Locations* — The equipment supplier should identify any critical equipment locations for exhaust ventilation, and quantify appropriate exhaust ventilation values for those locations. Measurements should be made to identify optimal exhaust ventilation levels and confirm that safety criteria are being addressed. Multiple validation and measurement methods may be needed.

NOTE 51: Process performance may be affected by exhaust ventilation values.

8.3 *Sampling and Measurement Locations*

8.3.1 The sample location(s) should be representative of the worst-case, realistic breathing zones (where exhaust ventilation is used to protect personnel from exposure) and potential ignition source locations (where exhaust ventilation is used to mitigate fire risk).

NOTE 52: Air or wipe sampling can be used to confirm that substances of concern are not being transported into unintended areas of the equipment.

8.3.2 Equipment users typically use a throttling damper for balancing where the duct for a piece of equipment connects to the rest of the exhaust ventilation system. Pressure and flow measurements should be taken on the equipment side of these balancing dampers.

8.4 *Testing Procedures and Methods*

8.4.1 *Validation of Criteria for Evaluating Ventilation Designs for Pocketing Exhaust Capture*

8.4.1.1 An enclosure containing, or potentially containing, substances of concern can be visually evaluated to determine if there is likely to be good airflow throughout, or if there are likely to be areas of low or no velocity.

NOTE 53: In some cases, a qualified professional will be able to determine, by visual inspection, whether the airflow patterns provide appropriate exhaust ventilation to prevent formation of pockets of unacceptable concentrations of contaminants. In other, more complicated cases, empirical methods (e.g., velocity profiling or aerosol visualization) should be used to make this determination.

8.4.1.2 Computer modeling can be performed to predict exhaust ventilation flow and substance-of-concern transport effectiveness in equipment by solving fluid mechanics conservation of energy and mass equations. Modeling can be used during the equipment design stage or to improve existing equipment. Computer models should be verified experimentally, using one or more of the methods discussed below.

NOTE 54: Computer modeling is a commercially available service.

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8.4.1.3 Velocity profiling within the equipment can be used to confirm expected airflows, capture velocity, the direction of flow, and the velocity at various distances from the exhaust ventilation inlet. It can also be used to verify that there are no locations of poor airflow within the enclosure.

8.4.1.3.1 *Test Method* — Multiple measurements using a velocity measuring device, such as a hot-wire anemometer, are recorded and minima and averages are determined.

8.4.1.3.2 *Aerosol Visualization* — Visible effluent created by equipment such as de-ionized water aerosol generators may be used to observe airflow patterns, the direction of flow, and the effect of distance on capturing contaminants and to verify that there are no areas of stagnation (aerodynamic "dead spots"). Aerosol visualization may also be acceptable for evaluating capture of vapors in open surface tanks, slot ventilation, coater bowls and similar open or partially open systems.

8.4.2 *Validation of Conformance to SEMI S2 Permissible Concentration Criteria*

8.4.2.1 When measuring airborne substances of interest directly, one should measure them using nationally or internationally recognized test methods.

NOTE 55: NIOSH test methods (available at http://www.cdc.gov/niosh/homepage.html) may be used to test for certain toxic materials.

8.4.2.2 Tracer gas fugitive emission testing (see Appendix 2 for the test method) is a means of testing the integrity of enclosures by simulating gas emission and measuring the effectiveness of controls. Testing until there is a failure, and then increasing the exhaust ventilation flow rate until the test is passed can be used to help minimize airflow specifications.

8.5 *Measurements to be Used for Validation of Installed Equipment*

8.5.1 As described elsewhere in this safety guideline, fugitive emission testing is necessary for the design verification. The sufficiency of exhaust ventilation can be verified by measuring volumetric flow (e.g., by use of a hot-wire anemometer) after equipment installation, once the enclosure requirement has been established during design verification.

8.5.2 Once capture has been verified by measurement of fugitive emissions (during design validation), measurements should be taken at specific openings (make-up air slots, accessways, or windows, etc.) to establish the minimum flow velocity at these specific openings while controlling fugitive emissions. Record the position of covers, doors, dampers, valve handle openings, etc., and flow restrictions (such as fluid levels in vessels which exhaust ventilation air serves or through which it flows) at the time of the exhaust ventilation tests so that the test conditions can be duplicated.

NOTE 56: These velocity measurements are necessary to provide a means of verifying exhaust ventilation performance which is more rigorous than simply relying on the equipment exhaust ventilation being set close to the suppliers' specifications at point of connection.

NOTE 57: Care should be exercised to assure that the readings are the result of the exhaust ventilation flow and not general room turbulence. Vapor visualization can help determine if the velocity readings are due to turbulence or if turbulence could adversely affect capture of contaminants.

8.6 *Correction Factors*

8.6.1 Specifications should be stated in Standard Air Density (kg/m3 or lb/ft3), as defined in *Industrial Ventilation*[11]. 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 data must be corrected, by the supplier, to sea level if they were measured above 600 meters elevation.

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

11 ACGIH, *Industrial Ventilation, A Manual of Recommended Practice*. 1330 Kemper Meadow Drive, Cincinnati, OH 45240-1634, USA. http://www.acgih.org; Library of Congress Catalog Card Number: 62-12929.

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

$$M^3/hr = (m^3/hr)(294.3/T_K)(D) \text{ or } CFM = (cfm)(530/T_R)(D)$$

where:

M^3/hr = Standard cubic meters per hour

m^3/hr = Measured cubic meters per hour

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

T_C = Measured temperature in degrees C

D = Altitude density correction factor (see Table 1)

CFM = Standard cubic feet per minute

cfm = Measured cubic feet per minute

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

T_F = Measured temperature in degrees F

Table 1 Density Correction Factors

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

8.6.3.1 Where air temperature is less than 37.8°C (100°F), no correction for humidity is necessary. For temperatures above 37.8°C (100°F), correction for humidity should be made when moisture content is greater than 2% water/dry air. Refer to *Industrial Ventilation, a Manual of Recommended Practice* for further details if necessary to correct for humidity.

NOTE 58: It is not expected that these conditions would exist in a user facility environment.

8.7 *Instruments*

8.7.1 The measuring instruments used should be capable of measurement in the range of interest and in good working condition and current calibration (i.e., calibrated as recently as, and in the manner, specified by the instrument manufacturer).

NOTE 59: The description, operation, maintenance, and limitations of instruments used to measure exhaust ventilation pressure and flow rates is covered in Chapter 9 of *Industrial Ventilation, a Manual of Recommended Practice*. A companion reference is Procedural Standards for Testing Adjusting Balancing of Environmental Systems[12].

8.7.2 The accuracy of the instruments should be included in the test report.

8.8 *Management of Fire Risk*

8.8.1 Testing for 25% of the LFL at potential ignition sources should be conducted using the method described in Appendix 4: Test Method: Air Pattern Assessment for Flammable Sources.

NOTE 60: It is recommended that one begin testing at a minimum airflow sufficient to dilute the flammable gas or vapor to 25% of its LFL at the enclosure outlet.

12 National Environmental Balancing Bureau, 1385 Piccard Drive, Rockville, MD 20850-4340

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8.8.2 The following hierarchy should be used for testing and validating that airborne concentrations of flammable materials are below 25% of the LFL.

8.8.2.1 Direct reading instruments are the preferred method for measuring flammable gases/vapors when they allow measurements at the potential sources of ignition.

8.8.2.2 Where direct reading instruments are not available for the substances of concern in question or do not allow measurements to be taken at the potential source of ignition, tracer gas analysis is an acceptable method.

8.8.2.2.1 An equivalent release rate and velocity should be determined (see Appendix 1).

8.8.2.2.2 The tracer gas should be released at potential leak points.

8.8.2.2.3 The samples should be collected at the potential sources of ignition.

8.8.2.2.4 The results should be reported in terms of percent LFL of the substance of concern in question.

NOTE 61: In the absence of such tests or if adequate reduction of flammable gas cannot be achieved, special electrical designs or other controls (e.g., LFL detectors, approved purging) may be required to reduce the probability of ignition. Removal of potential ignition sources is a means of reducing the exhaust ventilation requirement.

NOTE 62: If there is doubt about whether exhaust ventilation achieves reduction to below 25% of the LFL, gas or vapor; monitoring can be installed and interlocked to shut off either the potential ignition sources or the source of fuel. Removal of fuel sources is a means of reducing the exhaust ventilation requirement.

NOTE 63: Some jurisdictions require a monitoring point in the duct set at 10% LFL; this should not be confused with the criterion in this document for less than 25% near potential ignition sources.

8.9 Efficiency and optimization should be assessed by comparing the measured volumetric airflows to the criteria in § 7.

8.10 Testing of AEV should be conducted to verify that the concentrations of the substances of concern meet the criteria stated elsewhere in this safety guideline.

8.10.1 Measurement of capture velocity should be taken at the furthest point of contaminant release from the point of contaminant capture (e.g., face of the hood or exhaust ventilation duct opening). Measurements should be taken with an anemometer.

NOTE 64: Confirmation of capture may be made using aerosol visualization methods. The observed performance may depend on the airflow conditions in the room in which this is performed.

8.11 *Equipment Test Validation Reporting* — Equipment exhaust ventilation testing performed to determine conformance to the exhaust ventilation criteria in SEMI S2, should be reported as specified below:

8.11.1 All test measurements should be performed based on the test methods specified in this section and in the appendices.

8.11.2 Each result measured during the test should be provided with its tolerance.

8.11.3 *Equipment Information* — Describe the unit being tested by equipment supplier, model number, and serial number to provide identification.

8.11.4 *Equipment Configuration* — Describe the configuration of the equipment including the size and placement of air intakes, doors, panels, outlets, and factors affecting exhaust ventilation flow. Descriptions may include photographs or drawings when they help the reader visualize the equipment configuration.

8.11.5 *Equipment Process Recipe and Hazard Information* — Provide the process chemical name, supply concentration, maximum flow rate (both available at potential leak points and required for anticipated processes), LFL, and OEL for each substance of concern used within each enclosure being tested.

8.11.6 *Exhaust Ventilation Test Method and Equipment Condition Information*

8.11.6.1 Provide date, location of testing, and persons performing test.

8.11.6.2 Describe test methods.

8.11.6.3 Provide reference to recognized test methods used.

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8.11.6.4 Identify test equipment used and the date last calibrated.

8.11.6.5 Where sample media or tracer gas are used, identify expiration dates, calibration status, unique identifiers such as lot numbers, and any other pertinent information.

8.11.6.6 Describe any deviations from recognized test methods.

8.11.6.7 Describe test conditions affecting results.

8.11.6.8 Describe test location environmental conditions that may affect results (temperature, humidity, altitude, room airflow).

8.11.6.9 Describe the exhaust ventilation operating conditions during each test.

8.11.6.10 For fugitive emission testing, describe air velocity outside the enclosure between the sample point and the enclosure surface, air velocity at the sample point, the location of sample point(s).

8.11.6.11 Describe all test points.

8.11.6.12 Identify location of exhaust ventilation flow measurements and measurement method used (e.g., pitot tube, manometer, thermal anemometer).

8.11.7 *Exhaust Ventilation Test Results and Conclusions* — Present all results and clearly identify pass or fail status and the criteria used to determine status.

9 Minimum Information to be Provided to End User

9.1 The material in § 9 of this document should be used to determine conformance to this document.

9.2 *Equipment Exhaust Ventilation Specifications and Measurements* — The following exhaust ventilation specifications and information should be provided by the supplier in the documentation provided to the evaluator and to the end user.

9.3 *Description of the Basis for Exhaust Ventilation Design*

9.3.1 The documentation should describe the release rates for the substances of concern that were used as the basis of ventilation design. The description should include the engineering controls on which the designer relied for flow limitation (see § 7.2).

9.4 *Actions that Ensure that Equipment is in a Safe Condition*

9.4.1 Describe all automatic actions the equipment takes to ensure it is in a safe condition upon loss of exhaust ventilation.

9.4.2 If the equipment can be configured to take different actions upon loss of exhaust ventilation, describe how to determine which actions are appropriate for the installation and use of the equipment and how to configure the equipment to take those actions.

9.4.3 Describe the appropriate responses by personnel to the equipment having placed itself in a safe condition, including how to reset the equipment when exhaust ventilation is restored.

9.4.4 Identify appropriate actions, if any, to be performed by personnel in the event of extended facility exhaust ventilation failure (e.g., power failure greater than 15 minutes) to ensure protection of people and prevent damage to equipment and facilities.

9.5 *Information that Describes the Effluent*

9.5.1 The supplier should provide the user with a list of process chemicals or by-products that could be expected in the exhaust ventilation stream when the equipment and the users' exhaust ventilation system are operating within design specifications. This may be estimated by stoichiometric or mass-balance calculations, or based on the results of exhaust ventilation emission characterization testing based on the appropriate conformance criteria in SEMI S2. Information typically provided includes percentage (by weight or volume) and physical state (gas, liquid or solid).

NOTE 65: SEMI F5 provides information regarding effluent treatment.

9.5.2 The normal operating and maximum and minimum temperatures of the exhaust ventilation stream when it enters the facility exhaust ventilation system should be documented for the equipment supplier's baseline processes.

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