SEMI S30-0824
SAFETY GUIDELINE FOR USE OF ENERGETIC MATERIALS IN SEMICONDUCTOR R&D AND MANUFACTURING PROCESSES

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NOTICE: Conformance to the 'should' provisions of this Safety 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.

NOTICE: The section symbol (§) is used to reference a numbered section, paragraph, or header and all subordinate paragraphs, headers, and embedded material (i.e., EXCEPTIONs, lists) therein. The paragraph symbol (¶) is used to reference a particular numbered paragraph and embedded material therein. When duplicated (i.e., §§ and ¶¶) the symbols are used to reference more than one section or paragraph, respectively.

NOTICE: Paragraphs entitled 'NOTE:' are not an official part of this Standard or Safety Guideline and are not intended to modify or supersede the official Standard or Safety Guideline. These have been supplied by the global technical committee to enhance the usage of the Standard or Safety Guideline.

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1 Purpose

1.1 This Safety Guideline is intended as a minimum set of safety criteria for the procurement, storage, handling, and use of energetic materials in semiconductor research and development (R&D) and manufacturing processes in all phases of use, from process chemical supply through abatement.

1.2 This Safety Guideline is intended to be industry best practices as of its publication date.

2 Scope

2.1 The scope of this Safety Guideline is energetic materials, as defined in ¶ 5.2.19 and the equipment which contains them.

2.2 This Safety Guideline specifies the testing and criteria for determining whether a material is an 'energetic material' in the context of this Safety Guideline.

2.3 This Safety Guideline also describes the minimum characterization data to be provided in research and development, pilot-line, or high-volume semiconductor manufacturing equipment.

2.4 This Safety Guideline provides safety design criteria for process chemical supply, process, and post-process equipment for semiconductor processes using energetic materials.

2.5 This Safety Guideline provides industry-specific criteria, and refers to some of the many international codes, regulations, standards, and specifications that should be considered when designing semiconductor manufacturing equipment.

NOTICE: SEMI Standards and Safety Guidelines do not purport to address all safety issues associated with their use. It is the responsibility of the users of the Documents 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 is intended for use by suppliers and users as a reference for environmental, health, and safety (EHS) considerations. It is not intended to be used to verify compliance with regulatory requirements.

3.2 It is not the philosophy of this Safety Guideline to provide all of the EHS design criteria that may be applied to semiconductor manufacturing equipment.

3.3 This Safety Guideline was developed as a supplement, primarily addressing energetic material reaction risks, to other SEMI Standards Documents. The reader should consult those documents, including SEMI S2 and SEMI S6, for guidance for managing the safety, health, and other risks associated with energetic materials.

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

3.5 This Safety Guideline is not intended to apply to facilities or operations of energetic material manufacturers or distributors, or to the transportation of energetic materials beyond the boundary of any facility.

3.6 Materials within the Scope of SEMI S18 are not subject to this Safety Guideline, regardless of whether they conform to the definition of 'energetic materials'.

3.7 Aqueous process chemicals and their aqueous byproducts are not within the scope of this Safety Guideline.

NOTE 1: This Safety Guideline, especially § 16, was developed for closed process equipment, such as metal organic chemical vapor deposition (MOCVD), atomic layer deposition (ALD), and epitaxy equipment. Some of the risk controls may be applicable to open process equipment, such as aqueous cleaning equipment that uses energetic process chemicals or generate energetic byproducts, but the criteria of this Safety Guideline are not directly applicable to open process equipment.

4 Referenced Standards and Documents

4.1 *SEMI Standards and Safety Guidelines*

SEMI F66 — Specification for Port Marking and Symbol of Stainless Steel Vessels for Liquid Chemicals

SEMI F96 — Specification for Port Configuration on Canisters to Contain Liquid CVD Precursors

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SEMI S1 — Safety Guideline for Equipment Safety Labels

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

SEMI S3 — Safety Guideline for Process Liquid Heating Systems

SEMI S6 — Environmental, Health, and Safety Guideline for Exhaust Ventilation of Semiconductor Manufacturing Equipment

SEMI S7 — Safety Guideline for Evaluation of Personnel and Evaluating Company Qualifications

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

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

SEMI S12 — Environmental, Health, and Safety Guideline for Manufacturing Equipment Decontamination

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

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

SEMI S18 — Environmental, Health, and Safety Guideline for Flammable Silicon Compounds

4.2 *ASTM® Standards*[1]

ASTM F739 — Standard Test Method for Permeation of Liquids and Gasses through Protective Clothing Materials under Conditions of Continuous Contact

ASTM F903-10 — Standard Test Method for Resistance of Materials Used in Protective Clothing to Penetration by Liquids

ASTM F2302-08 — Standard Performance Specification for Heat and Flame Resistant Clothing

4.3 *NFPA® Standards*[2]

NFPA 55-2016 — Compressed Gases and Cryogenic Fluids Code

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

4.4 *Other Documents*

FM Global® Property Loss Prevention Data Sheet 7-59 — Inerting and Purging of Tanks, Process Vessels, and Equipment[3]

International Fire Code®[4]

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

5 Terminology

5.1 *Abbreviations and Acronyms*

5.1.1 *ATL* — accredited testing laboratory

5.1.2 *EHS* — environmental, health, and safety

5.1.3 *EMO* — emergency off

5.1.4 *GHS* — Globally Harmonized System of Classification and Labeling of Chemicals

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[1] ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959, USA; Telephone: +1.610.832.9585, Fax: +1.610.832.9555, http://www.astm.org. ASTM trademark is owned by ASTM International.

[2] National Fire Protection Agency, 1 Batterymarch Park, Quincy, MA 02269, USA; Telephone: +1.617.770.3000, Fax: +1.617.770.0700, http://www.nfpa.org. National Fire Protection Association trademark is owned by the National Fire Protection Association.

[3] FM Global, Corporate Headquarters, 270 Central Avenue, Johnston, Rhode Island 02919-4949, USA; Phone: +1.401.275.3000, Fax: +1.401.275.3029, https://www.fmglobal.com. FM Global trademark is owned by Factory Mutual Insurance Company.

[4] International Fire Code trademark is owned by International Code Council.

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5.1.5 *HSSD* — high sensitivity smoke detector

5.1.6 *PPE* — personal protective equipment

5.1.7 *R&D* — research and development

5.1.8 *SDS* — safety data sheet

5.2 *Definitions*

5.2.1 *abatement equipment* — equipment used to modify the effluent from a process in order to reduce emissions of hazardous materials.

5.2.2 *accelerating rate calorimetry (ARC)* — an analytical technique in which the temperature and pressure changes of a sample are measured adiabatically as the temperature is raised at a controlled rate.

5.2.3 *acceptable risk* — a risk of Low or Very Low, as defined by SEMI S10 or SEMI S14.

5.2.4 *accredited testing laboratory (ATL)* — an independent organization dedicated to the testing of components, devices or systems; that is recognized by a governmental or regulatory body as competent to perform evaluations based on established safety standards. [SEMI S2]

5.2.5 *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. [SEMI S18]

5.2.6 *administrative control* — a modification or restriction of the way in which a task is performed that is not realized through characteristics of equipment, other than labels and other instructions.

NOTE 2: The effectiveness of administrative controls depends on the actual conformance of personnel to the specified work practices as well as on the work practices themselves.

5.2.7 *aqueous* — comprised of water or materials dissolved or suspended in water.

5.2.8 *autoignition temperature (AIT)* — the temperature at which a solid in contact with air, or a liquid or gas (including a vapor) mixed with air, ignites without contacting a surface of higher temperature or there being an explicit source of ignition, such as a spark or flame. [SEMI S3]

5.2.9 *baseline* — the operating conditions, including process chemistry, for which the equipment was designed and manufactured.

5.2.10 *byproduct* — a material, other than the material the process is intended to produce, that is formed during operation, maintenance, or service.

5.2.11 *cleanroom* — a room in which the concentration of airborne particles is controlled to specific limits. [SEMI S2]

5.2.12 *closed process 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. [SEMI S6]

5.2.13 *combustible material* — a combustible material is any material that does propagate flame (beyond the ignition zone with or without the continued application of the ignition source) and does not meet the definition in this section for non-combustible material. See also the definition for non-combustible material. [SEMI S2]

5.2.14 *control of hazardous energy* — the practice by which personnel are protected from unexpected starting and release of hazardous energy during maintenance and service.

NOTE 3: Control of hazardous energy is addressed in § 19.

5.2.15 *de-energization (for an energetic material)* — the removal or conversion of residual energetic process chemicals or energetic byproducts so that acceptable risk is achieved. This could include a 'bake-out' step of the lines or intentionally introducing small amounts of a material that will cause a controlled reaction in order to mitigate the risks when the lines or components are opened.

5.2.16 *degradation (of PPE)* — mechanism of deterioration of a material due to chemical reaction with a substance.

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5.2.17 *differential scanning calorimetry (DSC)* — analytical technique in which the heat flow in or out of a sample is measured as the temperature is raised at a controlled rate.

5.2.18 *energetic byproduct* — a byproduct found, by evaluation in accordance with Figure 1, to be 'energetic'.

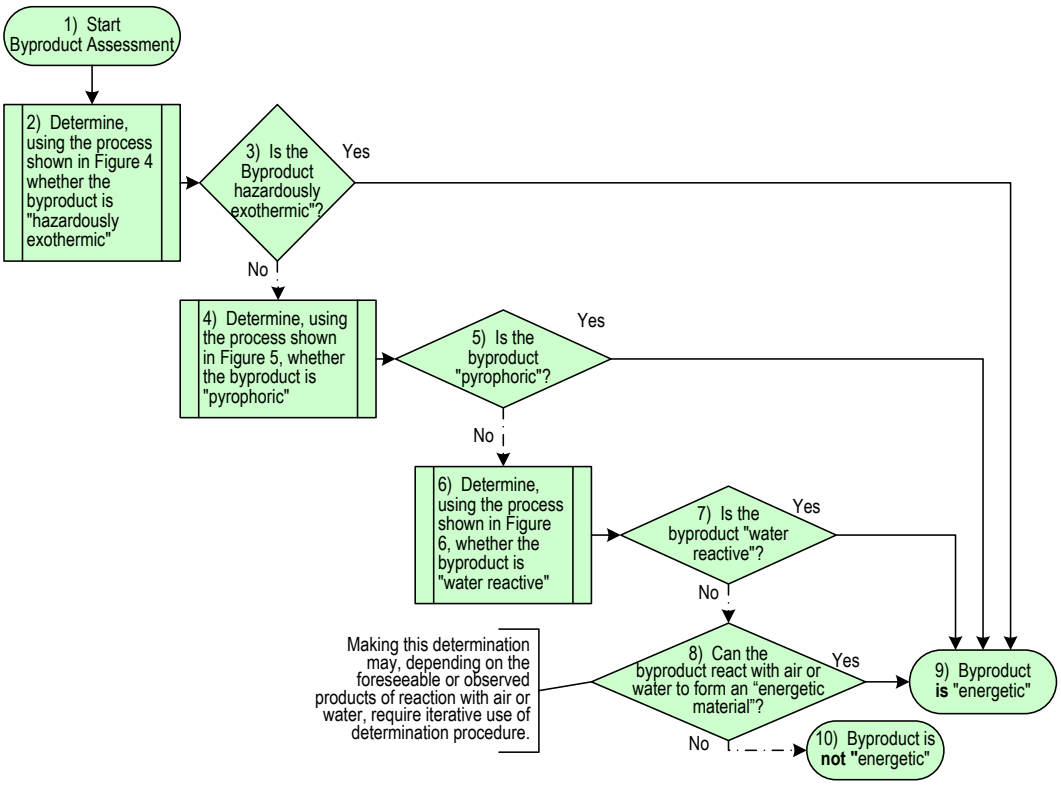

Figure 1
Determination Whether a Byproduct is Energetic

5.2.19 *energetic material* — a material that is either an energetic process chemical or an energetic byproduct.

5.2.20 *energetic material precursor* — a chemical or chemicals that are foreseen to be transformed into an energetic material.

5.2.21 *energetic materials container* — an assembly consisting of at least:

1. a vessel in which a material is stored and may be transported and from which it may be transferred to another container or to equipment,
2. fittings for fluid connections, and
3. one or more valves permitting isolation of each of its connections.

An energetic materials container may include additional valves, means of purging, or sensors (refer to § 11).

NOTE 4: There are many configurations that conform to this definition; Figure 2 contains examples of energetic materials containers that conform to the criteria of this Safety Guideline.

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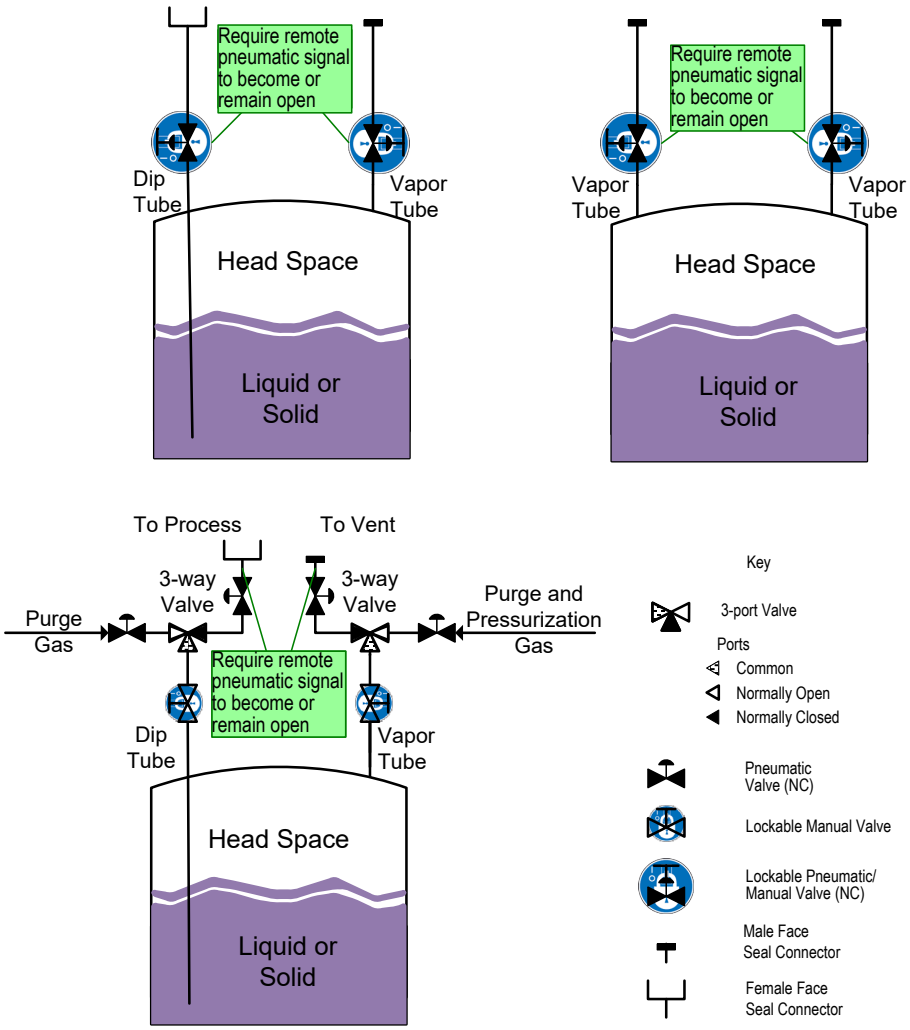

Figure 2
Examples of Energetic Materials Containers

NOTE 5: Energetic materials containers are also called: ‘canisters’, ‘cylinders’, ‘drums’, ‘tanks’, and ‘ampoules’. ‘Ampoule’ is traditionally used to refer to energetic materials containers inside process equipment.

NOTE 6: For some of the energetic materials containers within the scope of this Safety Guideline, SEMI F96 specifies the connectors and port locations, and SEMI F66 specifies the port marking.

5.2.22 *energetic materials path* — the places through which energetic materials pass or in which they are stored, accumulated, or used. This includes energetic process chemical containers, piping, process chambers, exhaust lines, vacuum pumps, and abatement equipment.

5.2.23 *energetic process chemical* — a process chemical found, by evaluation in accordance with Figure 3, to be ‘energetic’.

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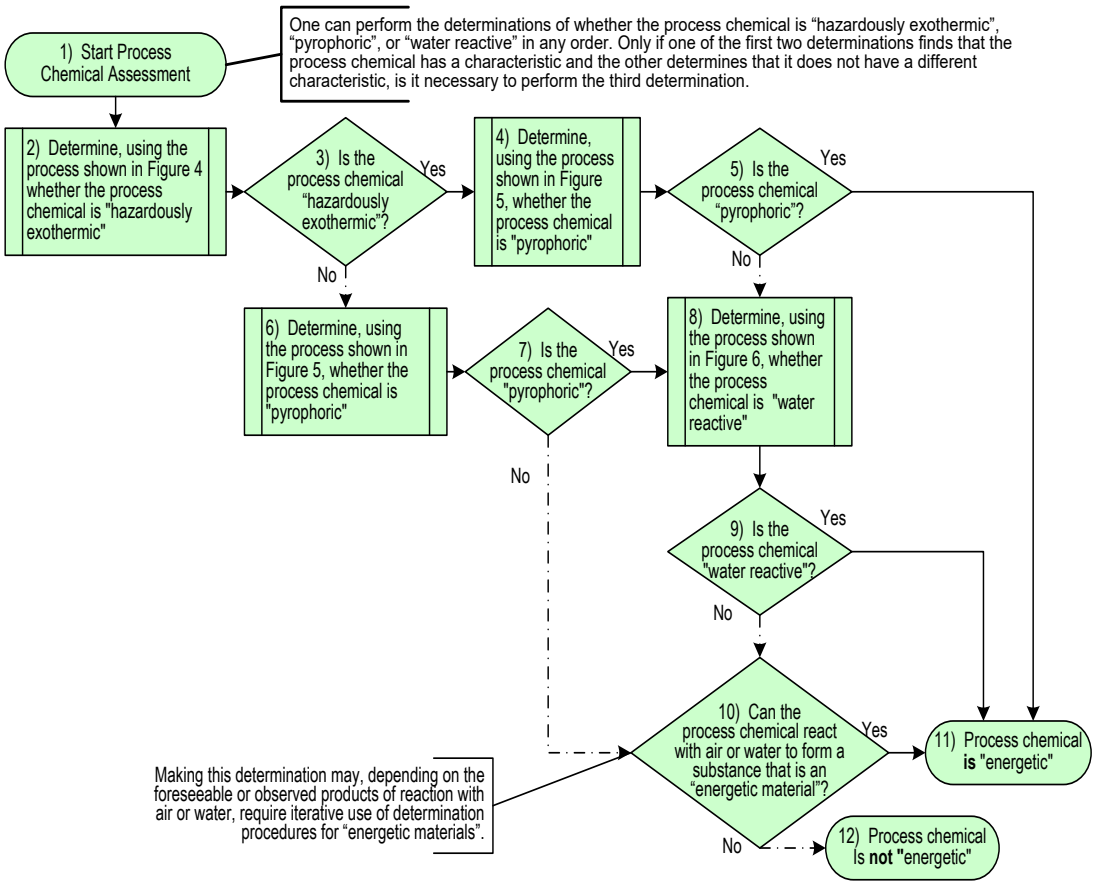

Figure 3
Determination Whether a Process Chemical is Energetic

5.2.24 *energetic process chemical supplier* — party that provides one or more energetic process chemicals directly to another party. An energetic process chemical supplier may be a manufacturer, a distributor, or a representative.

5.2.25 *engineering control* — a method to eliminate or mitigate a hazard through equipment design.

NOTE 7: The effectiveness of engineering controls is less dependent on conformance to the specified work practices than is the effectiveness of an administrative control.

5.2.26 *equipment* — a specific piece of machinery, apparatus, process module, or device used to execute an operation. The term 'equipment' does not apply to any product (e.g., substrates, semiconductors) that may be damaged as a result of equipment failure. [SEMI S2]

5.2.27 *equipment supplier* — party who provides equipment to and communicates directly with the user. An equipment supplier may be a manufacturer, an equipment distributor, or an equipment representative. [SEMI S24]

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

5.2.29 *flammable liquid* — a liquid having a flash point below 37.8°C (100°F). [SEMI S2]

5.2.30 *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. [SEMI S2]

5.2.31 *flow limiting device* — a device that will reduce maximum flow rate under full flow conditions. [SEMI S5]

5.2.32 *foreline* — vacuum line leading from process chamber to vacuum pump inlet.

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5.2.33 *harm* — physical injury or damage to health of people, or damage to equipment or environment.

5.2.34 *hazard* — condition that has the potential to cause harm. [SEMI S2]

5.2.35 *hazardous production material (HPM)* — a solid, liquid, or gas associated with semiconductor manufacturing that has a degree-of-hazard rating of 3 or 4 in health, flammability, instability, or water reactivity in accordance with NFPA 704 and that is used directly in research, laboratory, or production processes that have as their end product materials that are not hazardous (NFPA 1-2015, Fire Code).

5.2.36 *hazardously exothermic, adj.* — found, by evaluation in accordance with Figure 4, to be 'hazardously exothermic'.

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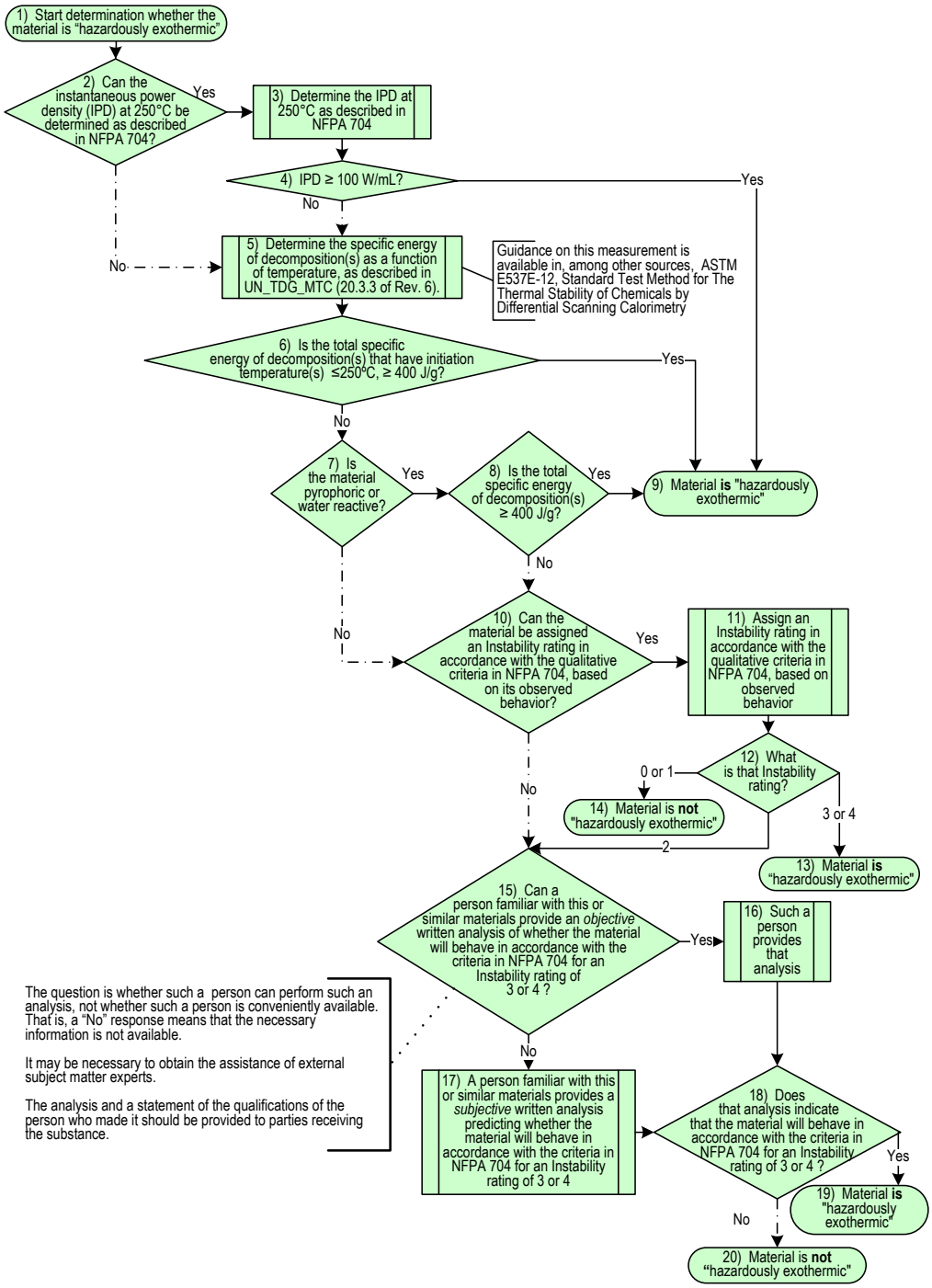

Figure 4
Determination whether a Material is Hazardously Exothermic

NOTE 8: Block 15 in Figure 4 is provided to allow completion of the determination process for materials that have not been fully characterized. This is foreseen to be necessary for new materials, such as those recently developed and intended to be used for R&D.

5.2.37 *hood* — a shaped inlet designed to capture contaminated air and conduct it into an exhaust duct system. [SEMI S2]

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5.2.38 *incompatible* — as applied to materials, describes materials that, when combined, may react violently or in an uncontrolled manner, releasing hazardous materials or energy that may create a hazardous condition.

5.2.39 *instantaneous power density (IPD)* — the rate at which energy is released by the self-reaction of a unit volume of a material. It is the product of the enthalpy of self-reaction and the self-reaction rate.

5.2.40 *interlock* — a mechanical, electrical, or other type of device or system, the purpose of which is to prevent or interrupt the operation of specified machine elements under specified conditions. [SEMI S3]

5.2.41 *likelihood* — the expected frequency with which harm will occur. Usually expressed as a rate (e.g., events per year, per product, or per substrate processed). [SEMI S2]

5.2.42 *local exhaust ventilation* — local exhaust ventilation systems operate on the principle of capturing a contaminant at or near its source and moving the contaminant to the external environment, usually through an air cleaning or a destructive device. It is not to be confused with laminar flow ventilation. Synonyms: LEV, local exhaust, main exhaust, extraction system, module exhaust, individual exhaust. [SEMI S2]

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

5.2.44 *mass balance* — a qualitative, and where possible, quantitative, specification of mass flow of input and output streams (including chemicals, gases, water, de-ionized water, compressed air, nitrogen, and byproducts), in sufficient detail to determine the effluent characteristics and potential treatment options. [SEMI S2]

5.2.45 *material* — a solid, liquid, or gas or a combination of two or more of them. This includes solutions, mixtures, and colloids.

5.2.46 *non-combustible material* — a material that, in the form in which it is used and under the conditions anticipated, will not ignite, burn, support combustion, or release flammable vapors when subjected to fire or heat. Typical non-combustible materials are metals, ceramics, and silica materials (e.g., glass and quartz). See also the definition for combustible material. [SEMI S2]

5.2.47 *open process 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. [SEMI S6]

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

5.2.49 *penetration (of PPE)* — movement of a chemical through pores or imperfections in a material or an item without a change of state. Chemical penetration can occur through voids and imperfections in closures, seams, interfaces and materials.

NOTE 9: Penetration does not require a change of state; solid chemicals move through voids in the materials as solids, liquids as liquids and gases as gases. Penetration is a distinctly different mechanism from permeation.

5.2.50 *permeation (of PPE)* — movement of chemicals through materials or items without passing through voids or imperfections. Permeation includes:

- absorption into the contact surface,
- diffusion of the absorbed molecules through the material or item, and
- desorption from the opposite surface.

5.2.51 *personal protective equipment (PPE)* — equipment and clothing worn to reduce potential for personal injury from hazards associated with the task to be performed (e.g., chemical gloves, respirators, safety glasses, etc.). In the context of this Document, cleanroom attire (e.g., gloves, smocks, booties, hoods) is not considered personal protective equipment. [SEMI S8]

5.2.52 *primary exhaust ventilation (PEV)* — airflow that, in normal operation, extracts substances of concern from the equipment. [SEMI S6]

5.2.53 *process chemical* — a material that participates in a chemical or physical reaction on the surface of a substrate as part of a manufacturing process.

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5.2.54 *process equipment* — equipment in which a wafer or other substrate is deliberately altered, such as by the addition, modification, or removal of material.

5.2.55 *purge (v)* — use a nonreactive fluid to remove air, process chemicals, byproducts, or other materials from fluid handling components. The fluid is one that neither reacts undesirably with any material foreseen to be in the components nor contaminates the components.

5.2.56 *pyrophoric, adj.* — found, by evaluation in accordance with Figure 5, to be 'pyrophoric'.

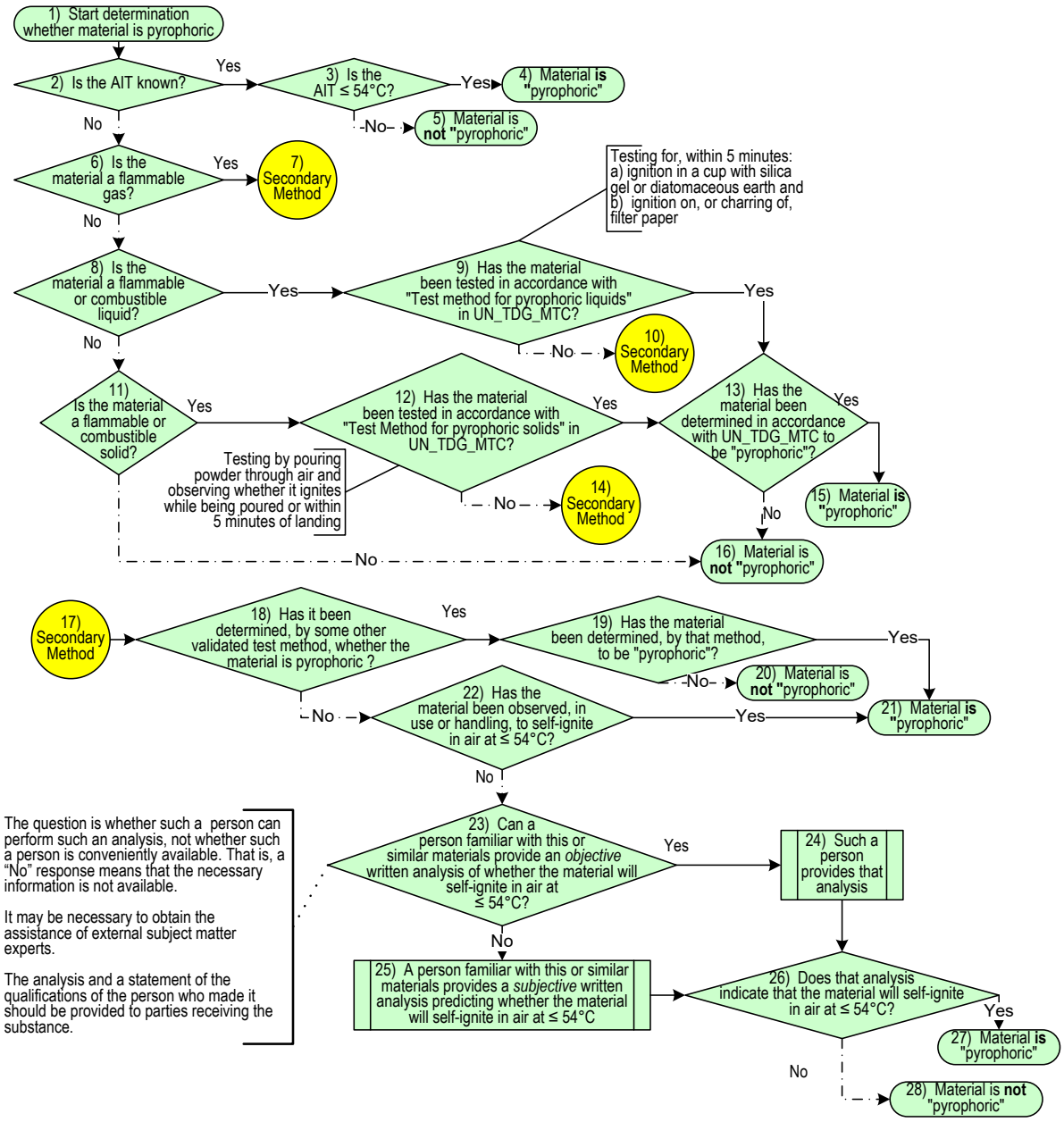

Figure 5
Determination Whether a Material is Pyrophoric

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NOTE 10: Block 23 in Figure 5 is provided to allow completion of the determination process for materials that have not been fully characterized. This is foreseen to be necessary for new materials, such as those recently developed and intended to be used for R&D.

NOTE 11: Globally Harmonized System of Classification and Labeling of Chemicals (GHS) defines a pyrophoric liquid as a liquid that ignites within 5 min. when added to an inert carrier and exposed to air, or it ignites or that chars a filter paper on contact with air within 5 min. GHS defines a pyrophoric solid as a solid that ignites within 5 min. when added to an inert carrier and exposed to air. The OSHA® [5] Hazard Communication Standard defines pyrophoric gas as a material in the gaseous state that will ignite spontaneously in air at a temperature of 130°F (54.4°C) or below. GHS does not address pyrophoric gases. Neither the GHS nor OSHA definition is used in this Safety Guideline; they are provided here only for convenience.

5.2.57 *remote* — not integral to process equipment.

5.2.58 *remote liquid delivery equipment* — equipment that includes a liquid material (such as a compound that is liquid at the relevant temperature, a mixture of liquids, or a solution of solid in solvent) in a storage energetic materials container and transfers it from the storage energetic materials container to a point-of-use energetic materials container. A motive force is applied to the liquid to allow the location of the storage energetic materials container to be far from the point of use energetic materials container. This does not include equipment that is within, or adjacent to, process equipment.

5.2.59 *risk* — the expected magnitude of losses from a hazard, expressed in terms of severity and likelihood. [SEMI S2]

5.2.60 *safe state* — a condition in which the equipment does not present any unacceptable risk to itself or to personnel. It does not allow hazardous production materials to flow. An acceptable safe state is determined by the designer of the equipment and is based on the risks in the design. [SEMI S18]

5.2.61 *safety critical part* — discrete device or component, the failure of which is, or could result in, unacceptable risk. This includes some devices or components that convey or contain hazardous energy or hazardous materials or are parts of safety interlocks.

NOTE 12: Whether a part is a safety critical part depends on its use and the consequences of its failure, not on whether a particular part is suitable for that use.

5.2.62 *safety data sheet (SDS)* — document that describes a material's properties and hazards and provides appropriate safety precautions and protective measures for handling, storing, and transporting it.

NOTE 13: The specific requirements are stated in regulations. In most jurisdictions of interest, the regulations are consistent with the UN Globally Harmonized System of Classification and Labeling of Chemicals (GHS). GHS is available at http://www.unece.org/trans/danger/publi/ghs/ghs_welcome_e.html

NOTE 14: 'Safety data sheet' has replaced the term 'materials safety data sheet'.

5.2.63 *salvage pressure receptacle* — a pressure receptacle with a water capacity not exceeding 1000 liters into which are placed damaged, defective, leaking, or nonconforming pressure receptacle(s) for the purpose of transport, for example, for recovery or disposal.

5.2.64 *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. [SEMI S6]

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

5.2.66 *severity* — the extent of potential credible harm. [SEMI S2]

5.2.67 *supplier* — an equipment supplier or an energetic process chemical supplier.

5.2.68 *tertiary exhaust ventilation (TEV)* — airflow, outside enclosures that have secondary exhaust ventilation, that operates continuously to extract substances of concern should they be released from their secondary containment due to failure or to maintenance or service operations.

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

[5] OHSA trademark is owned by Occupational Safety and Health Administration.

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5.2.70 *transfill* — fill a container by transferring a material to it from another container.

5.2.71 *unacceptable risk* — a risk of Medium, High, or Very High as defined by SEMI S10 or SEMI S14. [SEMI S18]

5.2.72 *user* — party that acquires equipment for the purpose of using it to manufacture semiconductors. See also the definition for supplier. [SEMI S2]

5.2.73 *vacuum pump exhaust line* — piping leading from vacuum pump outlet to an abatement device inlet, bypass connection or facility exhaust.

5.2.74 *vapor delivery equipment* — equipment that includes a container of liquid or solid material and transfers it as a gas from the container to the point of use. The motive force may be a result of the material's vapor pressure (which can be controlled by heating and cooling) or via a matrix (also known as carrier) gas. The vapor delivery equipment may be close to or far from the point of use.

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5.2.75 *water reactive, adj.* — found, by evaluation in accordance with Figure 6, to be ‘water reactive’.

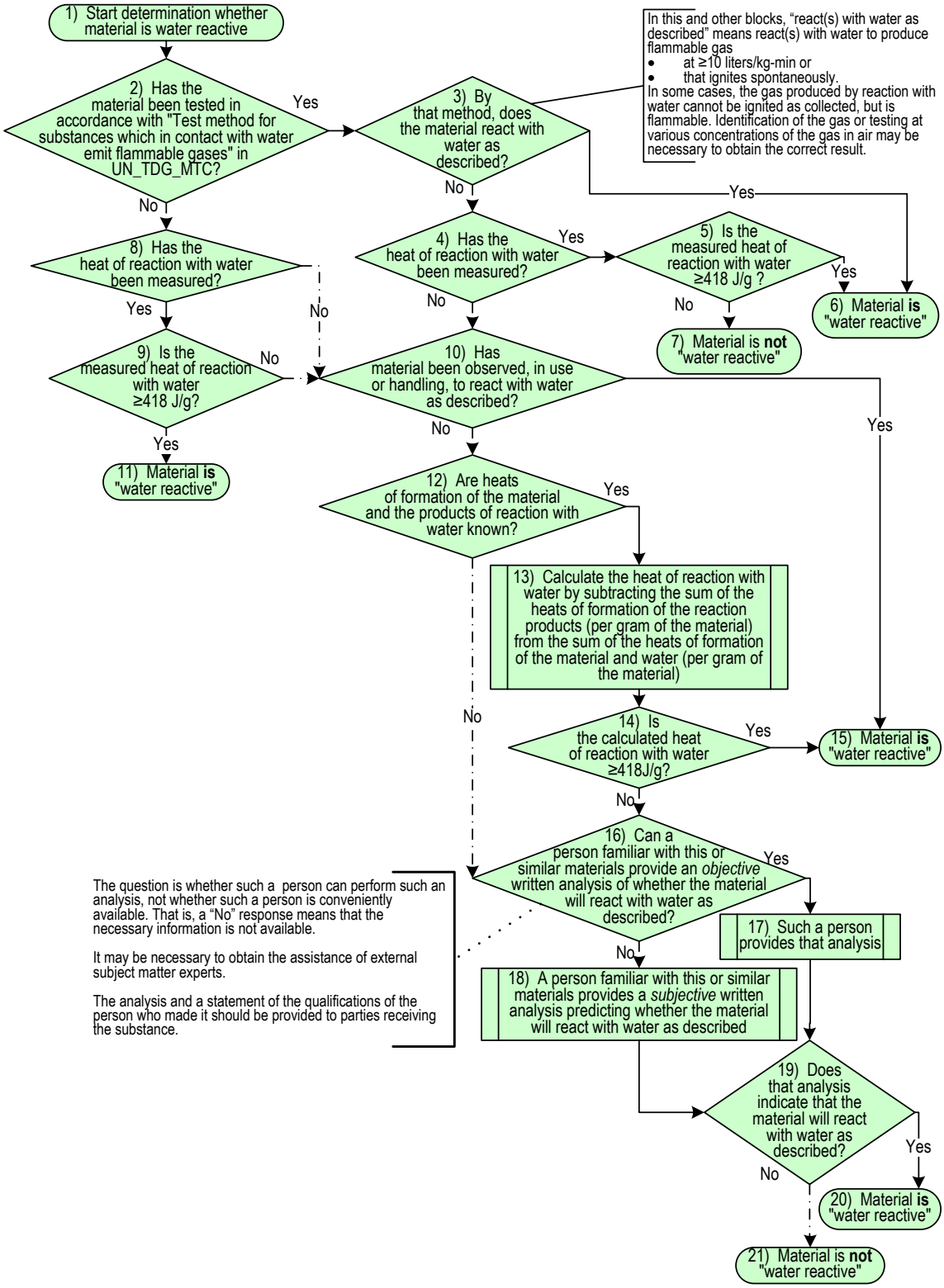

Figure 6
Determination Whether a Material is Water Reactive

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NOTE 15: Block 16 in Figure 6 is provided to allow completion of the determination process for materials that have not been fully characterized. This is foreseen to be necessary for new materials, such as those recently developed and intended to be used for R&D.

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. [SEMI S6]

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. For example, § 9.2 refers to ¶¶ 9.2, 9.2.1, 9.2.2, 9.2.3, and 9.2.4. When duplicated (i.e., §§), it refers to more than one section or subsection. [SEMI S6]

6 Safety Philosophy

6.1 A primary objective of this Safety Guideline is to eliminate hazards or control risks that accompany the use of energetic materials during R&D and manufacturing processes. As such, energetic materials should be used:

6.1.1 under conditions which will maintain the customary levels of employee safety, potential for fire or explosion, impact on the environment, and negative facility-related events, such as business interruption due to contamination and

6.1.2 such that the quantity of any energetic material that could leak, be transferred to, or is within the equipment is limited to the smallest amount necessary for effective production.

6.2 In order to meet this objective, equipment and energetic process chemical suppliers and users should ensure that:

6.2.1 The order of precedence for managing identified risks is as follows:

1. Design to eliminate hazards
2. Use of the safest materials suitable to the application
3. Incorporate safety devices
4. Provide warning devices
5. Provide hazard alerts
6. Develop administrative procedures and training
7. Use of personal protective equipment (PPE)

A combination of these approaches may be needed.

6.2.2 Designs meet:

- Regulatory requirements
- Industry standards
- This Safety Guideline
- Good engineering and manufacturing practices

6.2.3 A risk assessment (refer to § 9) is performed to identify and evaluate risks. The risk assessment should be initiated both early in the equipment design phase as part of the module SEMI S2 evaluation and in the overall equipment (supply module, process equipment, waste treatment equipment) integration phase. The latter, integrated risk assessment should include appropriate representatives from the material delivery equipment, process equipment, vacuum pump and abatement equipment suppliers and be updated as the design matures.

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6.2.4 Users validate the safe installation of research, pilot line and high volume manufacturing equipment to ensure applicable EHS regulations and best industry practices are satisfied prior to equipment start-up.

6.2.5 Users maintain a management of change (MoC) program for all equipment, recipe, or chemistry changes related to energetic process chemicals or that could generate energetic byproducts for both R&D and high volume manufacturing activities. That program should include guidance on how to evaluate such changes.

7 Evaluation Reporting

7.1 This section is provided to define what is expected in the evaluation reports for the different types of equipment that are addressed or included within this Safety Guideline.

7.1.1 Some of the criteria in this Document apply to the user and are unlikely to be included in any report that is shared among different organizations.

7.1.2 Other information is not related to equipment and is more likely to be used to communicate expectations clearly or to be included in purchase specifications (e.g., for the chemical suppliers).

7.2 The different types of equipment to which this Safety Guideline is expected to be applied are:

NOTE 16: If multiple portions of the equipment are provided by a single equipment supplier, they are responsible to provide report(s) that address all of these modules.

7.2.1 Remote Vapor Delivery Equipment and Remote Liquid Delivery Equipment

7.2.2 Process Equipment

7.2.3 Vacuum Pump Equipment

7.2.4 Abatement Equipment

7.3 *General* — The evaluating party should evaluate the equipment and related end user documentation according to this Safety Guideline and create a written evaluation report (refer to ¶ 7.6).

7.4 *Evaluation Report Contents: General* — The evaluation report should include the sections of this Safety Guideline that apply to the equipment module under consideration as indicated in § 7.5. The Appendix should be used in the evaluation, and referenced in the report, only as it pertains to the specific application.

7.4.1 For each numbered paragraph, the evaluation report should state one of the following, and provide supporting rationale, according to the criteria in §§ 7.4.3 through 7.4.6:

- ‘N/A’
- ‘Conforms to the Stated Criteria’
- ‘Conforms to the Performance Goal’
- ‘Addressed in Integration’
- ‘Does not Conform’

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

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

NOTE 17: ‘Conforms to the Stated Criteria’ and ‘Conforms to the Performance Goal’ are both findings indicating conformance. The findings are differentiated, as the appropriate supporting rationale for these findings differs.

EXCEPTION 3: If there is a written report of the evaluation of an aspect of the equipment to a criterion in this Document and that report includes a finding listed in § 7.4 and that report is available, that report may be incorporated by reference.

7.4.2 Within § 7.4, ‘equipment’ means the equipment under evaluation, or the related end user documentation provided with the equipment, as appropriate. (Refer to SEMI S13 for the meaning of ‘end user documentation’.)

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

NOTE 18: For example, a 'Not Applicable' finding would be given if the evaluator considers the paragraph to state a conformance criterion that pertains to a subsystem or component that is not included in equipment being evaluated and there is no criterion calling for that subsystem or component to be included. Also, a 'Not Applicable' finding would be given if the evaluator considers a conformance criterion to pertain to something outside the scope of the evaluation, such as a feature of a user's practices during an evaluation of a piece of equipment performed for an equipment supplier.

7.4.4 *Conformance Findings ('Conforms to the Stated Criteria' and 'Conforms to the Performance Goal')*

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

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

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

7.4.4.4 The supporting rationale for 'Conforms to the Performance Goal' should include:

7.4.4.4.1 a description of the equipment aspects,

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

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

7.4.4.4.3 and, to support the risk assessment;

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

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

7.4.5 *Addressed in Integration*

7.4.5.1 The finding of Addressed in Integration should be made for each criterion for which a conformance finding is not appropriate but it is determined the equipment will conform to the criterion if it is integrated in accordance with the documented instructions provided by its supplier.

7.4.5.1.1 This includes:

- criteria only part of which can be met by the equipment being evaluated (e.g., a downstream module ready interlock can be addressed only partially by an upstream module) and
- criteria that the equipment supplier indicates in their end user documentation are to be addressed by others (e.g., fall protection to be provided by the facility).

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7.4.5.1.2 The supporting rationale for this finding should address whether the portions of the criteria that are provided can be used in a manner that meets the documented criteria (e.g., does portion of module ready signal meet SEMI S2 interlock criteria).

7.4.5.1.3 This finding is not intended to be used for basic facility aspects that are necessary for the equipment to operate correctly (e.g., facility fluid and electrical supplies that meet documented specifications, adequate strength of the floor). This finding is to be used for features provided specifically to mitigate risks (e.g., fall protection tie-off points, gas leak detection, fire suppression).

7.4.5.2 In addition to being addressed in the paragraph by paragraph write-up of the report, all of the criteria determined to be 'Addressed by Integration' are to be included in a four-column table that clearly indicates:

- paragraph number and description of criterion,
- where in the end user documentation additional information can be found,
- what is provided by the equipment under evaluation, and
- what is expected to be provided by others.

7.4.6 *Does Not Conform*

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

- to which the paragraph pertains do not conform to the stated criteria and do not conform to the performance goal; or
- for which there is insufficient information available to the evaluator to reach a conclusion of any other finding.

7.4.6.2 The supporting rationale for this finding should include a description of the nonconforming equipment aspect(s), a description of the nonconforming characteristics, and a determination per SEMI S10 of the associated risk; or a description of the information needed to reach a conclusion for one of the other findings.

NOTE 16: For example, 'circuit breaker 42' is an equipment aspect; 'circuit breaker 42' being a supplementary overcurrent protector rather than a circuit breaker is a characteristic.

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

7.5 *Applicable Sections*

7.5.1 The sections to be included in an evaluation and report of remote liquid or remote vapor delivery equipment are:

- § 8 General Provisions
- § 9 Risk Assessments
- § 11 Criteria for Energetic Materials Containers Used in the Delivery of Liquid and Vapor Energetic Process Chemicals
- § 13 Remote Vapor Delivery Equipment and Remote Liquid Delivery Equipment – Supplier Criteria
- § 18 Equipment/Parts Cleaning and Waste Generation Criteria
- § 19 Control of Hazardous Energy

7.5.2 The sections to be included in an evaluation and report of process equipment are:

- § 8 General Provisions
- § 9 Risk Assessments
- § 11 Criteria for Energetic Materials Containers Used in the Delivery of Liquid and Vapor Energetic Process Chemicals

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- § 15 Energetic Materials Container Delivery Equipment Integral to Process Equipment – Equipment Supplier Criteria
- § 16 Gas Box and Process Chamber – Equipment Supplier Criteria
- § 18 Equipment/Parts Cleaning and Waste Generation Criteria
- § 19 Control of Hazardous Energy

7.5.3 The sections to be included in an evaluation and report of vacuum pump equipment or abatement equipment:

- § 8 General Provisions
- § 9 Risk Assessments
- § 17 Post Process Chamber Through Vacuum Pump/Abatement Equipment Design and Operational Criteria
- § 18 Equipment/Parts Cleaning and Waste Generation Criteria
- § 19 Control of Hazardous Energy

7.5.4 An evaluation of equipment included in more than one of §§ 7.5.1 through 7.5.4 is to include all of the document sections listed above for all of the types of included equipment.

7.5.5 An evaluation of equipment for which a list of sections is not provided above is to include those sections the evaluator finds to be technically relevant to the equipment being evaluated.

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

- manufacturer's model number;
- serial number of unit(s) evaluated;
- the date(s) that the equipment was evaluated;
- an equipment description including configuration, options, and essential diagrams;
- the process chemicals and reaction conditions considered; and
- statement of the qualifications of the evaluating party. This statement should address how the evaluating party meets the applicable provisions of SEMI S7.

8 General Provisions

NOTE 17: The equipment must comply with laws and regulations that are in effect at the location of use. This may be the direct responsibility of the equipment producer/importer or the workplace owner, depending on the regulation. All equipment requiring certification or approval by government agencies must have this certification or approval as required by regulations.

8.1 The supplier(s) should maintain an equipment/product safety program that identifies and eliminates hazards or controls risks in accordance with the order of preference. (Refer to § 6, Safety Philosophy.)

8.2 Each user should maintain an equipment safety program that ensures that equipment is used, maintained, and serviced in accordance with supplier criteria.

8.3 Supplier(s) should provide the user's designated representative with bulletins that describe safety related upgrades or newly identified significant risks associated with the equipment or materials. This should be done on an ongoing basis as needed.

8.4 Each user should ensure that equipment suppliers have the correct current name and contact information to which the information described in ¶ 8.3 is to be provided.

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

8.6 Means of performing control of hazardous energy to protect personnel during maintenance and service should be provided for all energetic material sources as specified in § 19, Control of Hazardous Energy.

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8.7 All equipment maintenance tasks should have specific procedures developed by the user or provided by the equipment supplier to minimize the risk of exposure to any hazardous energies.

8.8 As energetic materials have several hazardous properties, a PPE assessment should be conducted and, based on the PPE assessment, personnel should be instructed to follow the PPE requirements when working with energetic materials.

NOTE 18: Some jurisdictions require particular certification and maintenance logging of certain PPE.

8.9 A means of evacuation and purging should be provided for all piping and equipment containing energetic materials.

8.10 Decontamination should be addressed in accordance with SEMI S12.

8.11 Operators, maintenance personnel, and service personnel should be trained in the tasks they are intended to perform.

8.12 *Alarm Output Criteria* — Alarm outputs from safety and detection devices should be provided to allow for connection to equipment or chemical delivery shut down and the capability to interface with facility alarm systems.

8.12.1 Alarm outputs that are used as part of safety interlocks between subsystems or modules should be designed to meet the safety interlock criteria of SEMI S2 or SEMI S22 and end user documentation should specify how to connect to them.

NOTE 19: Dry contacts indicating a module ready status are a common method for addressing this.

8.12.2 Alarm outputs to provide status of fire and gas monitoring devices to the facility monitoring system are required at many facilities. The format of these outputs will need to be agreed by the user and supplier(s).

8.13 *Overtemperature Safety Interlocks* — Heaters should have overtemperature safety interlocks, including set points and sensor locations, appropriate for the level of risk.

8.14 *Undertemperature Safety Interlocks and Visual Warnings*

8.14.1 For each heated line through which energetic material or an energetic material precursor flows within equipment that processes substrates and for which there is a reasonably foreseeable safety consequence of the loss of heating, the equipment should have an undertemperature safety interlock that interrupts energetic material or energetic material precursor flow or have a means of visual warning as described in Figure 7.

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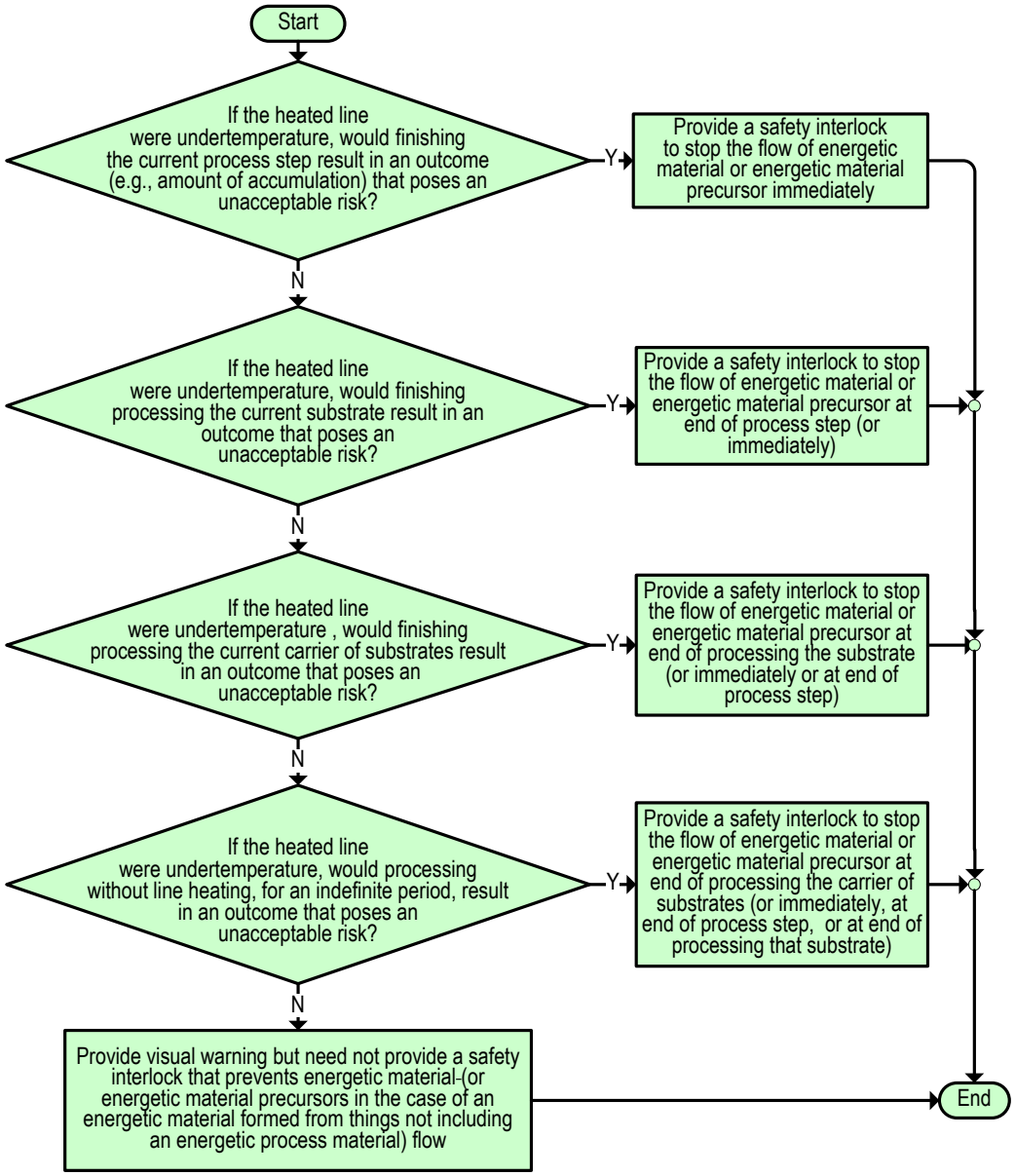

Figure 7
Undertemperature Safety Interlocks Within Equipment that Processes Substrates

8.14.2 For each heated line through which energetic material or an energetic material precursor flows that is not within equipment that processes substrates and for which there is a reasonably foreseeable safety consequence of the loss of heating, the equipment should have an undertemperature safety interlock that interrupts energetic material or energetic material precursor flow or a visual warning as described in Figure 8.

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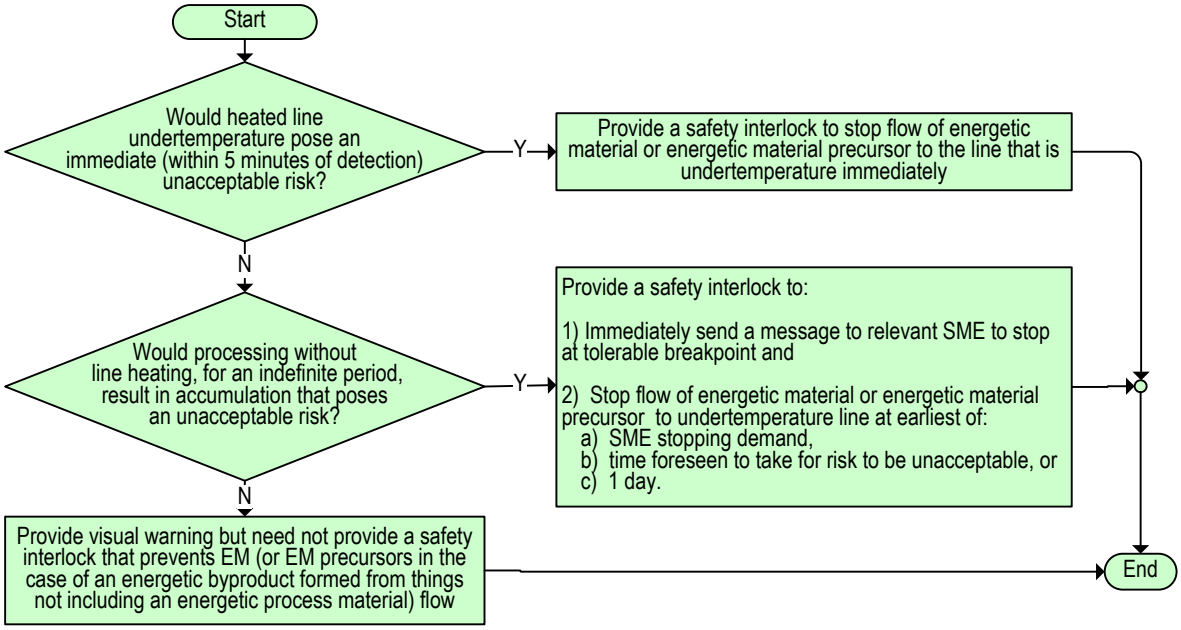

Figure 8
Undertemperature Safety Interlocks Not Within Equipment that Processes Substrates

NOTE 20: Activation of undertemperature safety interlocks during heating (sometimes called 'nuisance tripping'), which would require that deliberate action to reset the safety interlock be performed after the line has been heated to the minimum temperature, can be avoided by providing a process control that inhibits the start of processing (and, thereby, activation of the safety interlock) before the minimum temperature is achieved.

8.14.3 An engineering or administrative control should be provided that limits the number of times a heater is restarted without ensuring that there is no unacceptable accumulation of material in the lines. If an administrative control is used, it should be documented in the documents provided to the user.

8.14.4 If the energetic material foreseen to accumulate (considering relevant factors, including the rate of cooling, the amount of material that is available to condense, and the stability of that material) due to a loss of heating poses an unacceptable risk, the material should be removed as soon as is practicable after the loss of heating is detected. This administrative control should be documented in the documents provided to the user.

8.14.5 If restarting line heating without removing the accumulated materials poses an unacceptable risk of violent reaction, the line should have been purged and be discharging through a properly-functioning abatement system before line heating is restarted. This administrative control should be documented in the documents provided to the user.

9 Risk Assessments

9.1 There are multiple risk assessments that should be completed to ensure the energetic materials can be used safely within the facility.

NOTE 21: Related Information 1 provides suggestions for performing the risk assessments.

9.2 *Standalone Risk Assessments* — Standalone risk assessments by the material delivery equipment supplier, the process equipment supplier, the vacuum pump equipment supplier and the abatement equipment supplier on their respective equipment in accordance with SEMI S2 should be performed. These should be complete or at least be well underway prior to the user's integrated risk assessment.

NOTE 22: Integrated risk assessments are not expected to have been done at the time of assessment of separate pieces of equipment.

9.2.1 If two or more suppliers (e.g., material delivery equipment supplier and the process equipment supplier) are collaborating on process chemistry application(s), then those suppliers should complete, jointly, a risk assessment on their combined equipment in accordance with SEMI S2 at the earliest point feasible and prior to the user's scheduled integrated risk assessment.

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9.2.2 These risk assessments may need to be revised when an energetic material is added to the design or use of a piece of equipment.

9.3 *Integrated Risk Assessment* — The user should ensure completion of an integrated risk assessment to identify and evaluate risks associated with the complete energetic materials path. This integrated risk assessment should be initiated as early as feasible and include appropriate representatives from the energetic process chemical supplier, material delivery equipment, process equipment, vacuum pump, and abatement equipment suppliers, and the user's staff.

9.3.1 As hazards may differ with different energetic materials and combinations and configurations of supply, process, and waste treatment modules, this hazards analysis should be performed for each equipment use, installation, or configuration. An integrated risk assessment for a particular use, installation, or configuration may be prepared by modifying the integrated risk assessment of a predecessor or similar equipment use, installation, or configuration.

NOTE 23: The performance of an integrated risk assessment is a conformance criterion of this Safety Guideline, but is not the traditional practice in the semiconductor industry. Experience has shown, however, that it is important to ensuring safety.

9.3.2 The integrated risk assessment should consider and document, as a minimum:

9.3.2.1 The physical, chemical, and toxicological properties of the energetic material to be processed,

9.3.2.2 The potential byproducts and their physical, chemical, and toxicological properties and the locations of deposits,

9.3.2.3 The application or process at the maximum flow setpoints for the equipment, which are typically higher than the targeted process recipe values,

9.3.2.4 The hazards associated with each task,

9.3.2.5 Anticipated failure modes,

9.3.2.6 An analysis of interconnection hazards, based on proposed piping and instrumentation diagram (P&ID) and piping layout,

9.3.2.7 The anticipated level of expertise of exposed personnel and their frequency of exposure to the hazard,

9.3.2.8 The frequency and complexity (e.g., number of steps, required expertise) of operating, servicing, and maintenance tasks,

9.3.2.9 Identification and determination of suitability of safety critical parts,

NOTE 24: Determination of suitability should be based on the risk of failure. This can be achieved two ways:

- high reliability in the use or
- acceptability of the failure, such as by having other means (e.g., fault diagnostics or secondary containment) of mitigating the consequences of the failure.

9.3.2.10 PPE requirements,

9.3.2.11 The risk mitigation features, and

9.3.2.12 Ranking, in accordance with SEMI S10, Safety Guideline for Risk Assessment and Risk Evaluation Process, of the risks identified in the integrated risk assessment.

10 Information to be Provided by Energetic Process Chemical Suppliers

10.1 Energetic process chemical suppliers should provide the information described in this section, at the time negotiated with the user.

10.2 *Classifications* — A determination of 'pyrophoric', 'water reactive', and 'hazardously exothermic' classifications in accordance with the definitions and empirical tests specified in § 5 and including:

10.2.1 The objective test data and calculations on which the determinations were based. For determinations which were not based on objective data, the rationales used in making the determinations and the basis for considering the persons making the determination qualified to do so.

10.2.2 The completed Material Characterization Form provided in Appendix 1.

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10.2.3 Stoichiometry and thermodynamics of reaction with water and with oxygen, including any byproducts which are flammable or otherwise hazardous

10.2.4 Calorimetry results that show the time evolution of heat under defined reaction conditions

10.2.5 A video illustrating the salient properties and reaction of the energetic process chemical with air, water, and any other materials with which the energetic process chemical is foreseen to react exothermically should be provided to users by the chemical supplier. The video should clearly illustrate, to the end user and to those who do maintenance or service, the vigor and hazards a release could create. This information should be such that first responders (to leaks or spills) and those mentioned above can be trained, appropriate PPE provided, and safe work practices (including emergency response) determined. The video should be provided as an .avi or .mp4 file or through an accessible web link to such a video and should show:

- the contact of material with moisture in air under controlled conditions,
- the reaction of material with water moistened cleanroom compatible absorbent wipe, and
- the contact of material with liquid water (in an inert environment if reaction with air would obscure visibility) under controlled conditions.

10.3 *Byproduct Information* — The chemical identity of known and anticipated byproducts, based on user's process conditions, (such as a baseline recipe), if they are provided. The information should include:

- states of matter,
- difficulty of removal of byproducts, and
- any safety determinations made from byproduct quantitative or predictive model evaluation(s) or during the integrated process risk assessment conducted as described in § 9.3.

10.4 *PPE* — Recommendations (considering permeation, penetration, degradation, and fire) on proper PPE to support on site receipt, transportation, and installation and deinstallation activities, some of which occur in cleanrooms.

NOTE 25: The criterion of protection from permeation, penetration, degradation, and fire pertains to the PPE ensemble (the complete set of items of PPE to be used for a task), rather than each item, because it is not always possible to obtain a single item that has all of the needed protective properties. For example, some PPE ensembles include two pairs of gloves: an outer pair to provide mechanical protection (both for the worker and for the inner gloves) and an inner pair to provide chemical protection for the worker.

NOTE 26: The test methods that may be useful in determining the suitability of PPE include:

- ASTM F739
- ASTM F903-10
- ASTM F2302-08

10.5 Additional information, as agreed by the user and supplier.

11 Criteria for Energetic Materials Containers Used in the Delivery of Liquid and Vapor Energetic Process Chemicals

11.1 *Design* — Suppliers of liquid and vapor energetic process chemicals should provide such materials in an energetic materials container conforming to the following criteria.

11.1.1 *Valves*

11.1.1.1 Valve configurations of energetic materials containers should provide the capability for control of hazardous energy (refer to § 19).

11.1.1.2 The risk of valve failure should be acceptable. This can be achieved by, for example, using two (one pneumatic and one manual) valves on each line or using single valves of high enough reliability and with an appropriate actuator assembly. 'High enough reliability' means reliability such that the risk is acceptable.

NOTE 27: Risk of valve failure depends, among other factors, on the temperatures to which the containers and valves are exposed in transportation, storage and use, and the probability and consequences (such as elevated temperature and pressure) of reactions (such as decomposition) within the containers.

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