SEMICONDUCTOR FABRICATION FACILITIES

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1.0 SCOPE

This data sheet contains property loss prevention recommendations for semiconductor fabrication facilities. The loss prevention principals associated with this operating standard can be applied to related industries such as flat panel display manufacturing, photovoltaics (solar cell) manufacturing, wafer manufacturing, semiconductor tool manufacturers, etc.

When designing and operating semiconductor fabrication facilities, an organization should develop and manage a corporate property conservation policy based on the recommendations of this data sheet and management of manufacturing hazards. They should build inherently safer and more resilient facilities by constructing them from noncombustible materials, procuring noncombustible equipment or FM 4910 listed materials for both new and used tools, reducing the risks through a well-established process safety program to eliminate events with process chemicals and by minimizing process interruptions from loss of primary utilities and services.

1.1 Changes

April 2025. This document has been completely revised. Significant changes include the following:

A. Recommendations redundant to other FM Data Sheets were removed, including fire protection inspection and testing, control room protection and electric utility system studies.

B. The recommendation to retain a consulting firm specializing in seismic design for seismic zones was removed, because it is a building code requirement in those areas.

C. Recommendations related to sprinkler installation around ceiling obstructions for waffle-style ceilings were revised for clarity.

D. The recommendation for manual fire extinguishers was removed, because the need and location should be established in the facility emergency response plan (ERP).

E. The recommendation on location of zero footprint storage was removed, because relocating is generally impractical and does not have a significant impact on the loss scenario.

F. A recommendation was added to arrange switchgear in a way that allows inspection, testing and maintenance (ITM) without defeating interlocks.

G. The recommendation for independent HVAC units for each fab area was removed, because ballroom fabs don’t require a dedicated unit for each fab area to prevent smoke/air migration or loss of airflow.

H. Recommendations related to steam, hot water and chilled water equipment were removed because they were redundant with Asset Integrity recommendations.

I. A recommendation was added to provide a hard-wired interlock that automatically switches over the backup nitrogen supply if the primary supply deviates from specified purity limits.

J. Recommendations related to reprocessors were removed, because that equipment is not used in current fab operations.

K. Recommendations related to facility security were removed, because modern fabs are tightly controlled facilities.

L. The recommendation for metal trash containers was removed, because small plastic trash receptacles are not a significant hazard in the fab area.

1.2 Hazards

The critical hazards and exposures for the safe and continuous operation of a semiconductor fabrication facility are interruption of critical services such as power and bulk gas supplies, fire/explosion and fluid leakage.

Interruption of electrical power and nitrogen supplies have caused production stoppages and spoilage of work in process (WIP). The electrical, nitrogen and other critical utilities require a high level of reliability to minimize the impact of an outage on operations.

Semiconductor companies frequently introduce new and often hazardous process chemicals. Utilizing a process safety program to review new hazards being introduced and applying a high level of safeguards and protection are critical. The introduction of new technologies such as EUV brings much higher levels of operational risks that require diligent assessment and mitigation strategies to ensure reliability and inherent safety.

Fire and explosion hazards include combustible plastic construction materials (tools, ducts and scrubbers), pyrophoric (silane) and flammable (hydrogen) gases, and pyrophoric and ignitable liquids.

Liquid leakage from a variety of sources (including process liquids, HVAC systems, automatic sprinklers [improperly arranged or maintained] and waste systems) is a critical event. Water is the most common fluid associated with leakage. Process liquid leakage, including acids and other corrosives, can result in considerable damage and interruption to operations.

2.0 LOSS PREVENTION RECOMMENDATIONS

2.1 Introduction

The following loss prevention recommendations are written from a best practice or highly protected risk perspective.

2.2 Process Safety

Process safety is defined by FM as a structured approach to managing the hazards inherent in processes by applying good design, engineering and operating practices. The concepts of process safety are interrelated and were historically developed for the chemical process industries before being adopted by various regulatory agencies. As process safety concepts and practices have evolved, they have proven beneficial when applied in non-chemical facilities that have significant risks. The guidance in this data sheet can be applied when practicing these concepts to significantly reduce the overall risk of failure for equipment, systems or processes.

Process safety should be applied at semiconductor fabrication facilities using judgment to ensure it is commensurate with the hazards and exposures present at the facility. Fully implementing a complete process safety program like that expected at a chemical plant is unrealistic. The following systems/equipment contain hazards that can be addressed through a robust process safety program:

- Production tools
- Pyrophoric gas and liquid systems
- Nitrogen supplies (including purifiers)
- Ignitable liquid systems (including waste)
- Flammable gas systems
- Acid systems
- Abatement systems (e.g. point-of-use thermal oxidizers or scrubbers)

2.2.1 Develop a process safety program that addresses at least the following:

- Management commitment
- Process knowledge
- Process hazard analysis (PHA)
- Management of change
- Asset integrity
- Incident investigation

See also Appendix D, Process Safety Applications for Semiconductor Fabrication Facilities, Data Sheet 7-43, *Process Safety*, and Data Sheet 9-0, *Asset Integrity*, for guidance on developing an asset integrity program.

2.2.2 Develop a company-wide policy statement specifying the use of noncombustible (e.g., metallic) materials or FM 4910 listed plastics. Apply this policy to the purchase of new or used tools as well as replacement of combustible tools when the opportunity arises. Limit the use of non-FM 4910 listed plastics (for items such as knobs, buttons, electrical contacts, terminal strips, etc.) to no more than 1 lb/ft^2 (5 kg/m^2) of the tool footprint or 1% by weight of the total plastics used to make the tool.

2.2.3 Develop a company-wide policy statement specifying the use ofnoncombustible (unlined ferrous metal ductwork) or FM Approved to Approval Standard 4922, *Fume Exhaust Ducts or Fume and Smoke Exhaust Ducts*, listed under Fume and/or Smoke Exhaust Duct Systems for Use in Cleanrooms only (hereafter referred to as FM 4922 approved ducts). Apply this policy to new installations and for replacement of combustible ductwork when the opportunity arises.

2.3 Cybersecurity

2.3.1 Perform a cyber risk security assessment of equipment or controls in accordance with Data Sheet 7-110, *Industrial Control Systems*.

2.4 Fabrication Site and Building

2.4.1 General

2.4.1.1 Noncombustible Construction

2.4.1.1.1 Use noncombustible materials to construct semiconductor fabrication facilities, including all process support buildings.

2.4.1.1.2 If the use of plastic construction materials cannot be avoided, use plastic that has passed the FM Approvals Cleanroom Materials Flammability Test Protocol (hereafter referred to as FM 4910 listed plastic). FM 4910 listed plastic materials can be found in the Specification Tested section of the *Approval Guide*, an online resource of FM Approvals.

2.4.1.2 Testing of Safety Interlocks

2.4.1.2.1 At least annually, perform functional testing of critical interlocks identified in the PHA and/or interlocks critical to business continuity. At a minimum, this testing should include safety shutoff or isolation systems for ignitable liquids, flammable gases, energetic materials and corrosive fluids.

2.4.2 Location

2.4.2.1 Site Selection

2.4.2.1.1 Locate new fabs and related support facilities such as subfabs, utility buildings, waste-processing buildings, chemical storage and delivery buildings to avoid the following exposures:

A. Exposures from other occupancies within the facility. Avoid locating occupancies above the fab areas.

B. Exposures from natural hazards such as flood, windstorm, earthquakes and hail. Do not locate fabs or related support buildings within an identified flood zone.

C. Exposures from internal and external fire sources, including proposed adjacent occupancies, external adjacent structures, wildland fire potentials, conflagration, etc.

D. Liquid damage exposure from piping and other utility services, such as drainage systems and liquid delivery systems.

E. Contaminant exposure from adjacent exhaust systems and occupancies via the air intakes.

2.4.2.1.2 Do not locate fab buildings, critical systems or equipment in 100-year or 500-year flood areas (see Data Sheet 1-40, *Flood*). If flood studies are not available, retain the services of a professional hydrologist or coastal engineer to assess the flood exposure.

2.4.2.1.2.1 Locate new fabs and related support facilities at or above grade level to prevent flooding and sewer backup that could expose basement areas to loss.

2.4.2.1.2.2 Design the facility’s storm water management system per Data Sheet 1-40, *Flood*, to ensure a flood exposure isn’t created or worsened by the layout, grading or storm-water management system.

2.4.2.1.3 Perform a power supply reliability study using a qualified engineering firm that addresses at least the following:

A. The number, duration and causes of major system outages over a 10-year period.

B. Future load growth and the utility’s plans to address the growth.

2.4.2.1.3.1 If the local electric utility is unable to provide a reliable source of power for the semiconductor fabrication facility, select an alternate site; or provide mitigation measures such as onsite generation or separate feeds.

2.4.2.1.4 Have a power quality study of the local electric utility performed by a qualified engineering firm. Include both of the following tasks as part of the study:

A. Evaluate power quality for the previous year to account for seasonal variations.

B.Compare the measured power quality against the power acceptability curves in SEMI F47, *Specification for Semiconductor Processing Equipment Voltage Sag Immunity*, those created by the Information Technology Industry Council (ITI) or those used in another recognized standard.

2.4.2.1.4.1 Install power conditioning devices if the local electric utility cannot guarantee an acceptable level of clean power.

2.4.3 Construction

2.4.3.1 Walls

2.4.3.1.1 Provide a fire barrier with a minimum one-hour fire rating between cleanrooms and adjacent hazard category 2 (HC-2) occupancies (as defined in Data Sheet 3-26, *Fire Protection for Nonstorage Occupancies*).

2.4.3.1.2 Where the adjacent occupancy is more hazardous than HC-2, complete one of the following (listed in order of preference):

A. Locate the adjacent occupancies in separate buildings.

B. Provide a minimum two-hour fire barrier between the cleanroom and the adjacent occupancy. The rating of the separation is dependent on the hazard as evaluated in accordance with the applicable FM data sheet.

2.4.3.1.3 When subdivision walls are provided inside the cleanroom, use noncombustible construction. Extend the subdivision walls from the underside of the roof to the subfab floor.

2.4.3.1.4 Install normally-closed or automatic-closing, FM Approved fire doors in fire-rated walls.

2.4.3.1.5 Use noncombustible construction materials for wall and floor panels, floor coverings/coatings and interior finish components.

2.4.3.2 Roofs

2.4.3.2.1 Design roofs to be FM Approved and to meet all FM data sheet recommendations regarding windstorm, hail, rain and snow loading as applicable (based on the geographical location of the facility).

2.4.3.2.2 Use the following materials of construction for the roof above the cleanroom (listed in order of preference):

A. Fire-resistive (e.g., reinforced concrete or protected steel frame)

B. Noncombustible (e.g., concrete over steel deck on steel frame)

C. Class 1 (e.g., insulated steel deck with limited above-deck combustibles)

2.4.3.2.3 Do not use combustible roof construction, including gypsum board sheathed roof.

2.4.3.2.4 Avoid locating roof drain piping over cleanroom areas.

2.4.3.2.5 Provide roof drainage systems in accordance with Data Sheet 1-54, *Roof Loads and Drainage*, to prevent water from overflowing drains and entering the cleanroom. If blockage of primary drains allows water to accumulate, provide secondary (overflow or emergency) roof drains or scuppers.

2.4.3.3 Penetrations

2.4.3.3.1 Seal any penetrations through fire-rated wall systems using FM Approved wall penetration fire stop materials (installed by an FM Approved fire stop contractor, when available).

2.4.3.3.2 Ensure the FM Approved fire stop material used has fire rating equal to or greater than the wall, floor or ceiling through which the penetration passes.

2.4.3.3.3 Tightly seal all floor penetrations within a cleanroom where the fab and subfab are separated by a solid, noncombustible floor. Use minimum one-hour rated, FM Approved fire stop materials.

2.4.3.3.4 Provide a leakage-rated penetration seal with the lowest rating possible, but not exceeding 7 $ft^3/min/ft^2$ (2.1 $m^3/min/m^2$), in addition to the fire-resistance rating for equipment room penetrations (see Section 3.1.1).

2.4.3.3.5 Verify the integrity of wall and floor penetration sealing on a minimum yearly basis and in accordance with the manufacturer's specifications.

2.4.3.4 Waffle/Cheese Slab Formwork

2.4.3.4.1 Construct permanent waffle/cheese slab (stay-in-place) formwork of FM 4910 listed plastic or equivalent.

2.4.3.5 Insulation

2.4.3.5.1 Provide building insulation and elastomeric materials installed on the building and beneath a raised floor in accordance with Data Sheet 1-57, *Plastics in Construction*.

2.4.3.5.2 Ensure the insulation on pipes and ductwork is one of the following:

A. Noncombustible (e.g., foil-wrapped fiberglass or mineral fiber wool)

B. FM Approved to Approval Standard 4924, *Pipe and Duct Insulation* (hereafter referred to as FM 4924 Approved).

2.4.3.6 Pass-Through Cabinets

2.4.3.6.1 Construct vertical or horizontal pass-through cabinets or rooms out of noncombustible material. If corrosive liquids are being passed through the cabinets, use FM 4910 listed plastics to construct the cabinets or rooms.

2.4.3.6.2 When ignitable or corrosive liquids are temporarily stored in pass-through cabinets or rooms, limit the quantity to that needed for one shift.

2.4.3.6.3 Provide containment for the largest expected liquid release arranged to direct liquid to the dirty side (i.e., largest metal container and contents of all plastic or glass containers), or provide drainage connected to a compatible waste-liquid drainage system for each cabinet.

2.4.3.6.4 On each side of the cabinet, provide doors made of materials that will maintain the fire rating of the wall to which they are mounted.

2.4.3.6.5 Use metallic construction for ignitable liquid cabinets and their containment.

2.4.3.6.6 Provide separate pass-through cabinets for incompatible chemicals.

2.4.3.7 Liquid Leakages

2.4.3.7.1 Where the occupancies above the cleanroom have potential for liquid leakage (e.g., HVAC equipment in cleanroom plenums), provide liquid-tight floors with adequate containment and drainage to a safe location.

2.4.3.7.2 Where liquid piping and fittings are unavoidable above the cleanroom, provide leak containment and detection at probable leakage points, such as mechanical connections, valves and areas where previous leaks occurred.

2.4.3.7.3 Brace liquid pipes above the cleanrooms in accordance with Section 2.4.3.8.5.

2.4.3.7.4 Test sprinkler pipework with air during commissioning to ensure all drain valves and potential leak points have been sealed.

2.4.3.8 Earthquake

2.4.3.8.1 Provide earthquake protection in accordance with this section at locations in FM 50-year through 500-year earthquake zones per Data Sheet 1-2, *Earthquakes*.

2.4.3.8.2 Use importance factors to increase normal code-required seismic design forces for structures and equipment whose damage or failure could impair the continued operation of the facility (even if not considered "critical" or "essential" by traditional building code criteria). The importance factor should be at least 1.25 for structures and 1.5 for equipment restraint. Consider designing the entire site for earthquake, using higher forces and more stringent detailing than required for "ordinary" buildings and equipment. For example, in the four-tiered system defined by ASCE 7 where risk categories/importance classes are [I] for minor structures, [II] for ordinary structures, and [IV] for essential facilities like hospitals, the fabrication facility should be designated a risk category [III].

2.4.3.8.3 Design earthquake protection for fire protection systems in accordance with Data Sheet 2-8, *Earthquake Protection for Water-Based Fire Protection Systems*.

2.4.3.8.4 Mitigate the potential for fire following earthquake in accordance with Data Sheet 1-11, *Fire Following Earthquakes*.

2.4.3.8.5 Design earthquake restraint for equipment and nonstructural items in accordance with Data Sheet 1-2, *Earthquake* or the guidance below, whichever is more conservative:

A. Design equipment anchoring and restraint (scanners, furnaces, implanters, gas cabinets, etc.) to resist a minimum horizontal seismic force, based on Allowable Stress Design, equal to "G Factor" of 0.5, multiplied by the weight of the equipment.

B. Design raised floors to resist a minimum horizontal force, based on local code requirements or the Allowable Stress Design, equal to "G Factor" of 0.5, multiplied by the total effective weight, whichever is higher. Take the total effective weight as the sum of the weight of the floor plus 100% of the weight of equipment attached to the floor, plus 25% of the weight of equipment supported on, but not attached to, the floor.

C. Provide hot and chilled water supply and return piping systems (typically for air-handler units) above the fabrication area with earthquake bracing designed to resist a minimum horizontal force, based on Allowable Stress Design, equal to "G Factor" of 0.5, multiplied by the weight of the water-filled pipe.

D. Provide seismic protection for emergency power supply equipment, including the following:

1. Restrain diesel generators and anchor diesel generator batteries and fuel tanks to resist a minimum horizontal force, based on Allowable Stress Design, equal to "G Factor" of 0.5, multiplied by the weight of the equipment.

2. Anchor battery racks and battery cabinets; provide a method to prevent batteries from falling from their support. Provide shims between batteries and between racks and batteries, or provide other means to prevent batteries from shifting.

E. Provide seismic protection for vertical furnaces in accordance with Section 2.4.3.8.5(A) and the following:

1. Provide seismic restraint of the vertical furnace quartz tubes in accordance with manufacturer's specifications.

2. Provide seismic restraint for the spare quartz tube storage arrangement to reduce potential cracking of the tubes during an earthquake.

2.4.3.9 Windstorm

2.4.3.9.1 Design buildings for wind forces in accordance with Data Sheet 1-28, *Wind Design*, and Data Sheet 1-29, *Roof Deck Securement and Above-Deck Roof Components*.

2.4.3.9.2 Minimize exterior windows to the fabrication building. When they are necessary, provide them in accordance with Data Sheet 1-28, *Wind Design*.

2.4.3.10 Freeze

2.4.3.10.1 Evaluate exposure and mitigation for freeze-ups due to cold temperatures in accordance with Data Sheet 9-18, *Prevention of Freeze-Ups*, and Data Sheet 10-1, *Pre-Incident and Emergency Response Planning*.

2.4.4 Fabrication Building Protection

Protection for production tools can be found in Section 2.6.

2.4.4.1 Provide automatic sprinkler protection at the ceiling in semiconductor fabrication areas and associated plenum spaces above cleanrooms and subfabs as follows:

A. Design the sprinkler system to provide a density of 0.2 gpm/ft^2 (8 mm/min) over the hydraulically most remote 3,000 ft^2 (280 m^2) with an additional allowance of 250 gal/min (946 L/min) for hose streams.

B. Ensure the water supply is capable of providing the sprinkler water and hose stream flow requirements for a duration of 60 minutes.

C. Where combustible loading is unavoidable in an area where sprinklers are obstructed, provide additional sprinklers immediately over the combustibles.

D. Use nominally rated 160°F (70°C) FM Approved quick-response pendent sprinklers. Sprinklers having minimum K factor of K8.0 (K115) are preferred. Sprinklers having a K factor of K5.6 (K80) can be used where the density/area recommendations are achieved with the smaller sprinkler.

E. Do not use extended coverage, sidewall or concealed sprinklers in cleanroom areas.

F. Do not exceed a maximum sprinkler spacing of 130 ft^2 (12 m^2).

G. Where the ceiling construction consists of solid ceiling structural members, install sprinklers in accordance with Data Sheet 2-0, *Installation Guidelines for Automatic Sprinklers*.

H. Where a waffle-style ceiling is installed in the sub-fab, position sprinklers not more than 6 in. (150 mm) directly under the solid structural member. See Figure 2.4.4.1-1 Provide additional protection over large concentrations of combustibles.

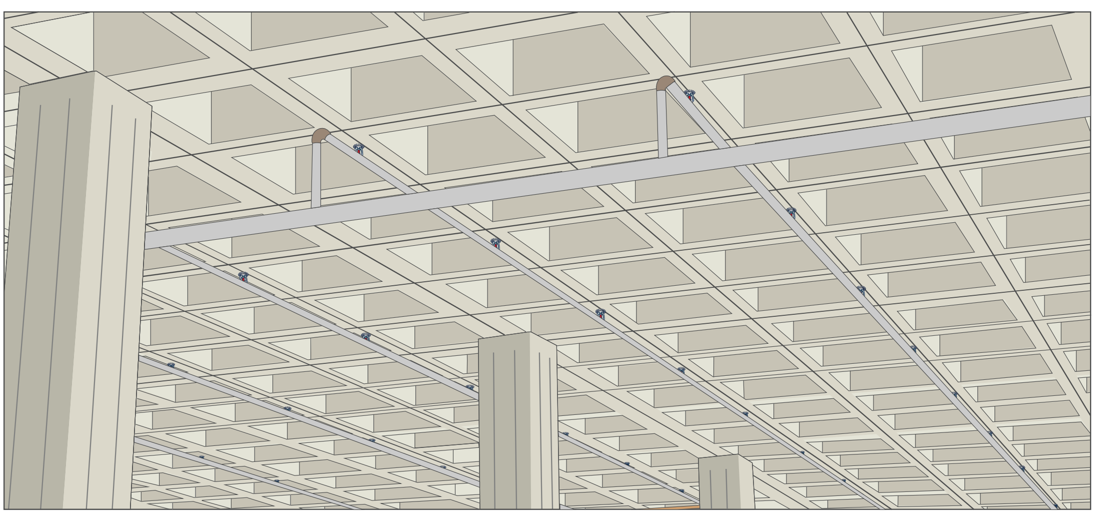


Fig. 2.4.4.1-1. Waffle-style ceiling sprinkler installation

2.4.4.2 Install the automatic sprinkler system in accordance with Data Sheet 2-0, *Installation Guidelines for Automatic Sprinklers*.

2.4.4.3 Use schedule 40 pipe for automatic sprinkler systems in cleanrooms, because it has fewer corrosion-related problems than lighter pipe schedules. See Data Sheet 2-1, *Corrosion in Automatic Sprinkler Systems*, for additional information.

2.4.4.4 Do not use plain-end couplings or fittings.

2.4.4.5 Use FM Approved flexible sprinkler hoses listed for the specific application and compatible with the installed ceiling to connect sprinkler branch lines to sprinklers installed in ceilings or ducts.

A. Ensure the radius of the hose installation is in accordance with manufacturer's installation guidelines and the FM Approval listing.

B. At locations subject to freezing temperatures, ensure the flexible metal hose assembly is installed so water will not be trapped within the assembly.

2.4.4.6 Provide automatic sprinkler protection inside hazardous process material (HPM) dispensing cutoff rooms using one of the following options:

A. If the HPM dispensing room is used for ignitable liquid, provide automatic sprinkler protection in accordance with Data Sheet 7-32, *Ignitable Liquid Operations*.

B. If the HPM dispensing room is used for dispensing gas, provide automatic sprinklers hydraulically designed to provide a density of 0.30 gpm/ft^2 (12 mm/min) over the entire room area or over 3,000 ft^2 (280 m^2), whichever is less. Use standard response sprinklers rated at 286°F (141°C).

C. If the HPM dispensing room is used for both ignitable liquid and gas, provide automatic sprinkler protection in accordance with Data Sheet 7-32, *Ignitable Liquid Operations*.

2.4.4.7 Provide automatic sprinkler protection in other areas, such as electrical equipment rooms, in accordance with Data Sheet 3-26, *Fire Protection for Nonstorage Occupancies*.

2.4.4.8 Provide an FM Approved very early warning fire detection system (VEWFD) capable of detection at a minimum sensitivity of 0.2% per ft (0.06% per m) within the cleanroom makeup and return air paths. Arrange the VEWFD system to alarm at a constantly attended location.

2.4.5 Pass-Through Cabinets Protection

2.4.5.1 Provide automatic sprinkler protection for all pass-through cabinet rooms and for pass-through cabinets that stage or store ignitable liquids.

2.4.6 Zero Footprint Storage (ZFS) - Under and Side-Track Storage Protection

2.4.6.1 Provide additional sprinkler coverage where the ceiling sprinklers are shielded by the under and side-track storage of FOUPs. Where additional sprinkler protection is installed, decrease the sprinkler spacing along the storage to one-half of the original sprinkler spacing, but to not less than 4 ft (1.2 m) minimum.

2.4.6.2 Where ZFS supporting structure/members are attached directly to the underside of a suspended ceiling, use one of the following methods to ensure sprinklers are unobstructed:

A. Relocate the obstructing member(s) or relocate the sprinkler(s) in accordance with Data Sheet 2-0, *Installation Guidelines for Automatic Sprinklers*, Figure 2.5.2.5.1.1(a): Objects near ceiling level not considered obstructions to standard-coverage Nonstorage pendent and upright sprinklers.

B. Extend the sprinkler further below the ceiling, so the sprinkler deflector is located below the obstruction.

2.4.6.3 Where catwalks or service platforms are installed over ZFS, provide open grating as defined in Data Sheet 2-0, *Installation Guidelines for Automatic Sprinklers*, to ensure water from ceiling sprinklers can pass through; or install additional sprinklers under surfaces that do not meet the definition of open grating.

2.4.7 Finished Product (Tape Reel) Storage Protection

2.4.7.1 Store finished product (tape reels) inside closed metal cabinets equipped with nitrogen purge.

2.4.7.2 Provide an FM Approved smoke detection system in the finished product storage areas, and provide protection in accordance with Data Sheet 8-9, *Storage of Class 1, 2, 3, 4 and Plastic Commodities*.

2.4.8 Work-In-Process (WIP) and Reticle Storage Protection

2.4.8.1 Store work-in-process (WIP) wafer boxes or reticle jewel boxes on noncombustible wire carts or noncombustible open-shelf storage.

2.4.8.2 Do not store WIP wafer boxes or reticle jewel boxes on shelves higher than 6 ft (1.8 m).

2.4.8.3 Do not exceed 3000 ft^2 (280 m^2) in any one storage area. Storage areas are defined by the accumulation of WIP wafer boxes or reticle jewel boxes. Carts or shelves separated by at least 8 ft (2.4 m) are considered separate storage areas.

2.4.8.4 Do not store any other combustibles or incidental storage in a WIP wafer box or reticle jewel box storage area.

2.5 Utilities and Support Systems

2.5.1 General

2.5.1.1 Maintain a N+1 (number of permanently installed viable equipment/systems required plus one) approach to utility and support system reliability.

The complex and sensitive semiconductor fabrication process requires reliable utilities and support systems to ensure uninterrupted operations. Redundancy of critical equipment and electrical supplies provides the best opportunity for preventing forced outages. For utilities that are sufficiently critical, additional redundancy (N+2) could be justified based on anticipated maintenance outages. Proper arrangement and maintenance are essential.

2.5.2 Electrical Power Systems

The primary goal of the design of the electrical power system is to ensure a reliable, resilient power supply to maintain uninterrupted operation of the fab. However, even with all safeguards in place, the possibility of a regional power outage affecting the redundant supplies always exists. Therefore, emergency power systems should be treated with equivalent importance to the primary power system. The design should address the following critical elements:

A. The electrical system must be designed with sufficient redundancy so that the failure of a single piece of equipment will not result in the loss of fab cleanliness, damage to the tools or loss of large quantities of wafers in process (WIP).

B. The power quality of the electrical distribution must meet the requirements of the consuming equipment. Fab tools and data center equipment may have strict guidance concerning the quality of the power supplied.

C. Sufficient emergency power must be provided to allow a controlled shutdown of the fab or process and to maintain the clean room envelope.

D. The design of the electrical system must allow for maintenance of the major components. Special attention may be needed when designing automatic transfer switches and emergency power systems to allow functional testing of the devices.

2.5.2.1 Electric Utility

2.5.2.1.1 Provide a minimum of two independent utility supplies, each capable of supplying the facility's maximum power demand, to the facility's main substation (Figures 2.5.2.1.1-1 and 2.5.2.1.1-2). Recognize that having multiple independent utility supplies does not completely mitigate the possibility of power outage to the facility. Arrange the utility supplies as follows:

A. Deliver each supply from a separate substation. Establish power supply from substations that are as electrically independent as possible.

B. Arrange the utility's protective scheme so that a fault in one substation or supply will not cause the tripping of the other substations or supplies to the facility.

C. Arrange each supply so that no single event, such as a substation fire, mechanical impact, wildland fire or excavation, etc., will affect more than one supply.

D. Where the utility supplies enter the main facility substation, route critical cables so that a single fire event does not affect more than one supply. Provide an FM Approved fire blanket for critical cables that cannot be routed separately.

E. Provide adequate lightning protection and surge protection for each supply in accordance with Data Sheet 5-11, *Lightning and Surge Protection for Electrical Systems*.

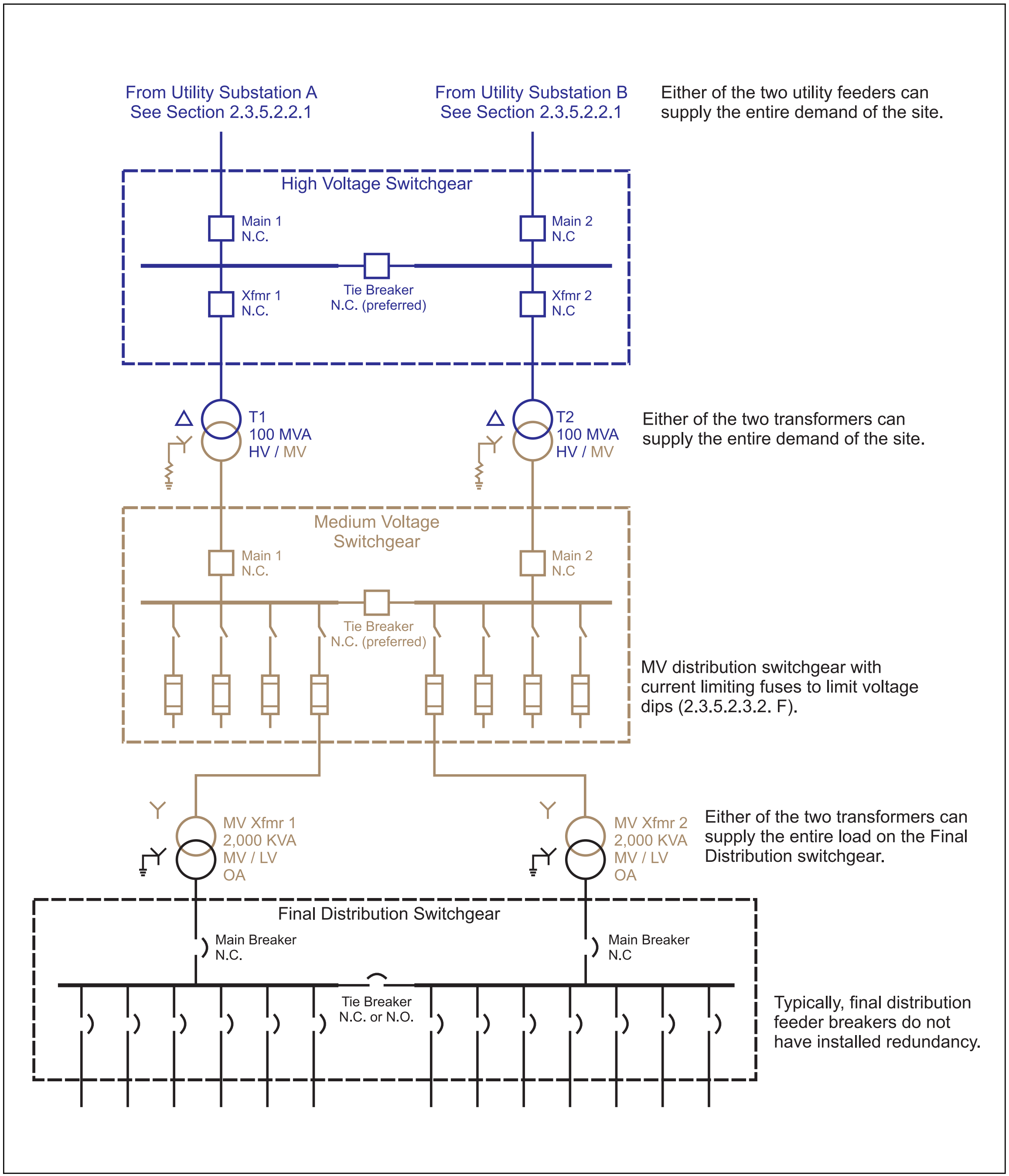


Fig. 2.5.2.1.1-1. Electrical system for a semiconductor fabrication facility with two utility feeds and N+1 transformer redundancy

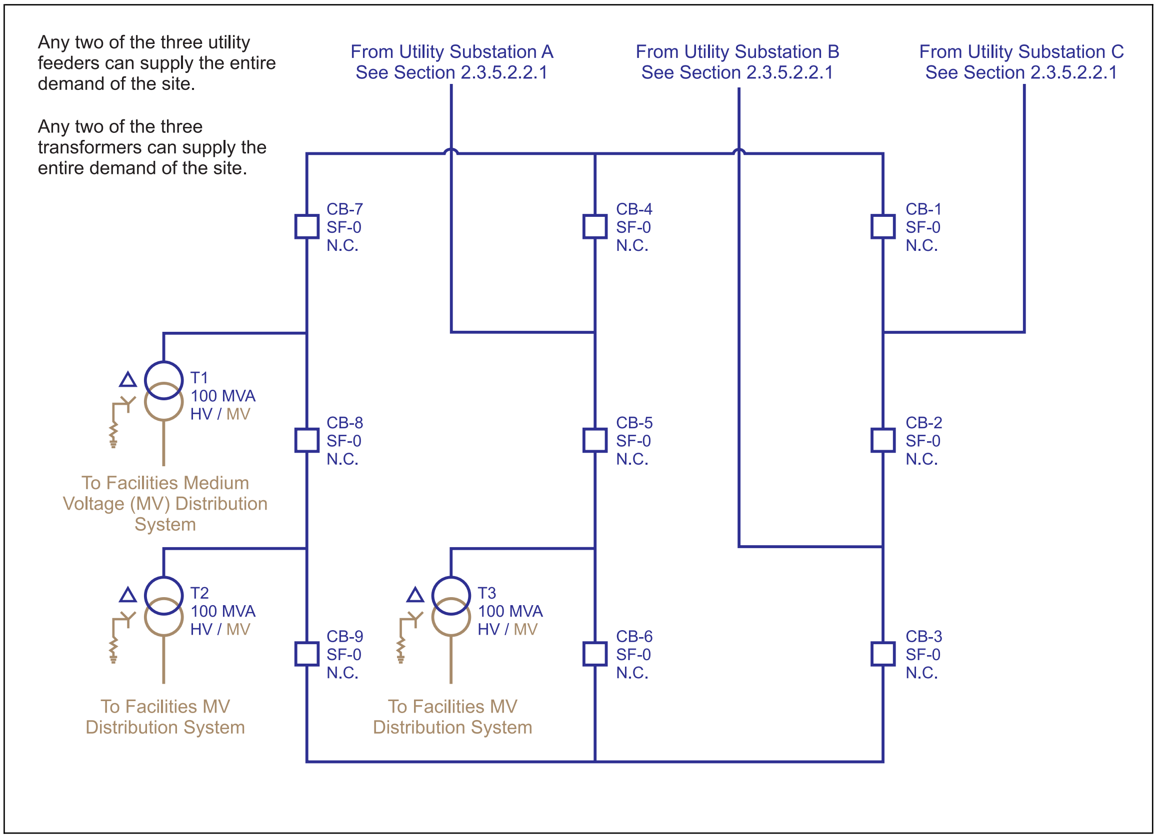


Fig. 2.5.2.1.1-2. Example of a high voltage (HV) substation with a ring bus arrangement with multiple utility feeders

2.5.2.2 High and/or Medium Voltage (HV and MV) Distribution Systems

This section applies to distribution systems and substations, owned by either the operating facility or by the utility company, and located within 1000 ft (305 m) of the property line.

2.5.2.2.1 Establish a documented inspection, testing, and maintenance (ITM) plan for any portion of the electrical system operated by the utility.

Some utilities may consider a breakdown maintenance program or risk-based maintenance program acceptable for distribution level transformers and switchgear. Most utilities do not consider business interruption when developing their ITM programs.

2.5.2.2.2 Incorporate the following into any substation(s):

A. Provide a minimum of N+1 transformers at the HV and MV level (see Figures 2.5.2.1.1-2 and 2.5.2.2.2-1).

B. Install transformers in accordance with Data Sheet 5-4, *Transformers*.

C. Arrange the control systems and supply cables/bus ducts so they are not subject to a single event, such as substation fire, mechanical impact, wildland fire or excavation damage.

D. Arrange the distribution system so the full demand of the site can be supplied with any one component of the system out of service for maintenance or repair.

E. Design the MV distribution system to limit voltage dips at sensitive equipment from faults in the MV and LV downstream equipment. This design can be accomplished using current-limiting fuses, uninterruptible power supplies (UPS) or other means.

F. Arrange switchgear to allow inspection, testing and maintenance without loss of supply to the fab or defeating of any physical interlocks.

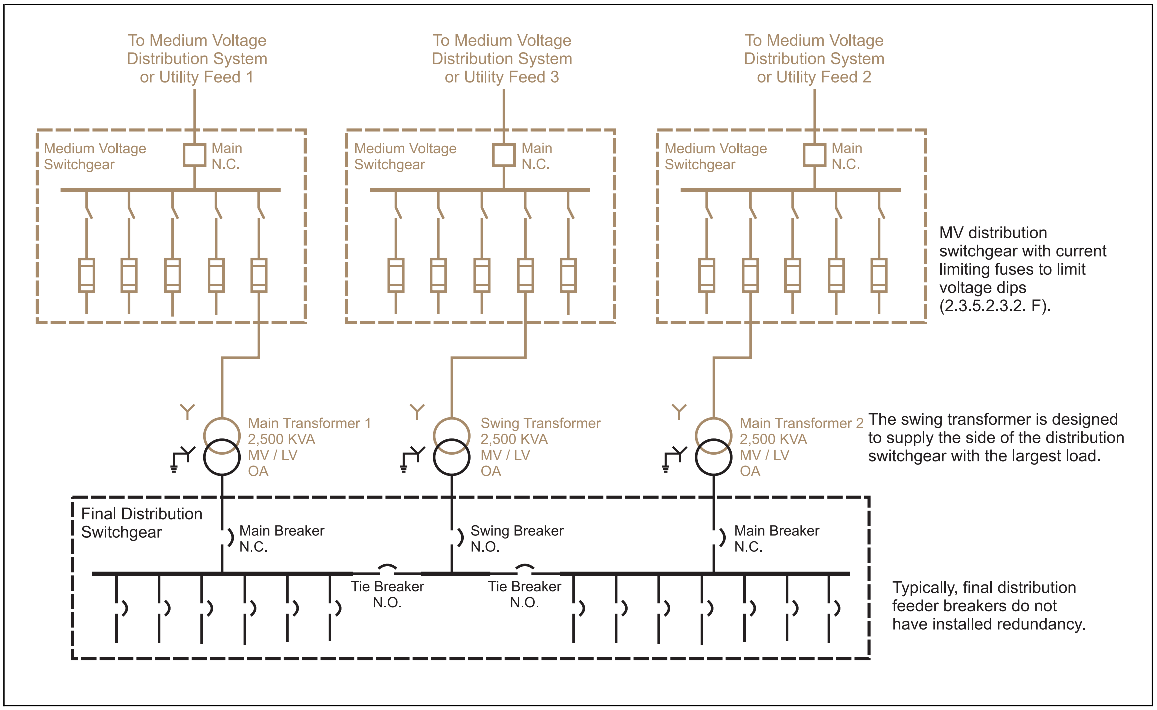


Fig. 2.5.2.2.2-1. Example of a typical triple-ended switchgear

2.5.2.3 Final Power Distribution

2.5.2.3.1 Arrange the final distribution system so the loads can be maintained with any one component of the system out of service for maintenance or repair.

2.5.2.4 Electrical Supervisory System

2.5.2.4.1 Install a supervisory system to monitor the incoming electrical utility, which includes at least the following:

A. Measures and records the quality of the incoming power at the utility connections.

B. Measures and records the quality of the electrical power at key points in the electrical distribution system, such as at the switchgear that supplies fab tools or the data center.

C. Alerts facility personnel of abnormal conditions in the electrical system.

2.5.2.5 Emergency Power and Uninterruptible Power Systems

2.5.2.5.1 Provide uninterruptible power systems (UPS) for data centers supporting production, critical process safety controls, critical control systems, supervisory control and data acquisition (SCADA) systems, safety monitoring equipment and emergency lighting.

2.5.2.5.2 Install UPS systems greater than 20 kWh in accordance with Data Sheet 5-28, *DC Battery Systems*, or 5-33, *Lithium-Ion Battery Energy Storage Systems*, as applicable.

2.5.2.5.3 Perform an analysis to identify support equipment necessary to achieve a controlled shut down of critical fab tools and systems and maintain the cleanroom envelope (i.e. positive pressure, temperature, and humidity) following loss of primary power. This analysis can include uninterruptible power supplies on specific equipment and the emergency power system (generator or energy storage). The emergency power system should be designed to maintain the cleanroom envelope for a minimum of three days.

The intent is to achieve a controlled shutdown that prevents tool damage and facilitates restart. The emergency power supply is not intended for long-term manufacturing support.

The analysis should include at least the following systems for emergency power needs:

- Lithography tools
- Furnaces
- Make-up and recirculation air
- Process chilled water pumps
- De-ionized water plant
- Acid waste neutralization
- Central source nitrogen supply system critical components
- Vacuum pumps
- Scrubbed exhaust systems

2.5.2.6 Inspection, Testing and Maintenance of Electrical Equipment

2.5.2.6.1 Inspect, test, maintain and operate electrical equipment in accordance with the following Data Sheets, as applicable:

Data Sheet 5-4, *Transformers*
Data Sheet 5-12, *Electric AC Generators*
Data Sheet 5-17, *Motors and Adjustable Speed Drives*
Data Sheet 5-19, *Switchgear and Circuit Breakers*
Data Sheet 5-20, *Electrical Testing*
Data Sheet 5-23, *Design and Protection of Emergency and Standby Power Systems*
Data Sheet 5-28, *DC Battery Systems*

2.5.2.6.2 Conduct infrared thermal scans for all tools at tool startup and at least annually for electrical components of combustible plastic tools. Tools of noncombustible construction should be scanned in accordance with OEM guidelines.

2.5.3 Air-Handling Systems

2.5.3.1 Locate outside air intakes to prevent smoke or fumes discharged during normal or emergency conditions (e.g., smoke/contaminant exhaust stacks, fuel gas regulator vent pipes, scrubbers) from entering the intake system where it could contaminate the fabrication areas.

2.5.3.2 Provide N+1 redundancy for each of the various air systems, including make-up air, recirculation air and the various exhaust systems (scrubbed/acid exhaust, general exhaust, VOC exhaust).

2.5.3.3 Evenly distribute the electrical supply cables/bus ducts to the make-up air, recirculation air, and the various exhaust systems (scrubbed/acid exhaust, general exhaust, VOC exhaust) between independent supplies. Supply adjacent air handling units from alternate supply cables/bus ducts and motor control centers (MCC) as demonstrated in Figure 2.5.3.3-1. If one utility source is lost or one MCC fails, air flow can be maintained to all air zones of the fab.

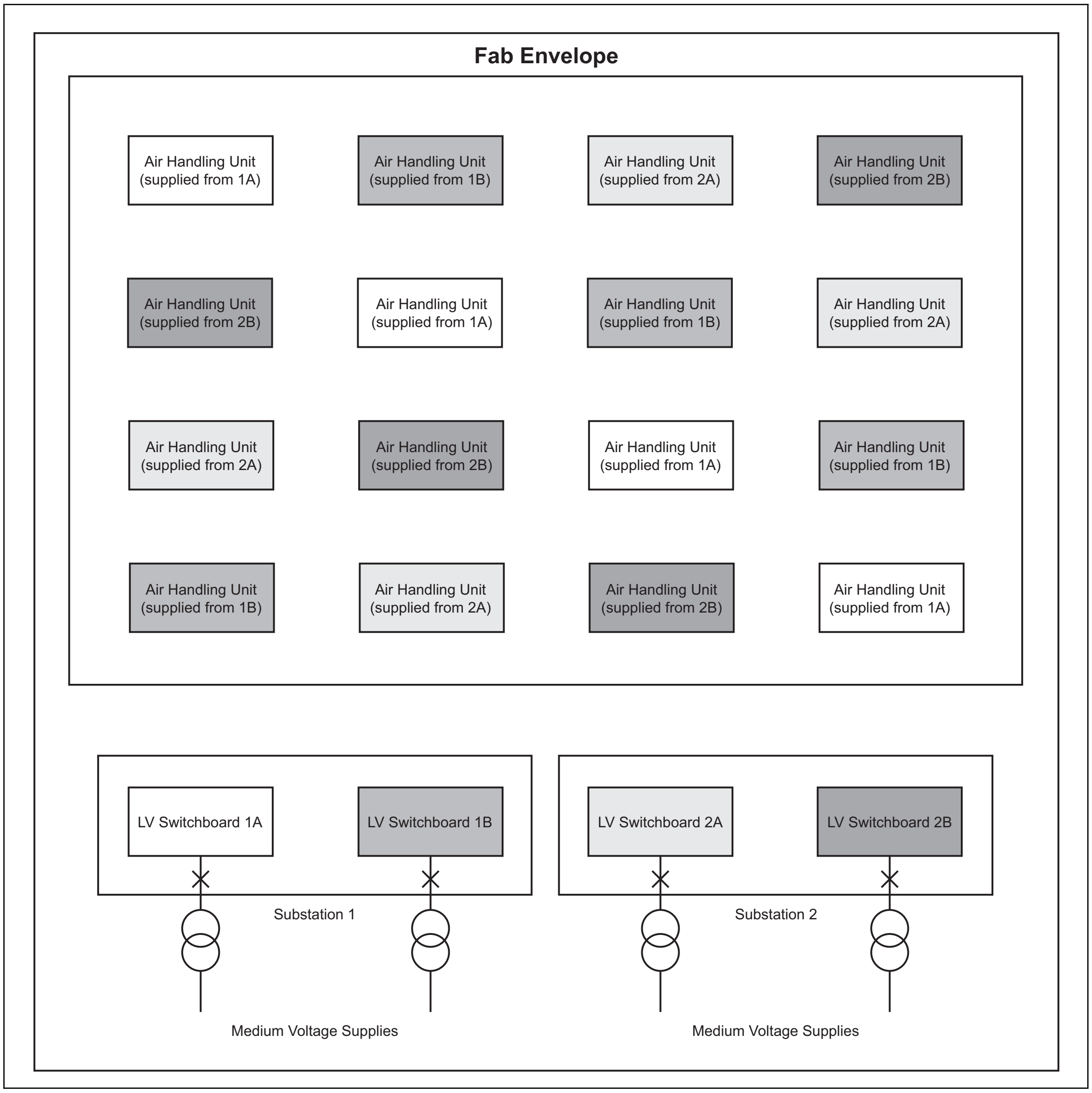


Fig. 2.5.3.3-1. Air handing units supplied from multiple independent supplies

2.5.3.4 Air-Handling Filters and Ductwork

2.5.3.4.1 Use HEPA (high efficiency particulate air) or ULPA (ultra-low penetration air) ceiling-mounted filter modules FM Approved to Approval Standard 4920, *Filters Used in Cleanroom Facilities* (hereafter referred to as FM 4920 Approved) whenever process and cleanroom compatibility will allow.

2.5.3.4.2 Use noncombustible materials or FM 4910 listed plastic for the filter housings, including fan-filter unit housings, louvers and ceiling grids.

2.5.3.4.3 Use noncombustible materials for exposed acoustical lining and for insulation of air-handling fan enclosures or fan-filter unit housings.

2.5.3.4.4 If foam insulation material is applied to the exterior of air-handling ductwork, use materials specified in Section 2.4.3.5.

2.5.3.4.5 Do not store spare filters in the fan deck.

2.5.4 Steam, Hot Water and Chilled Water Systems

2.5.4.1 Provide redundancy (N+1) for critical mechanical equipment such as boilers, deaerators, chillers, cooling tower cells, pumps, compressors, humidification equipment, etc.

2.5.4.2 Evenly distribute the electrical supply cables/bus ducts to the Process chilled water (PCW) pumps between independent supplies.

2.5.5 Ultrapure Water (UPW) Systems

2.5.5.1 Provide N+1 redundancy for all pumping and process equipment in the UPW plant.

2.5.5.2 Evenly distribute the electrical supply cables/bus ducts to the critical systems in the UPW plant between independent supplies.

2.5.6 Air Compressors

2.5.6.1 Provide redundant (N+1) air compressors for the system.

2.5.6.2 Arrange air compressors in accordance with Data Sheet 7-95, *Compressors*.

2.5.6.3 Arrange intakes for air compressors so contaminants cannot be drawn into the system and delivered to manufacturing tools and other susceptible equipment.

2.5.6.3.1 Ensure the air compressor delivers air at the cleanliness and humidity level required by the equipment or tool. Where a dryer is provided, arrange to prevent operation of the air compressor unless the dryer is also in operation.

2.5.6.3.2 Provide continuous monitoring of the compressed air supply's moisture content, arranged to alarm at a constantly-attended location.

2.5.7 Central Source Nitrogen Supply Systems Operated by Facility or Contractor

2.5.7.1 Install air-separation processes in accordance with Data Sheet 7-35, *Air-Separation Processes*.

2.5.7.2 Design the nitrogen supply system so that automatic valves can be isolated and maintained without interruption to the plant's nitrogen supply.

2.5.7.3 Where nitrogen is supplied by an air separation plant, establish a backup nitrogen supply to maintain plant operations at 100% production during a short-term outage period. The backup nitrogen supply could include a secondary air separation plant, or liquefied nitrogen tanks and support equipment, with replenishment delivered before the supply reaches 20% liquid remaining. See Figure 2.5.7.3-1 for a sample layout of a central source nitrogen supply system with ASU and liquefied nitrogen backup.

A short-term outage could be associated with a routine maintenance activity or a repair that does not involve the cold box but requires bringing the ASU to ambient conditions. A short-term outage includes the warm-up period, the repair/maintenance time and the time required to bring the plant back to cryogenic conditions. A short-term outage for a smaller plant could be seven days; a larger plant should expect up to 20 days outage. (See Section 2.10.5.)

2.5.7.4 Install N+1 redundancy for nitrogen vaporizers (ambient or hot water).

2.5.7.5 Train operators in accordance with Data Sheet 10-8, *Operators*, with a focus on alarm management and emergency operating procedures, including for nitrogen purifiers.

The training should focus on emergency response procedures for responding personnel and communications with Remote Operators.

2.5.7.6 For nitrogen purifiers subject to overheating (i.e., oxygen contamination), provide high temperature interlocks arranged to automatically shut down and isolate the affected purifier(s). Arrange the control system to provide notification in the control room, to another constantly attended location or to specific operations' personnel.

2.5.7.7 Test safety control functions such as automatic switchover to backup supplies, alarm notifications and emergency response procedures at least annually, or more frequently when recommended by the equipment manufacturer. Coordinate these tests with a nitrogen supply contractor, as appropriate.

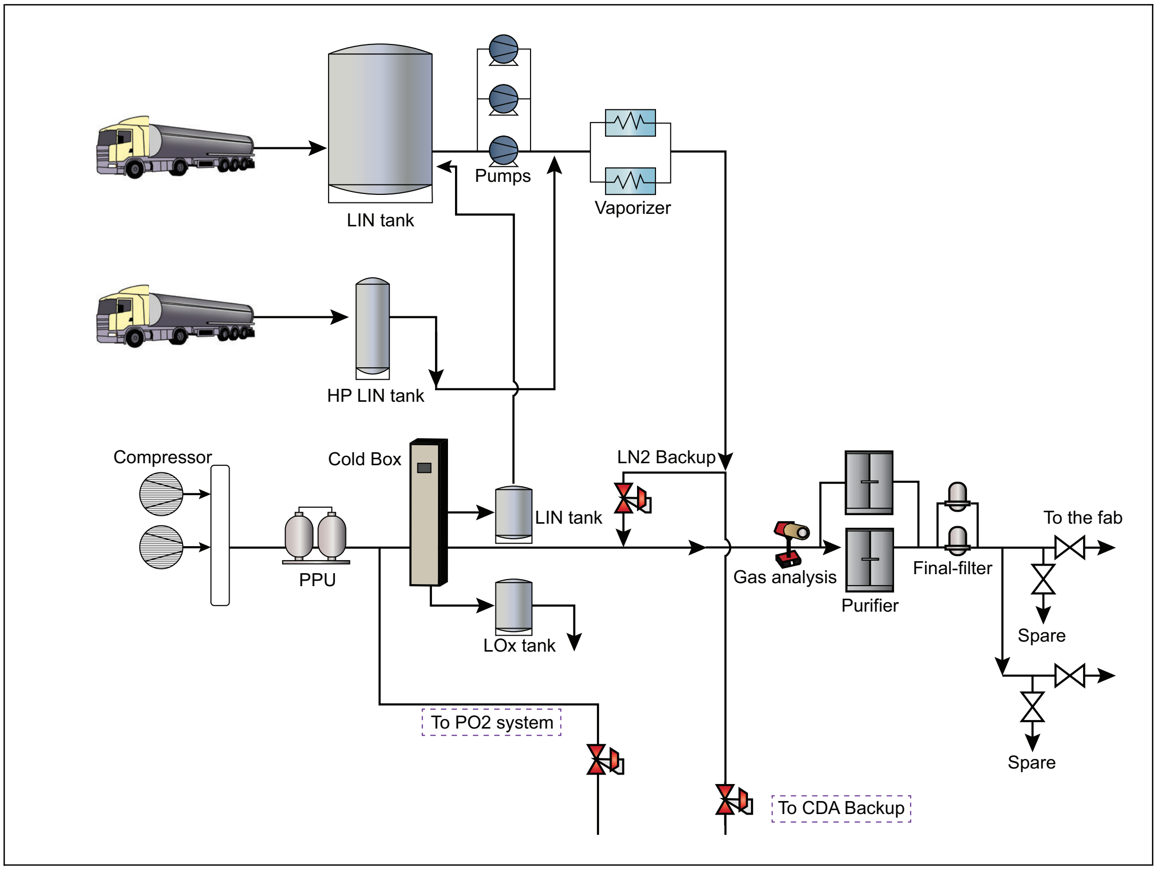


Fig. 2.5.7.3-1. Sample layout of a central source nitrogen supply system with ASU and liquefied nitrogen backup

2.5.7.8 Establish control bypass criteria for the nitrogen purity sensors to ensure that quality parameter deviations do not impact downstream equipment.

2.5.7.9 Install and maintain gas analysis equipment immediately downstream of the nitrogen supply source to constantly monitor nitrogen supply quality.

2.5.7.9.1 Provide N+1 redundancy or multiple independent sensors with deviation alarms for gas analysis equipment.

2.5.7.9.2 Provide an uninterruptible power supply and emergency power for gas analysis equipment.

2.5.7.9.3 Arrange the control system to provide notification in the control room and to another constantly attended location, or to specific operations personnel, of quality parameter deviations.

2.5.7.10 Provide a hard-wired interlock to automatically switch to the backup nitrogen supply, if the primary supply deviates from the specified purity limits.

2.5.7.10.1 Provide emergency power to the backup nitrogen system to ensure continuous operation in the event of a power outage.

2.5.7.11 Provide fire protection in accordance with Table 2.5.7.11-1 and spot protection over any potential spray or pool fire sources, such as large lube oil tanks.

Table 2.5.7.11-1. Sprinkler Protection for Compressors with a Lube-oil Hazard

Response, Nominal Temperature Rating, Orientation	*K factor gpm/psi$^{0.5}$ (L/min/bar$^{0.5}$)*	*Density gpm/ft^2 (mm/min)*	*Demand Area ft^2 (m^2)*	*Host Streams gpm (L/min)*	*Duration minutes*
SR/High/Any	≥8.0 (115)	0.3 (12)	4000 (370)	500 (1900)	60
SR/Ordinary/Any			6000 (560)		

2.5.8 Waste Treatment

2.5.8.1 Fume Exhaust Systems

2.5.8.1.1 Specify the use of only noncombustible (unlined ferrous metal) ductwork, or ductwork FM Approved to Approval Standard 4922, *Fume Exhaust Ducts or Fume and Smoke Exhaust Ducts*, listed under ″Fume and/or Smoke Exhaust Duct Systems for Use in Cleanrooms″ (hereafter referred to as FM 4922 approved ducts).

Other ductwork categories in the *Approval Guide* should not be considered for cleanroom application, including Fume or Smoke Exhaust Duct Systems, and Fume Exhaust Duct Systems.

2.5.8.1.2 Avoid the use of aluminum ducts, as they are subject to early collapse under fire conditions.

2.5.8.1.3 Do not connect combustible, flexible ductwork to combustible tools or tools using ignitable liquids.

2.5.8.1.4 Provide low-point condensate drains where condensate may accumulate in FM 4922 Approved ducts used for fume exhaust.

2.5.8.2 Gas Treatment Systems

2.5.8.2.1 Provide a point-of-use (POU) gas treatment (i.e., abatement) system if flammable gases in concentrations above 25% of their LEL can be present in gas cylinder purge panel vent lines, process equipment purge lines or process equipment vacuum pump exhaust. Arrange the gas treatment system to achieve the following conditions, as appropriate:

A. If the effluent contains both corrosive and flammable gas components, treat the flammable effluent first.

B. When hydrogen or other flammable gases are diluted instead of burned, monitor the hydrogen or flammable gas concentration to ensure it remains below 25% of the LEL.

2.5.8.2.2 Use noncombustible or FM 4922 Approved fume/smoke exhaust ductwork from the outlet of the flame oxidation system to the lateral (i.e., collector) duct connection point.

2.5.8.2.3 Protect fixed bed adsorbers as outlined in Data Sheet 7-2, *Waste Solvent Recovery*.

2.5.8.2.4 Protect fume incinerators, such as regenerative thermal oxidizers (RTOs), as outlined in Data Sheet 6-11, *Thermal and Regenerative Catalytic Oxidizers*.

2.5.8.3 Liquid Treatment Systems

2.5.8.3.1 Do not collect liquid waste beneath tools within the fab.

2.5.8.3.2 Provide coaxial (i.e., double containment) piping for liquid waste systems that are pumped (pressurized).

2.5.8.3.3 Provide separate drainage systems for incompatible liquid waste streams.

2.5.8.3.4 Use metallic piping for ignitable liquid waste.

2.5.8.3.5 Label drainage systems to identify their intended contents.

2.5.8.3.6 Protect collection containers located in the subfab as follows:

A. Provide high liquid level sensors on collection drums or totes arranged to initiate an alarm at a constantly attended location.

B. Provide secondary containment.

C. Provide sprinkler protection or an FM Approved gaseous suppression system for ignitable liquid waste containers located inside a cabinet or other enclosure.

D. Provide leak detection arranged to initiate an alarm at the tool and at a constantly attended location.

2.5.8.3.7 Protect facilities using waste solvent recovery systems, such as carbon bed adsorbers, in accordance with Data Sheet 7-2, *Waste Solvent Recovery*.

2.5.8.4 Facility (Central) Scrubbers

2.5.8.4.1 Do not locate scrubbers in the cleanroom envelope or on the floors above the cleanroom.

2.5.8.4.2 Locate scrubber discharge stacks away from the cleanroom air-handling system air intakes. Perform fume dispersion calculations to confirm safe separation distances if any uncertainty exists regarding actual separation distances.

2.5.8.4.3 Protect scrubbers in accordance with Data Sheet 7-78, *Industrial Exhaust Systems*.

2.6 Production Tools

2.6.1 General

2.6.1.1 Install production tools constructed predominantly of noncombustible (e.g., metallic) materials or FM 4910 listed plastics. Limit the use of non-FM 4910 listed plastics (for items such as knobs, buttons, electrical contacts, terminal strips, etc.) to no more than 1 lb/ft^2 (5 kg/m^2) of the tool footprint or 1% by weight of the total plastics used to make the tool. Avoid concentrations of non-FM 4910 listed plastics.

2.6.1.2 If a tool contains combustible materials in excess of 1 lb/ft^2 (5 kg/m), the fire hazard can be reduced using one of the following methods (listed in descending order of preference):

A. Replace combustible plastic components with FM 4910 listed plastic.

B. Provide adequate fire detection and suppression to protect the tool and associated process hazards (See Section 2.6.4.3).

2.6.2 Photolithography

2.6.2.1 Steppers and Scanners

2.6.2.1.1 Use FM 4920 Approved HEPA/ULPA filters within the self-contained air-conditioning units for the stepper and scanners, typically located in the subfab.

2.6.2.1.2 Ensure the stepper or scanner air-handling ductwork materials of construction are in accordance with Section 2.5.3.4.

2.6.2.1.3 If foam insulation material is applied to the exterior of the air-handling ductwork, use materials specified in Section 2.4.3.5.

2.6.2.2 Extreme Ultraviolet (EUV)

2.6.2.2.1 Arrange the electrical supply to the EUV in accordance with the applicable parts of Section 2.5.2.

2.6.2.2.2 Arrange and safeguard hydrogen storage and distribution systems per Data Sheet 7-91, *Hydrogen*; and NFPA 2, *Hydrogen Technologies Code*.

2.6.2.2.3 Arrange and safeguard the abatement systems for waste gas treatment in accordance with Section 2.5.8.2.

2.6.2.2.4 Provide interlocks to ensure the abatement system is in operation prior to the pre-purge step.

2.6.2.2.5 Provide very early warning fire detection (VEWFD) for the EUV system. Arrange detection to alarm locally and at a constantly attended location.

2.6.2.2.6 Provide hydrogen detection for the EUV system at points of potential leakage such as exhausted enclosures. Arrange detection to alarm locally and at a constantly attended location.

2.6.2.2.7 Provide leak detection for the cooling water system, arranged to alarm locally and at a constantly attended location.

2.6.2.2.8 Use noncombustible air supply and return ductwork. If foam-insulating material is applied to the air supply and return ductwork, use noncombustible material or FM 4924 Approved plastic for flexible ductwork and FM 4910 listed plastic for rigid ductwork.

2.6.2.2.9 Where cranes are used to remove or restore components in EUV equipment, establish and maintain lift plans with detailed standard operating procedures on safe lifting of components for equipment maintenance and service. Only allow these procedures to be performed by trained personnel.

2.6.2.2.9.1 Inspect, operate and maintain cranes associated with EUV equipment in accordance with Data Sheet 1-62, *Cranes*, and local codes/regulations.

2.6.2.3 Photolithography Equipment Protection

2.6.2.3.1 Install a wet pipe sprinkler system in accordance with Section 2.4.4.1.

2.6.2.3.2 In areas where water leakage will result in significant tool downtime, a pre-action system activated by the very early warning fire detection system specified in Section 2.4.4.8 is acceptable if the design meets the following criteria:

A. Corrosion mitigation measures, such as nitrogen charge or vacuum sprinkler pipe systems, are used.

B. Test frequency is in accordance with Data sheet 2-81, *Fire Protection System Inspection, Testing, and Maintenance*, to ensure operability on demand.

C. An FM Approved, high-sensitivity smoke detection system that will detect a developing fire is dedicated to the photolithography area.

D. The maximum water delivery time at the most remote head is 60 seconds.

E. Additional fittings are installed to facilitate drainage following activation.

2.6.2.4 Wafer Tracks

2.6.2.4.1 Locate HPM liquids used in coating and developing wafer track tools within the tool or in a separate noncombustible distribution cabinet located at fab or subfab levels.

2.6.2.4.2 Design the wafer track to contain the minimum amount of in-process chemical storage for efficient production.

2.6.2.4.3 Use noncombustible ductwork for the wafer track process exhaust hookup (branch) duct or FM 4922 Approved fume/smoke exhaust duct systems for use in cleanrooms.

2.6.2.4.4 Ensure materials of construction for the wafer track air handling ductwork are in accordance with Section 2.5.3.4.

2.6.2.4.5 If foam insulation material is applied to the exterior of the air handling ductwork, use materials as specified in Section 2.4.3.5.

2.6.2.4.6 Use stainless steel containers for dispensing ignitable liquids. Use nitrogen or another inert gas for liquid transfer.

2.6.2.4.7 Where stainless-steel containers are not available, provide secondary containment for liquids dispensed from plastic or glass containers; and design the containment to hold all the liquids within the tool's plastic and glass containers.

2.6.2.4.8 Provide liquid leak or vapor detection interlocked to shut down the flow of liquid and alarm to a constantly attended location.

2.6.2.4.9 Use electrical equipment suitable for the hazardous environment in accordance with one of the two options below:

A. If adequate ventilation is present to maintain the vapor-air concentration below 25% of the LFL, provide electrically rated equipment suitable for a Class I, Division 2 (Zone 2) environment.

B. If ventilation is insufficient to maintain the vapor-air concentration below 25% of the LFL, provide electrically rated equipment suitable for a Class I, Division 1 (Zone 1) environment.

2.6.2.4.10 Interlock the wafer track power to shut down if the vapor-air concentration exceeds 25% of the LFL.

2.6.2.4.11 Use one of the following to convey ignitable liquids from their dispensing canisters to their point of application:

- Metallic (stainless steel or other suitable material) piping or tubing
- Coaxial piping or tubing with a metallic outer encasement

2.6.2.4.12 Use metallic piping or tubing for ignitable liquids, and coaxial (double containment) plastic piping or tubing for nonignitable liquids from the subfab distribution cabinet to the tool at fab level.

2.6.3 Electron Beam Exposure System (E-Beam)

2.6.3.1 Locate an electron beam exposure system (E-beam) in a cutoff room or dedicated enclosure. Provide noncombustible walls and a separate air-handling system. For multiple systems, enclose each in a separate cutoff room or enclosure.

2.6.3.2 Provide a cooling water leak detection system connected to a local and supervised alarm system.

2.6.3.3 Provide very early warning fire detection (VEWFD) in the exhaust ducting connected to the tool or the E-beam chamber. Connect the VEWFD system to a constantly attended location and interlock it to safely shut down power to the tool.

2.6.4 Wet Processing Tools

2.6.4.1 Process Liquid Heating Systems

2.6.4.1.1 Use a noncombustible (metal) bench or tool for heating ignitable liquids.

2.6.4.1.2 Do not use electric immersion heaters.

2.6.4.1.3 Maintain process liquid heating systems in accordance with the manufacturer's recommended maintenance schedule. Of particular importance is the recommended frequency of replacement for items such as seals, tanks, heater elements, etc.

2.6.4.1.4 Provide the following basic safeguards as applicable:

A. Low-liquid level safety interlocks in addition to process control of the liquid level.

B. Redundant, high-temperature limit switches, which are independent of process temperature control. Arrange these switches to shut off power to the heating system and sound an alarm.

2.6.4.1.5 For bonded heaters, provide the following additional safeguards:

A. Use noncombustible material or FM 4910 listed plastic for the outer enclosure around the bonded heater.

B. Review the location of the bonded heating system with respect to other combustible materials. If located adjacent to combustible materials, provide a noncombustible barrier around the heating system.

2.6.4.1.6 Conduct preventive maintenance and testing of all safety interlocks on liquid heating systems as follows:

A. Conduct quarterly tests on low-liquid level and high-temperature interlocks to ensure proper operation.

B. Visually inspect all electrical connections to heating systems and their controls on a semiannual basis.

2.6.4.1.6.1 Use nonignitable or FM Approved heat transfer media in process liquid heating systems. If an ignitable transfer liquid cannot be avoided, heat the liquid remotely in a properly designed heat exchanger that is external to the tool.

2.6.4.2 Hot Plates

2.6.4.2.1 Do not use hot plates within the cleanroom envelope. If their use is unavoidable, incorporate the following safeguards in the design of these systems:

A. Limit hot plate usage to noncombustible tools whenever possible. If the use of a hot plate on an existing combustible tool is necessary, provide a stainless-steel insert for the hot plate.

B. Use inherently safe design for hot plates, so they can be operated for extended periods at full power without deforming or overheating any external surfaces.

C. Provide redundant, high-temperature limit switches, independent of process temperature controls, for all hot plates. Arrange these switches to shut off power to the heating system and sound an alarm if the high- temperature limit is exceeded.

D.Provide non-digital hot plates with a “power-on” indicator light and a temperature control knob that stops at a clearly marked “OFF” position.

E. Do not leave hot plates in the “ON” position during non-working hours. Install a timer on the hot plate that will automatically shut it off if left unattended.

F. Do not store combustible material or ignitable liquid near hot plates in a way that could allow a spill to come in contact with the unit.

2.6.4.3 Wet Processing Tools Protection

2.6.4.3.1 Provide an FM Approved fire suppression system (e.g., CO^2 or water mist) in wet processing tools containing ignitable liquid. Design the fire suppression system for the specific end-use application of the semiconductor equipment in accordance with Appendix C.

The need for active fire suppression can be evaluated through the PHA, performed in accordance with Section 2.2, when the analysis addresses engineering controls, construction and compartmentalization of ignitable liquids within the wet processing tool.

2.6.4.3.2 For wet processing tools not meeting the criteria in Section 2.6.1.1 and constructed of non-FM 4910 listed plastics or other combustible materials, provide fixed fire detection and suppression in accordance with Appendix C.

2.6.4.3.3 Protect the subsurface area of noncombustible wet processing tools handling ignitable liquid unless both of the following conditions are met:

A. No plastic tanks, plastic piping or other combustible material is present in the subsurface area.

B. The existing hook-up (branch) duct to the wet processing tool is 1) a noncombustible, FM 4922 Approved, fume/smoke exhaust duct for use in cleanrooms or 2) protected by an automatic sprinkler system installed within the tool transition piece or in the ductwork no more than 2 ft (0.6 m) from the duct connection point to the tool.

2.6.4.3.4 Provide process exhaust to reduce the concentration of ignitable vapor to less than 25% of the lower flammability limit (LFL) in tools using ignitable liquid.

2.6.4.3.5 Provide wet processing tools used in cleanrooms with a perforated raised floor and/or open waffle slab and spill containment features sized to contain the entire liquid contents of the tool or remove a spilled liquid.

2.6.4.3.6 Do not store chemicals or ignitable liquid within the wet processing tool. Use FM Approved safety cabinets for storage within the fab.

2.6.5 IPA Vapor Dryer

2.6.5.1 Protect canisters dispensing IPA in accordance with Section 2.6.2.4

2.6.5.2 Provide the IPA dryer with vapor detectors in each control cabinet and exhaust plenum as follows:

A. Arrange detectors to alarm when the vapor-air mixture reaches or exceeds 25% of the lower explosive limit.

B. Have them interlocked to alarm on detector failure

2.6.5.3 Provide the heater system with overcurrent protection, over-temperature protection and low/high liquid level sensors interlocked to shut off power to the dryer in the event of an alarm.

2.6.6 Ion Implanters

2.6.6.1 Use non-oil-filled transformers (e.g., cast resin dry-type) or motor generator (MG) sets to supply power to the ion implanter whenever process compatibility allows.

2.6.6.2 Protect mineral oil-filled transformers against high-energy and internal arcing faults by the following method:

A. Determine the three-phase, bolted, short-circuit current at the terminals of the ion implanter isolation transformer.

B. Determine if any current-limiting fuses are located upstream of the ion implanter's main circuit breaker.

C. If current-limiting fuses are provided, determine if the fuses will limit the let-through energy to less than 250,000 A^2s in the event of a three-phase fault at the terminals of the ion implanter isolation transformer. A typical electrical schematic is provided in Figure 2.6.6.2-1.

D. If current-limiting fuses are not provided, or if the existing fuses are not adequate, recommend the installation of current-limiting fuses capable of protecting the ion implanter isolation transformer against three-phase, bolted, short circuit faults at the transformer's terminals—even if the circuit breaker can limit the fault energy to less than 500,000 A^2s.

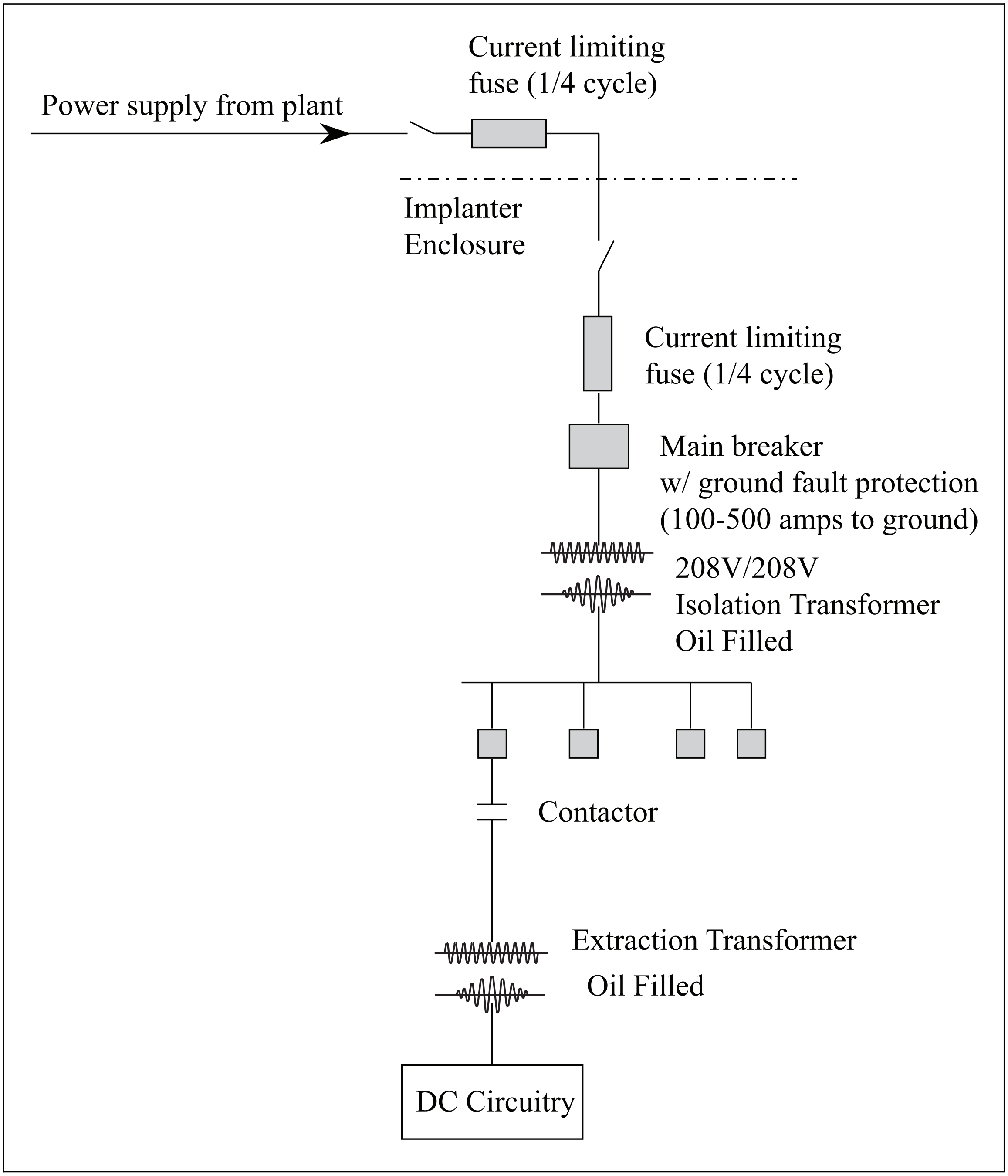


Fig. 2.6.6.2-1. Typical electrical feed for ion implanter (current-limiting fuse options shown)

2.6.6.3 Provide temperature monitoring devices interlocked to safely shut down the power to the ion implanter upon detection of overtemperature conditions in the power supply.

2.6.6.4 Provide optical or air-sampling smoke detection systems interlocked to de-energize high-voltage power, shut off the gas supply from the “gas-box,” and alarm at the tool and to a constantly attended location.

2.6.6.5 Arrange dopant gas sources in ion implanters in accordance with Section 2.8.9.

2.6.7 Rapid Thermal Anneal Tools

2.6.7.1 Protect oil-filled capacitors used in rapid thermal anneal tools in accordance with Data Sheet 5-30, *Power Factor Correction and Static Reactive Compensator Systems*.

2.6.8 Furnaces

2.6.8.1 Provide an uninterruptible power supply (UPS) to the process control circuits (typically 120 V power) on all furnaces and reactors (diffusion, chemical vapor deposition [CVD], low-pressure chemical vapor deposition [LPCVD], plasma enhanced chemical vapor deposition [PECVD], etc.).

2.6.8.2 Prevent quartz tubes/boats from exposing filter banks to high temperatures by one of the following methods:

A. Interlock process controls with ventilation to ensure quartz tubes/boats will not leave the furnace unless airflow is established.

B. Provide uninterruptible power supply to the ventilation fans.

2.6.8.3 Provide seismic restraint of the vertical furnace quartz tubes in accordance with Section 2.4.3.8.5(E).

2.6.8.4 Use dry-type vacuum pumps whenever process compatibility allows.

2.6.8.5 Use inert vacuum pump oil with no fire point or flash point when oil-lubricated pumps are employed.

2.6.8.6 Where use of hydrocarbon oils cannot be avoided, provide a de-mister or coalescing-type oil filter to trap oil mist before it collects in exhaust ducts.

2.6.8.7 Install a foreline trap between furnaces and vacuum pumps that use hydrocarbon oil to prevent oil from entering the furnace tubes.

2.6.8.8 Equip vacuum pumps handling flammable waste gas in excess of 25% LEL with a waste gas treatment system (see Section 2.5.8.2).

2.6.9 Epitaxial Reactors

2.6.9.1 Provide hydrogen detection at points of potential leakage, such as exhausted enclosures. Arrange detectors to alarm locally and at a constantly attended location.

2.6.9.2 Provide point-of-use abatement systems for waste gas treatment, and arrange them in accordance with Section 2.5.8.2.

2.6.9.3 Provide an interlock to ensure the abatement system is in operation prior to the pre-purge step.

2.6.9.4 Use noncombustible ductwork or FM 4922 fume/smoke exhaust duct systems Approved for use in cleanrooms.

2.7 Automated Material-Handling Systems (AMHS) and Stockers

2.7.1 AMHS and Stockers Construction

2.7.1.1 Use noncombustible or FM 4910 listed plastic for AMHS track system components such as Litz cable holder and FOUP nests.

2.7.1.2 Use FM Approved fire doors/shutters when AMHS system tracks penetrate fire walls.

2.7.1.3 Use noncombustible or FM 4910 listed wall panels for the stocker housing (shell) enclosure.

2.7.2 AMHS and Stocker Protection

2.7.2.1 Locate stockers of 18 ft (4.3 m) or less in height so that cleanroom ceiling sprinklers are within the footprint of the stocker. Install K8 (K115) sprinklers over stockers at maximum 8 ft (2.4 m) spacing. (See Section 2.4.4 for sprinkler design criteria.) Where a stocker is enclosed at the top, provide automatic sprinkler protection inside the stocker.

For stockers over 18 ft (4.3 m) in height, contact your FM client service team for guidance.

2.7.2.2 Use air-handling filters in accordance with Section 2.5.3.4.

2.7.2.3 Install very early warning fire detection (VEWFD) inside the stocker enclosure, interlocked to shut down power to the stocker in the event of a third-level alarm condition. Transmit alarms locally and to a constantly attended location.

2.7.2.4 Install two-hour, fire-rated, FM Approved, horizontal-sliding fire doors in multi-level stockers at each floor penetration.

2.7.3 AMHS Controls

2.7.3.1 Provide redundant servers in different process control rooms or communications rooms if they are essential for the AMHS systems to operate.

2.7.4 Mask/Reticle Stocker Smoke Detection

2.7.4.1 Install very early warning fire detection system (VEWFD) in stockers that store high-value or critical masks/reticles.

2.7.5 Zero-Footprint Storage

2.7.5.1 Arrange zero-footprint storage and tracks such that it does not obstruct sprinkler heads over combustibles.

2.8 Process Gases: Storage and Handling

2.8.1 Gas Cylinder Storage

2.8.1.1 Arrange and protect the storage of gas cylinders in accordance with Data Sheet 7-50, *Compressed Gases in Portable Cylinders and Bulk Storage*.

2.8.2 Location of Cylinders Dispensing Hazardous Production Material (HPM) Gases

2.8.2.1 Locate silane cylinders in accordance with Data Sheet 7-108, *Silane*.

2.8.2.2 Isolate cylinders containing HPM gases on outdoor pads or in detached noncombustible buildings (see Figure 2.8.2.2-1).

2.8.2.3 When process gas cylinders containing flammable, highly reactive or pyrophoric materials (other than silane - see Data Sheet 7-108, *Silane*) are located in locations 3 through 6 of Figure 2.8.2.2-1, provide the room or building with damage-limiting construction (DLC) features in accordance with Data Sheet 1-44, *Damage-Limiting Construction*.

2.8.2.4 Locate outdoor process gas cylinder dispensing away from external exposures such as outdoor transformers, ignitable liquid storage, strong oxidizers and other yard storage.

2.8.2.5 Where outdoor process gas cylinder dispensing is exposed to external hazards, provide separation distances per Data Sheet 1-20, *Protection Against Exterior Fire Exposure*, fire barriers or a fixed suppression system.

2.8.2.6 Limit the number of process cylinders in service to the minimum necessary for efficient operations.

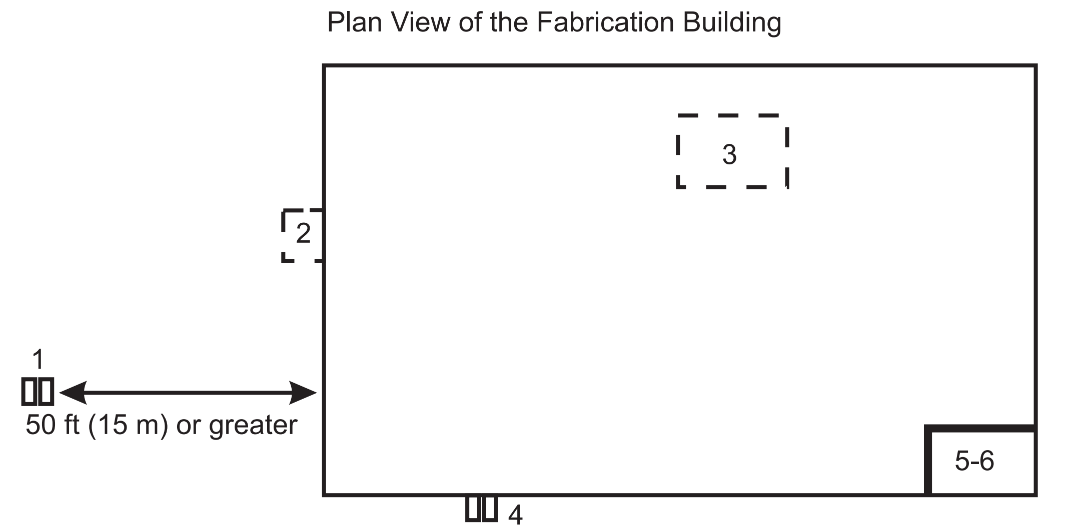
2.8.3 Construction of Cutoff Rooms

2.8.3.1 Construct a gas storage and dispensing cutoff room in accordance with Data Sheet 7-50, *Compressed Gases in Portable Cylinders and Bulk Storage*.

2.8.4 Gas Cabinets

2.8.4.1 For cabinets that hold flammable gas cylinders, install 165°F (74°C) rated, quick-response sprinklers designed to flow a minimum of 30 gpm (114 L/min).

2.8.4.2 Provide continuous internal ventilation inside gas cabinets and other enclosures that hold flammable, corrosive and toxic gas cylinders.



Recommended Locations
1. Gases located at least 50 ft (15 m) away from all major buildings
2. Outside ground level cutoff room provided with damage limiting construction (DLC)
3. Roof mounted room or cabinets with floor and/or room provided with DLC
4. Cabinets adjacent to outside of building with adjacent building wall provided with DLC
5. Ground level cutoff room provided with DLC
6. Second story cutoff room provided with DLC

Fig. 2.8.2.2-1. Process gas cylinder dispensing locations

2.8.4.3 Size the ventilation system to provide a minimum of 100 linear ft/min (0.51 linear m/s) of internal ventilation velocity across any potential leakage points such as cylinder heads, pressure regulators and controls. This air flow should be available with the cabinet doors and access window closed (i.e., air taken from cabinet louvers only).

2.8.4.4 For ventilation systems within the cabinets or enclosures, provide continuous ventilation monitoring connected to a constantly attended location.

2.8.4.5 Provide gas monitoring linked to a constantly attended location. Upon activation of the HPM gas monitoring system, automatically shut off the gas flow at the cylinder; and initiate an alarm to the emergency control system as follows:

A. For flammable, toxic, highly toxic, reactive and corrosive gases, automatically shut off the gas flow via normally-closed, pneumatically held open, automated cylinder valves (ACVs) located on the cylinder.

B. For other gases, locate automatic emergency shutoff valves (ESOV) as closely as practical to each cylinder CGA connection (threaded outlet on gas cylinder valve body).

C. For all gases, provide remote, manual actuation of the ACVs and ESOVs outside the gas distribution room and at the fabrication area exits.

2.8.4.6 Label gas cylinder cabinets to indicate the gases they contain and the particular gas concentration. Label gas lines and valves within the cabinet as to their function (i.e., process, purge or vent).

2.8.4.7 Limit the number of cylinders in an individual gas cabinet to no more than two. The two-cylinder limit does not include the purge gas cylinder.

2.8.4.8 Provide electrical equipment suitable for Class I, Division 2 (Zone 2) inside the gas cabinets in accordance with Data Sheet 5-1, *Electrical Equipment in Hazardous (Classified) Locations*.

2.8.5 HPM Gases Interlocks and Administrative Controls

2.8.5.1 Provide interlocks to automatically close the emergency shutoff valves or automated cylinder valves of HPM gas cylinders upon any of the following conditions:

A. Activation of the gas monitoring system (per Section 2.8.4.5)

B. Loss of cabinet ventilation

C. Activation of cabinet fire detectors for cylinders containing flammable or pyrophoric gases

D. Activation of an excess flow switch

E. Activation of a seismic sensor linked to the ESOV on the gas panel

2.8.5.2 Provide an excess flow valve, or an excess flow switch connected to the ACV or emergency shutoff valve, for all HPM gas cylinders.

2.8.5.3 Where feasible, provide a restrictive flow orifice (RFO) in the cylinder valve body for HPM gases. Size the RFO at 0.010 in. (0.25 mm) unless a larger orifice is needed to meet process demands.

An RFO might not be feasible for certain gases such as ammonia, dichlorosilane, chloride trifluoride and boron trichloride due to corrosion issues or low vapor pressure.

2.8.5.4 Connect only one cylinder to the process piping at any time. An automatic changeover system for the two process cylinders can be used to expedite the changeover process.

2.8.5.5 Limit the use of a common purge gas supply for compatible gases and cylinders located in the same room or gas pad.

2.8.5.6 Supply purge gases such as nitrogen, argon or helium from cylinders rather than from a central supply, which is susceptible to backflow of process gas.

2.8.5.7 Do not use a check valve as the only isolation device between the purge and process gas.

2.8.5.8 When flammable gases in concentrations above 25% of the LEL can be present in gas cylinder purge panel vent lines, process equipment purge lines or process equipment vacuum pump exhaust, provide a waste gas treatment system in accordance with Section 2.5.8.2.

2.8.6 Valve Manifold Boxes (VMBs) for Hazardous Production Material Gases

2.8.6.1 Use metallic construction for VMBs handling flammable gases.

2.8.6.2 Use noncombustible or FM 4910 listed materials for VMBs handling corrosive gases if they are located in the cleanroom or subfab.

2.8.6.3 Provide gas detection for gas VMB. Arrange detection to alarm at a constantly attended location and to shut down the gas flow via pneumatically controlled shutoff valves.

2.8.6.4 Provide continuous ventilation within the VMB. Monitor the ventilation at a constantly attended location, and automatically close the nearest isolation valves in the following locations upon loss of ventilation:

A. At local gas boxes near the tool or in the tool’s gas jungle

B. At individual sticks of the VMB

C. At the gas source

D. At the bulk source

2.8.7 Low Vapor Pressure Gases

2.8.7.1 In addition to the recommendations in Sections 2.8.1 through 2.8.5, provide heat tracing of the lines or a heated cylinder jacket with an appropriate high-temperature cut-off switch, where necessary, to achieve the required flow and pressure at the tool.

2.8.8 Chloride Trifluoride (ClF_3)

2.8.8.1 In addition to the recommendations in Sections 2.8.1 through 2.8.5, adhere to the following:

A. Place cylinders dispensing ClF_3 inside a gas cabinet, and locate the gas cabinet outside the cleanroom envelope.

B. Construct cylinders and piping out of materials suitable for ClF_3 service as recommended by the supplier.

C. Provide heat tracing to ensure the low vapor pressure ClF_3 gas does not condense into liquid in valves and process tubing. Design the heat trace system to limit the heating capacity to a maximum of 125°F (52°C), and provide a high-temperature cut-off switch.

D. Locate distribution piping so it slopes from the tool to the source cylinder cabinet. Eliminate all "dead legs."

E. Use coaxial (i.e., double containment) piping or tubing. Monitor the annular space for leakage, using either pressure or vacuum.

F. Provide gas detection inside ClF_3 cabinets and exhaust ductwork. Interlock the detectors to shut off the ClF_3 supply if either hydrogen fluoride or chlorine dioxide gas is detected.

G. Provide a heat or smoke detector in the gas cabinet. Interlock the detector to shut off the CIF_3 supply upon activation.

H. Do not install sprinkler protection inside ClF_3 gas cabinets, because chloride trifluoride will react violently with water if a leak occurs.

2.8.9 Dopant Gas Sources

2.8.9.1 Use sub-atmospheric gas sources (SAGS) instead of high-pressure cylinder sources whenever process compatibility will allow.

2.8.9.2 Provide and arrange sub-atmospheric gas cylinders and enclosures as follows:

A. Gas cabinets per Section 2.8.4

B. Ventilation per Sections 2.8.4.3 and 2.8.6.4

C. Ventilation monitoring per Section 2.8.4.4

D. Gas monitoring per Section 2.8.4.5

E. Interlocks per Section 2.8.5

F. Labeling per Section 2.8.4.6

G. Electrical equipment per Section 2.8.4.8

2.8.9.3 Provide sub-atmospheric gas cylinders with a pressure sensor designed to shut off the cylinder if the pressure exceeds 14 psi (1 bar).

2.8.10 Hydrogen

2.8.10.1 Design and install hydrogen storage and distribution systems in accordance with local code requirements; Data Sheet 7-91, *Hydrogen*; and industry standards.

2.8.10.2 Provide excess flow valves for hydrogen systems as close to the supply source as possible.

2.8.10.3 Provide emergency shutoff valves (ESOV) at the supply source.

2.8.10.4 Provide independent gas monitoring in areas where EUV equipment is installed, and arrange it to shut down the gas supply and alarm to a constantly-attended location upon activation.

2.8.10.5 Locate hydrogen purifiers outdoors or in detached, lightweight buildings.

2.8.10.6 Provide the following protection for hydrogen purifier areas or buildings:

A.Hydrogen gas detection and FM Approved optical hydrogen flame detection

B.An emergency power-off (EPO) switch in an accessible location

2.8.10.7 Protect forming gas (H_2 & N_2) mixing operations as follows:

A. Test gas analyzers and protection systems on the forming gas supply in accordance with Data Sheet 5-49, *Gas and Vapor Detectors and Analysis Systems*.

B. Provide an excess flow switch that is interlocked to automatically shut off the hydrogen supply at the main manifold.

C. Identify and clearly label the manual shutoff valve for the forming gas at the utility riser.

D. Train facility personnel to operate the manual shutoff valves at the utility riser in the event of a fire.

2.8.11 Silane

2.8.11.1 Protect silane storage and delivery systems in accordance with Data Sheet 7-108, *Silane*.

2.9 Process Liquids: Storage and Handling

2.9.1 Storage

2.9.1.1 Store ignitable liquids in accordance with Data Sheet 7-29, *Ignitable Liquid Storage in Portable Containers*.

2.9.1.2 Do not store HPM liquids within the cleanroom envelope. If these liquids must be located within the cleanroom envelop, arrange them as follows:

A. Limit quantities of HPM liquids to no greater than a daily supply.

B. Store ignitable liquids inside FM Approved safety cabinets that have self-closing doors.

C. Store corrosive liquids inside FM Approved metal safety cabinets or inside cabinets made with FM 4910 listed plastic materials.

D. Do not store acids and oxidizers in the same cabinet with ignitable liquids.

E. Provide each cabinet with the necessary features to contain at least 110% of the volume of the largest container within the cabinet.

2.9.2 Location of Dispensing Operations for Hazardous Production Material (HPM) Liquids

2.9.2.1 Locate dispensing operations that involve ignitable liquids (including liquid dopant containers and bubblers) in accordance with Data Sheet 7-32, *Ignitable Liquid Operations*.

2.9.2.2 Locate ignitable liquid storage and dispensing operations in separate cutoff rooms, separated by a one-hour rated fire wall.

2.9.3 Handling of HPM Liquids

2.9.3.1 Handle ignitable liquids as follows:

A. Fill pressurized stainless-steel canisters, safety cans, squeeze bottles and other small containers in a room separate from fabrication areas.

B. Dispense ignitable liquids used in fabrication areas from stainless steel canisters no larger than 1 gal (3.8 L) in capacity.

C. Provide carriers designed to protect glass or plastic ignitable liquid containers from spills during transit.

2.9.3.2 Do not transport corrosives, oxidizers and ignitable liquids in the same cart.

2.9.3.3 Design the cart to transport containers within an enclosure and to contain a spill from the largest single container transported.

2.9.3.4 Limit the size of a container transported in a cart to 1 gal (3.8 L).

2.9.3.5 Do not exceed 25 gal (95 L) total capacity with carts used for transporting process chemicals.

2.9.3.6 Do not store ignitable or combustible chemicals within plastic wet processing tools.

2.9.4 Bulk Hazardous Production Material (HPM) Liquid Distribution

2.9.4.1 Use welded stainless-steel tubing/piping to carry ignitable liquids.

2.9.4.2 Use stainless steel or coaxial (i.e., double containment) plastic piping or tubing for corrosive liquids. Use coaxial piping or tubing (plastic inner and steel outer) for ignitable, corrosive liquids.

2.9.4.3 Locate tubing/piping to prevent physical damage.

2.9.4.4 Use metallic construction for bulk chemical distribution units that handle ignitable liquids.

2.9.4.5 Arrange the coaxial (double containment) piping of pumped corrosives liquids to drain back to the bulk chemical system.

2.9.4.6 Provide bulk chemical distribution units with double containment and drainage to a bulk waste tank, disposal area or treatment plant.

2.9.4.7 Provide leak detection for the distribution piping network, and have it interlocked to shut off the flow, activate a local alarm and send a signal to a constantly attended location. See Data Sheet 7-32, *Ignitable Liquids Operations*, for more information about leak detection systems.

2.9.4.8 Provide a manual emergency shutoff switch at each tool served by the bulk chemical system and at the bulk chemical distribution area. Arrange the emergency shutoff switch at the tool to simultaneously shut down all chemical systems supplying the affected tool (i.e., the flow from the valve manifold box).

2.9.4.9 When bulk chemical storage tanks are used, provide unique tank fill connections for each different chemical. Arrange supply hose connection outlets from the chemical supply vendor to only fit the specific chemical tank fill connection.

2.9.5 Valve Manifold Boxes (VMBs) for Hazardous Production Material (HPM) Liquids

2.9.5.1 Use metallic construction for VMBs that handle ignitable liquids.

2.9.5.2 Use FM 4910 listed plastics for VMBs that handle corrosive liquids if they are located in the cleanroom or subfab support areas.

2.9.5.3 Provide liquid leak or vapor detection for liquid VMBs. Interlock the liquid or vapor detection to shut down the pneumatic valves on the supply line to the VMB and send an alarm to a constantly attended location.

2.9.5.4 Provide continuous ventilation within VMBs that handle ignitable liquids. Monitor the ventilation at a constantly attended location. Arrange for an alarm to sound locally and at a constantly attended location if the ventilation fails.

2.9.6 Pyrophoric and Reactive Liquids

The following applies to pyrophoric and reactive (energetic) liquids that are very easy to ignite and classified by NFPA 704 as unstable reactive materials.

2.9.6.1 Locate cabinets and bulk containers dispensing pyrophoric and reactive liquids in a cutoff room that is outside the cleanroom envelope.

The optimal arrangement for pyrophoric and reactive liquids distribution is to have a bulk supply located in the dirty sub-fab, connected to an ampoule or “day tank” on-board the tool. This arrangement limits the potential for an uncontrolled release in the cleanroom envelope by limiting the quantity in the cleanroom and avoiding transport of ampoules through the cleanroom envelope.

2.9.6.2 Limit the quantity of pyrophoric or reactive liquid stored in each bulk cabinet to 5 gal (19 L).

2.9.6.3 Limit the maximum capacity of ampoules on-board process tools to 0.5 gal (2 L).

2.9.6.4 Provide pyrophoric and reactive liquid cylinders with different connection types for inlet and outlet connections to prevent misorientation.

2.9.6.5 Provide the following on a reactive or pyrophoric liquid bulk distribution cabinet:

A. Minimum 12-gauge (0.097 in. [2.5 mm]) steel construction with self-closing doors

B. A reservoir to contain spilled liquid up to the volume of the largest single container in the cabinet

C. An exhaust system to remove the byproducts of combustion and convey them directly to an exhaust path

D. An FM Approved optical flame detector or very early warning fire detection (VEWFD). Confirm the optical flame detector will respond to the flame signature of the pyrophoric or related liquid being dispensed. Interlock the detection systems to automatically close the shutoff valve(s).

E. An interlock to prevent dispensing with the door open

F. An emergency or continuous nitrogen inerting system to control the rate of combustion of released material. Design the inerting system in accordance with Data Sheet 7-59, *Inerting and Purging Vessels and Equipment*.

G. An interlock to prevent distribution until the emergency or continuous inerting system is verified and available.

2.9.6.6 Provide grounding for the distribution cabinet and container.

2.9.6.7 Provide a normally-closed, pneumatically held-open, automatic shutoff valve on each container of pyrophoric or reactive liquid. Interlock this valve to shut off liquid flow, and to shut off and vent the nitrogen supply to the container, upon any of the following conditions:

A. Activation of fire detection system in the cabinet

B. Loss of electrical power to the cabinet and/or tool

C. Activation of seismic sensor, where applicable

D. Any action that shuts down the tool being supplied with liquid

2.9.6.8 Design the distribution system control as a safety instrumented system in accordance with Data Sheet 7-45, *Safety Controls, Alarms, and Interlocks (SCAI)*.

2.9.6.9 Initiate a local alarm (both audible and visual) within the fabrication area, and transmit a signal to a constantly-attended location upon closure of the automatic shutoff valve on the container of pyrophoric liquid.

2.9.6.10 Provide a manual emergency shutoff switch at the tool and at the distribution cabinet. Locate them in a readily accessible location.

2.9.6.11 Establish and maintain detailed container and ampoule change-out procedures for this high-risk activity. Only allow container and ampoule change-out to be performed by personnel trained in this procedure.

2.9.6.12 Establish emergency response procedures for loss of containment involving pyrophoric or reactive materials.

2.9.6.13 Leave containers in their shipping packages until moved to distribution cabinets. Move containers using stable carts with fail-safe, automatic brakes.

2.9.6.14 Store cylinders awaiting use in a dedicated cut-off room or area having minimum one-hour fire walls, or in an Approved flammable liquids cabinet in an HPM cutoff room.

2.9.6.15 Use stainless steel piping or tubing for the pyrophoric liquid distribution system.

2.9.6.16 When a liquid bath is used for temperature control of pyrophoric and reactive liquids in a metal organic chemical vapor deposition (MOCVD) process, thoroughly inspect the baths and containers (ampoules) on a monthly basis. Doing so will ensure leak tightness to prevent the interaction of the liquid and the reactive material.

2.10 Human Element

2.10.1 Emergency Response Team (ERT)

2.10.1.1 Develop documented emergency operating procedures. Include emergency procedures for sounding an alarm, providing prompt access to the building, shutting off all process gases, maintaining fume exhaust and manually activating smoke control systems that are not automatic.

2.10.1.2 Establish an emergency response team (ERT) for all operating shifts in accordance with Data Sheet 10-1, *Pre-Incident Planning*. Train personnel to respond promptly and safely to liquid or gas incidents, perform incipient firefighting, handle liquid leakage releases and conduct salvage operations. Integrate the ERT into the local agency incident command structure.

2.10.1.3 Provide quarterly, documented training for the ERT. Include the fire service and other responding agencies in the training program as appropriate. Ensure the ERT is familiar with the location of emergency shutoffs for various gases and liquids, emergency exhaust systems, power disconnects and protection of vital processes and equipment. Prepare the ERT to handle other emergencies, including earthquakes, floods, windstorms, etc., as appropriate for the location.

2.10.1.4 Develop and maintain a pre-incident plan in accordance with Data Sheet 10-1, *Pre-Incident Planning*. Coordinate the pre-incident plan with the fire service and any other responding agencies to address the above items. Work closely with these agencies when developing the plan to make certain they are fully aware of the items outlined above and to ensure proper coordination of emergency efforts. At least yearly, conduct a joint exercise (drill) involving the agencies that would normally respond to an emergency.

2.10.2 Disaster Recovery Planning

2.10.2.1 Develop a detailed disaster recovery plan for the fab (refer to Data Sheet 10-5, *Disaster Recovery Planning*).

2.10.2.2 Annually review and test the disaster recovery plan to ensure it is current and functional.

2.10.2.3 Establish pre-arranged contracts with qualified restoration vendors who have semiconductor industry experience and who will guarantee an expedited (24-hour) response.

2.10.3 Business Continuity Planning

2.10.3.1 Develop a detailed, written business continuity plan for the fab. At a minimum, include the following information:

- Executive management support
- Utilization/relocation of personnel
- Facilities and equipment
- IT/telecom
- Suppliers
- Clients
- Plan implementation and testing

2.10.3.2 Annually conduct a corporate/site review and plan testing to ensure the plan is current and functional.

2.10.4 Contingency Planning

Redundancy (viable N+1) is the best approach to mitigate the potential for a loss due to equipment breakdown. However, all systems have required inspection, testing, and maintenance which will produce temporary periods where redundancy is not available. Developing an equipment contingency plan to mitigate the potential for an in-service failure during these periods is prudent. The equipment contingency plan can include critical equipment sparing, temporary installations or rental equipment.

2.10.4.1 Equipment Contingency Planning

When a semiconductor fab utility and/or support system equipment breakdown results in an unplanned outage to site processes and systems considered key to the continuity of operations, develop and maintain a documented, viable utility and support system equipment contingency plan (ECP) per Data Sheet 9-0, *Asset Integrity*. See Appendix C of that data sheet for guidance on the process of developing and maintaining a viable equipment contingency plan. Also refer to sparing, rental and redundant equipment mitigation strategy guidance in that data sheet.

Conduct a systematic, strategic assessment of fab utilities and support system equipment. Consider process bottlenecks, single points of failure, and unique, long lead-time equipment. Evaluate equipment integrity, reliability, remaining useful life, fitness for service and operating history/trends. Evaluate the type and scope of ECP needed to mitigate the equipment-specific breakdown exposures.

The semiconductor ECP includes recovery options/mitigation strategies—including repair/replacement/rental lead time options, used and/or surplus equipment, redundancy and sparing—to respond to and recover from the equipment breakdown exposures and minimize the downtime.

2.10.4.1.1 Evaluate at least the following elements in the contingency planning process specific to semiconductor utilities and support system equipment:

A. Electrical System Equipment:

- Primary power electrical distribution equipment (includes transformers, circuit breakers/switchgear). Evaluate unique, long lead-time equipment options, including sparing.
- Emergency power and UPS equipment

B. Air-Handling Equipment:

- Make-up air, recirculation air fans and various exhaust systems (scrubbed exhaust, general exhaust, VOC exhaust and calamity exhaust)
- Fan/motor package options, including sparing

C. Steam, Hot Water and Chilled Water Equipment:

- Boilers and deaerators
- Chillers and cooling tower cells
- Pumps and compressors
- Piping systems
- Rental equipment connections and installation considerations for steam and chilled water equipment

D. Ultrapure Water Equipment:

- Pumping and process equipment

E. Air Compressors:

- Rental equipment connections/installation considerations

F. Nitrogen Systems:

- Soft start transformer options, including sparing

G. Waste Treatment Systems:

- Fume exhaust
- Gas and liquid treatment
- Acid neutralization
- Critical system components, control systems and backup emergency holding tanks
- Scrubbers

2.10.4.1.2 Review and validate the ECP annually and when significant changes have occurred on site to manage change and confirm efficacy of the plan.

2.10.4.2 Sparing

2.10.4.2.1 Sparing can be a mitigation strategy to reduce the downtime caused by a semiconductor fab utility and support system equipment breakdown, depending on the type, compatibility, availability, fitness for the intended service and viability of the sparing. For general sparing guidance, see Data Sheet 9-0, *Asset Integrity*.

2.10.4.3 Equipment Breakdown Spares

2.10.4.3.1 Equipment breakdown spares for semiconductor fab utility and support system equipment are spares to be used in the event of an unplanned outage of this equipment to reduce downtime and restore operations. Provide equipment breakdown spares for circuit breakers in semiconductor fab HV and MV electrical utility equipment determined key to the continuity of operations.

2.10.4.3.2 Maintain the semiconductor fab utilities equipment breakdown spare viability per Data Sheet 9-0, *Asset Integrity*.

2.10.5 Service Interruption Planning

2.10.5.1 When the loss of utility and/or support system services for a semiconductor fab results in an unplanned outage to site processes and systems considered key to the continuity of site operations, develop and maintain a documented, viable service interruption plan (SIP).

Conduct a systematic, strategic assessment of fab utilities and support system services to identify in advance the impact , and response to, loss of service. Consider recovery from damage to work in process, tools, product spoilage in storage and process equipment, and impact on the process/equipment operating conditions and environment. Consider the timeline for an orderly shutdown and isolation of equipment per the documented emergency operating procedures, evaluate the state of the equipment and then restart and restore full operations per the documented standard operating procedures.

2.10.5.2 The semiconductor SIP includes recovery options/mitigation strategies to respond to/recover from the loss of services and mitigate the exposure. For electrical and nitrogen services, evaluate at least the following elements in the SIP process:

A. Electrical Service:

- System design/redundancy for critical electrical paths

  - Single points of failure
  - Critical load flexibility/continuity
  - Load shedding

- Capabilities/viability of the emergency power systems

  - Uninterruptible Power Systems (UPS)
  - Orderly transition from normal to emergency power
  - Duration of operation with on-site fuel supplies
  - Fuel supply/replenishment

B. Nitrogen Service:

- Ensure storage tank(s) are sized in terms of time (i.e., days of operation) to support 100% production
- Consider sizing and operation of vaporizers, including emergency operating procedures
- Ensure backup nitrogen supply is sized to maintain plant operations during short-term outages. (See Section 2.5.7.3.)
- Review the plan to replenish backup nitrogen supply for prolonged outages associated with air separation unit (ASU) equipment breakdown or shutdown due to a malfunction.
- Ensure the delivery of nitrogen in volumes to support production before the onsite supply is expected to be depleted.
- Ensure the delivery of the primary nitrogen supply in volumes to support production during a prolonged outage, such as a failure of a major subsystem or component.
- For trucking deliveries, consider transportation contingencies. Evaluate off-loading physical vehicle capacity, connection spacing to allow simultaneous unloading at each station, and individual/overall flow capacity.
- Where “soft-start” drives are used, establish procedures to replace the drive with a spare maintained as part of the ECP or to provide direct online start capability.

- Establish load shedding and shutdown processes/procedures due to loss of nitrogen, including process/equipment control and operating conditions/environment considerations.

2.10.5.3 Review and validate the SIP at least annually and when significant changes have occurred on site to manage change and confirm efficacy of the plan.

2.10.6 Housekeeping

2.10.6.1 Establish and maintain good housekeeping practices throughout the cleanroom envelope (airstream) spaces. Implement a regular inspection program. Keep a written record of the inspections, any deficiencies that are identified and how/when the deficiencies were corrected. Increase inspection frequency during construction projects or tool installations to ensure combustible loading is minimized.

2.10.6.2 Limit the storage of combustible materials within the cleanroom envelope to an absolute minimum. Keep necessary spare parts, manuals, etc. in normally closed metal cabinets.

2.10.6.3 Do not store non-process ignitable liquids (maintenance liquids) or ordinary combustibles inside or behind process equipment (tools).

3.0 SUPPORT FOR RECOMMENDATIONS

3.1 Construction and Location

3.1.1 Penetrations

Fire-resistance rated penetration seals do not prevent the passage of smoke until the seal expands when exposed to heat from a fire. A penetration seal with a leakage-rating will limit the passage of smoke before the seal is exposed to high temperatures. Laboratory leakage tests are conducted at ambient temperature and at 400° F (204° C).

3.1.2 Air-Handling Filters and Ductwork

Activated carbon filters (ACF) are used to reduce airborne molecular contamination (AMC). AMC is a collective term for molecules that react adversely with wafer surfaces and chip circuits. The main sources of AMC in the cleanroom include outside air, personnel, the out-gassing of construction materials, and process chemicals.

ACF usage can be found in fan filter units (FFU), process tools (such as wafer tracks and stepper/scanner air handling systems) and cleanroom make-up/recirculation air-handling unit intakes.

3.2 Utilities

3.2.1 General Electricity Types

General electricity at a wafer fabrication facility can be classified into three types:

A. Primary power. This is the normal power that runs the wafer fabrication facility. It is usually supplied by a public utility.

B. Uninterruptible power (UPS). This is power that comes on when problems occur with the quality of primary power (voltage sags, surges, momentary interruptions and other transients). Uninterruptible power is of short duration and is only designed to supply power to critical tools and processes long enough to allow the emergency power sources to come online. Uninterruptible power is typically supplied by static UPSs using batteries as the backup power source. These static UPSs have power supply durations measured in minutes.

C. Emergency/standby power systems. This is power that comes on when long-term interruptions of primary power occur. Typically, emergency power is sized to maintain cleanroom conditions and to run critical processes so the facility can restart quickly when primary power is restored. Emergency power cannot keep the wafer fabrication facility operating at full capacity. Emergency power is typically supplied by emergency diesel generators. These emergency power sources have power supply durations measured in hours or days.

3.2.2 Waste Treatment

3.2.2.1 Gas Treatment Systems

Two general types of treatment systems are used: facility (central) and point-of-use (POU).

The facility (central) acid exhaust system usually has the largest rate of airflow, which can be hundreds of thousands of cubic feet per minute (thousands of cubic meters per minute). Facility (central) acid scrubbers are used to treat emissions from the acid exhaust system before discharge to atmosphere. Other facility (central) exhaust systems that may be provided include ammonia, volatile organic compounds (VOC), general, heat, pyrophoric, etc.

Point-of-use (POU) systems are used to treat waste streams directly from the process tool before they enter the facility (central) exhaust system. POU systems are used to prevent exhaust restrictions, fires and explosions, corrosion, etc.

POU system types include wet scrubbers, oxidation, cold bed, hot bed, etc. The five types of oxidation systems include: passive air addition, flame oxidation, hot chamber oxidation, non-flame oxidation and catalytic oxidation.

The flame oxidation system uses either natural gas (less than 10 psi [0.69 bar]) or hydrogen to establish a flame curtain. A significant loss experience is associated with these systems, and Section 2.5.8.1 should be followed to reduce fire risk.

3.3 Protection

3.3.1 Third-Party Reviews

Semiconductor Equipment Material International (SEMI) is an industry trade group representing companies that supply products to the semiconductor industry. SEMI also publishes safety and facilities standards. Most notable is SEMI S2, mditEnvironmental, Health, and Safety Guideline for Semiconductor Manufacturing Equipment. This standard is typically used by third parties to assess semiconductor processing tools. Used in conjunction with SEMI S2 is SEMI S14, *Safety Guidelines for Fire Risk Assessment and Mitigation for Semiconductor Manufacturing Equipment*.

During a SEMI S2 review, each line item is assessed, and a determination is made as to whether it “Conforms,” “Does Not Conform,” or is “Not Applicable.” When a line item does not conform, a risk ranking, using a classic likelihood vs. consequence risk matrix, is assigned per SEMI S10, *Safety Guideline for Risk Assessment and Risk Evaluation Process*.

3.3.2 Fire Detection and Suppression for Wet Processing and Other Tools

In open-style tools, application of these recommendations is generally limited to tools with air exhaust flow rates not exceeding 150 cfm/linear ft (0.24 m^3/sec./linear m), unless the suppression system selected is specifically designed for higher air exhaust flow rates.

All clean room tool gaseous suppression systems (CO_2) testing was conducted by FM with a maximum threshold value established at 150 cfm/linear ft (0.24 m^3/sec/linear m) for exhaust. This testing does not mean a properly designed system on a tool having a higher exhaust rate is unacceptable. It means that particular scenario has not been tested and is beyond the scope of design parameters specified in this data sheet. In such cases, the suppression contractor will default to NFPA 12 for the design of the system.

3.3.3 Tool Construction Materials

FM 4910 listed plastic materials are primarily sheet stock (e.g., 4 ft x 8 ft [1.2 m x 2.4 m] sheets) used for constructing tool shells, internal partitions, enclosures, viewing windows, etc. The sheet stock is typically shipped with a very thin protective plastic sheet that is typically marked with the product name and reference to its FM 4910 listing.

FM 4910 listed plastics include a wide variety of material groups such as CPVC, ECTFE, FRP, Halar, PVC, PVDF and PP.

Many other components go into the building of a tool. These include printed circuit boards, knobs, hinges, handles, low-voltage cables, piping, process tanks, valves and pumps (in addition to other items not listed here). These components may or may not be available in FM 4910 listed plastic materials. Judgment is needed when evaluating non-FM 4910 listed plastic materials in tools, and the following should be considered:

A. Among non-FM 4910 listed plastics, polypropylene (PP), polyethylene (PE), PVC, polycarbonate (PC) and acrylics should be avoided in favor of Halar, PVDF and Teflon.

B. If PP, PE, PVC, PC and acrylic plastics are used, they should be spread throughout the tool (i.e., limit concentrations).

C. For process reasons, wetted surface compounds (tanks, pumps, valves, piping) are commonly made from PVDF, Halar and Teflon. Often, they are not the FM 4910 listed variety, or their listing status cannot be determined.

Consideration should be given to the proximity of the non-FM 4910 listed plastic to an ignition source. For example, a polypropylene outer shell on a heated tank is a much bigger hazard than a Lexan viewing window.

3.3.4 Stocker Fire Protection

In 2023, FM Research undertook a project to establish a scientific basis for fire protection recommendations related to stockers. The project consisted of fire testing representative samples of front-opening unified pods (FOUPs), water transport tests, and full-scale fire tests of a representative stocker design. Note that the protection guidance developed in this study does not focus on the source of the fire, but rather on how to mitigate the consequences of a fire in a stocker once the event is initiated.

3.3.4.1 FOUP Testing

To ensure the applicability of the research, FOUP samples having a base material of polycarbonate were tested to determine their flammability characteristics, including fire propagation index (FPI), thermal response parameter (TRP), and critical heat flux (CHF). Comparison of these test results enabled the selection of a specific FOUP to incorporate into the full-scale testing.

3.3.4.2 Water Transport Tests

Water transport tests were conducted to understand 1) the amount of time it takes for water from the sprinkler to reach various locations in the stocker, and 2) the distribution of water at any tier. The water transport testing was conducted with multiple sprinklers, including the K8 (K115) recommended in Section 2.7.2.1. (**Note:** the unit for K-factor is gpm/psi$^{1/2}$ [L/min/bar$^{1/2}$]) The sprinklers were arranged in accordance with the 8 ft x 8 ft (2.4 m x 2.4 m) spacing recommended in Section 2.7.2.1, with the K8 (K115) tests conducted with the sprinkler located at the centerline of the stocker and in a corner of the stocker footprint. The water transport testing established the transient time for water to reach various locations in the stocker, which was then used to inform the development of the full-scale fire tests.

3.3.4.3 Full-Scale Fire Tests

Two fire tests were conducted under the 20 MW Fire Products Collector (FPC) at the FM Research Campus to evaluate sprinkler protection for stocker fires (Figure 3.3.4.3-1). Both tests used the K8 (K115) sprinkler operating at the recommended pressure of 50 psi (3.45 bar). During the first test, the sprinkler was centered above the stocker; in the second test, the sprinkler was installed with an offset.

The test results show that the protection was adequate for both fire scenarios. It supports the recommendation to use K8 (K115) sprinklers at 50 psi (3.45 bar) with 8 ft (2.4 m) spacing for fire protection if the sprinkler is located within the stocker envelope.

Figure 3.3.4.3-2 shows an elevation view of the stocker design based on FM client reports. The test setup consisted of a stocker mockup 18 ft (5.5 m) tall, 6.9 ft (2.1 m) wide, and 22 ft (6.7 m) long. The main components of the test setup are: (1) plenum, (2) blower (for generating the downward airflow), (3) the mockup structure consisting of columns, steel walls, FOUPs and holders, (4) all instruments to record experimental data. As depicted in Figure 3.3.4.3-2, the mockup structure (capable of storing 120 FOUPs) held 12 tiers of FOUPs with five units per tier on each side across a 1.8 ft (0.56 m) aisle, during each fire test. Five FOUPs could be placed with spacing designed per client reports and fire protection recommended in Section 2.7.2 of this data sheet. The ceiling was replicated by a plenum placed on top of the stocker. The plenum surface was 30% open with 0.0625 in. (1.6 mm) perforation size to provide the downward air velocity.

Fig. 3.3.4.3-1. Fully assembled stocker structure under 20 MW (19 kBTU/sec) calorimeter in the Large Burn Laboratory (LBL) displaying the FOUP array behind the south wall (left) and fully enclosed setup (right).

A total of 120 FOUPs were installed inside the stocker, 60 FOUPs on each side. FOUPs were placed with their lids facing the aisle space in the stocker and the back of each FOUP against one of the long sides of the stocker wall. The ignitors were placed between two FOUPs to allow for a more challenging fire growth, instead of in the middle of tier 12 under a single FOUP (under column three). That way, the fire could grow on two FOUP columns simultaneously.

The instrumentation used for collecting experimental data included a fiberoptic cable system, a laser system for smoke measurements, cameras for visualization, thermocouples and heat flux sensors, and Simulated Thermal Elements (STEs). Four STEs were installed to monitor the thermal environment at the ceiling, including two that were installed to evaluate the likelihood that the fire would activate any additional sprinklers besides the one in the center.

The ignition location is marked on Tier 12 in Figure 3.3.4.3-2. Ignitors were placed towards the aisle space, facing the lid of the FOUP to increase the risk of fire jumping across the aisle. The ignitors were operated remotely because of the presence of the wall, which prevented direct access to the stocker at the time of ignition.

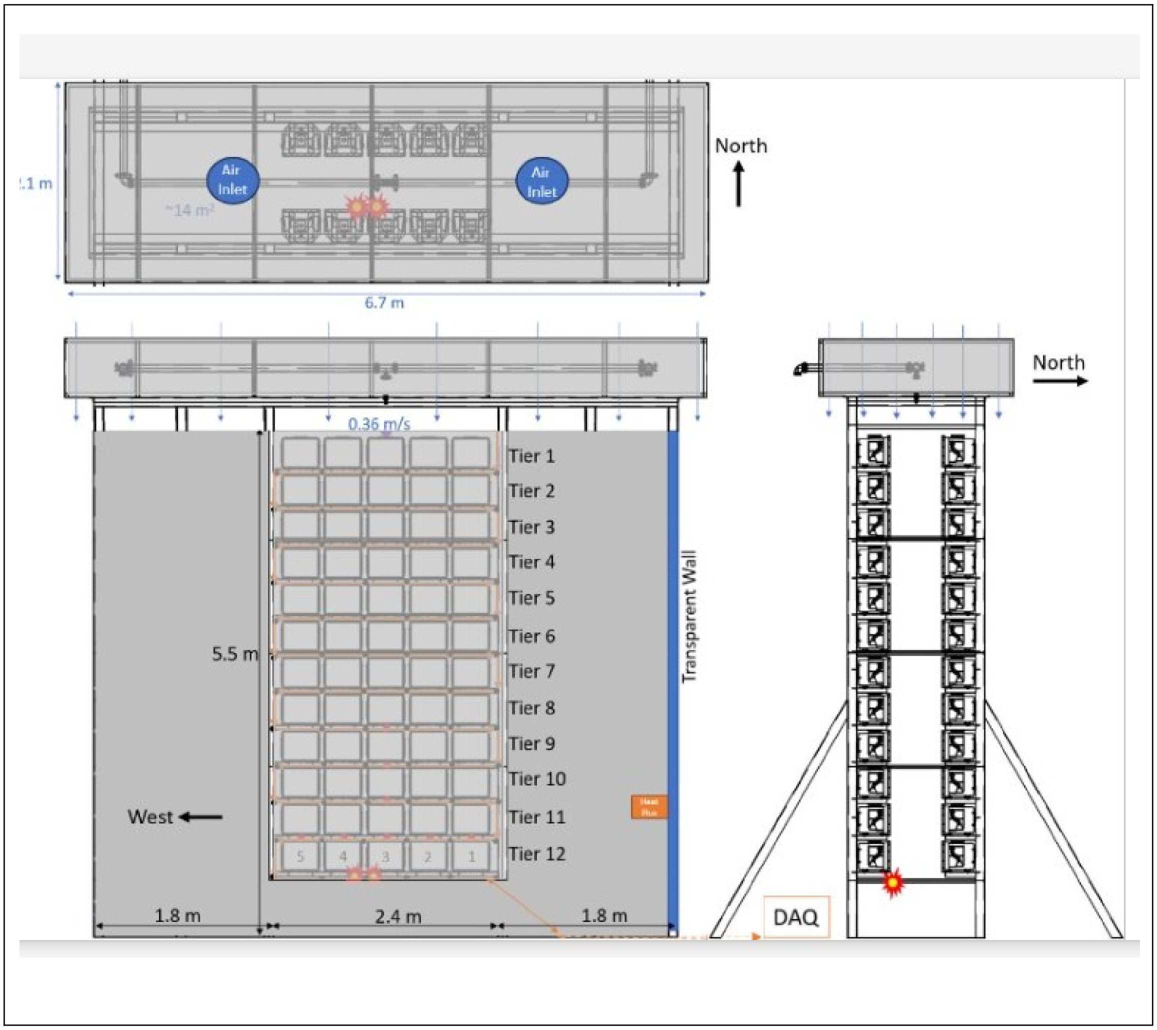


Fig. 3.3.4.3-2. Elevation view (lower left) showing ignition location, storage arrangement (behind the south wall), key dimensions and various instrumentation locations, accompanied with elevation view facing east (right) and plan view (top) above the plenum where air is forced to flow downward for the detailed mockup stocker.

3.3.4.3.1 Full-Scale Fire Test Results for Center Sprinkler Location

The first test was conducted with a single sprinkler installed over the center of the stocker with water pre-loaded up to 60 psi (4.14 bar). The sprinkler activated five minutes and 26 seconds after ignition. Upon activation, water wetted the commodity within seconds and extinguished the fire, which was mainly on the front side of the FOUPs (toward the aisle space) located at the ignition side of the storage array. The test ended 25 minutes after ignition at which time the fire was completely extinguished.

After completion of the test, examination of the FOUPs showed that thermal damage was limited to FOUPs centered above the ignition area up to Tier 7, as indicated in the temperature profiles recorded by the fiberoptic cable in Figure 3.3.4.3.1-1. For each tier, two temperature profiles were recorded at two different times: 326 seconds (blue line) and 420 seconds (red line), corresponding to the approximate sprinkler activation time and the peak temperature observed via the fiberoptic cable, respectively. Images from inside the stocker for these two distinct times are shown in the middle and right-most pictures in Figure 3.3.4.3.1-2 to illustrate the different fires at these different times. Fire did not propagate horizontally beyond columns three and four, where the ignition was centered. Clearly, the protection was adequate to control the fire inside a stocker of height up to 18 ft (5.5 m).

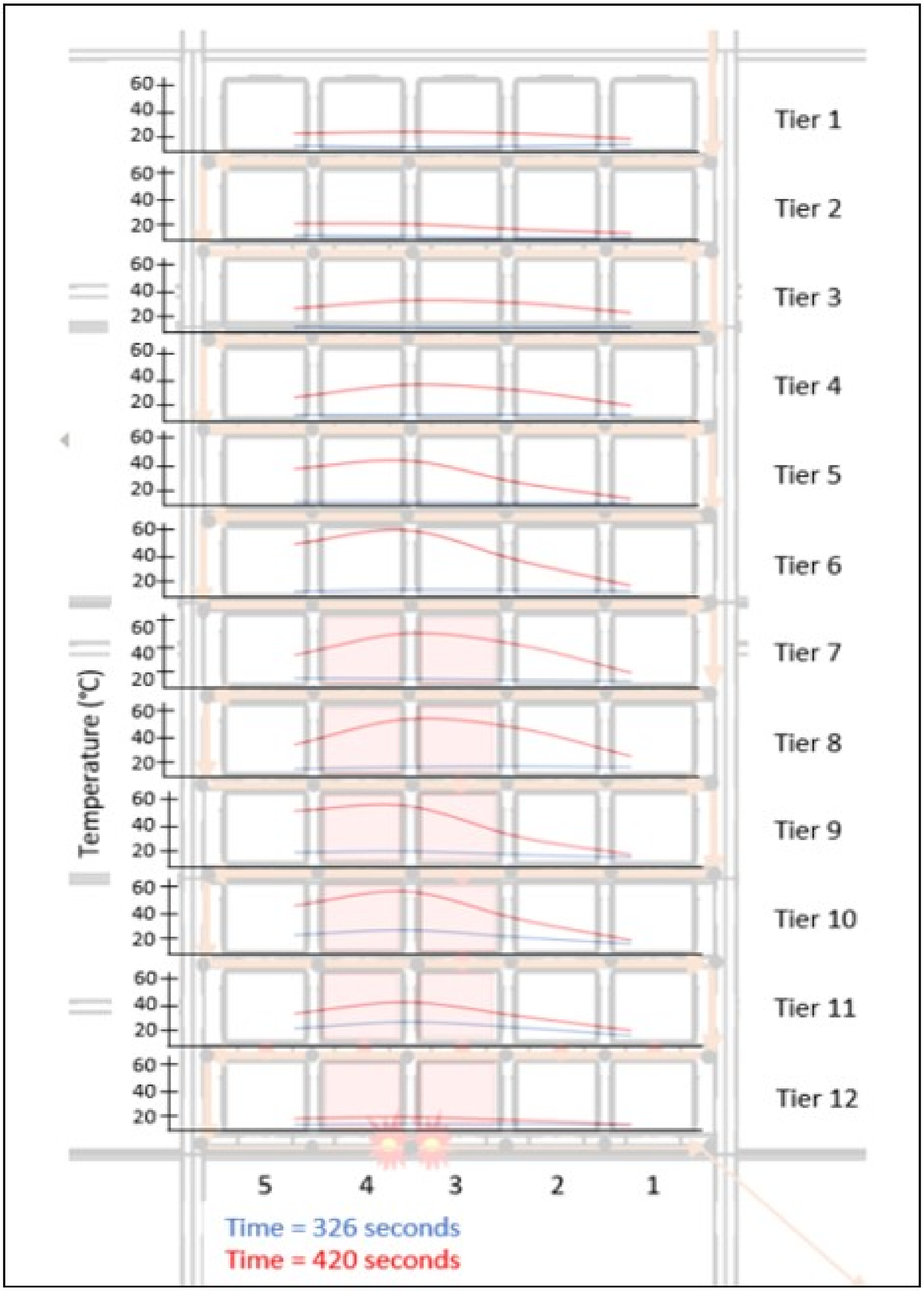


Fig. 3.3.4.3.1-1. Fiberoptic cable temperature measurements shown along with the thermally damaged FOUPs for center sprinkler configuration

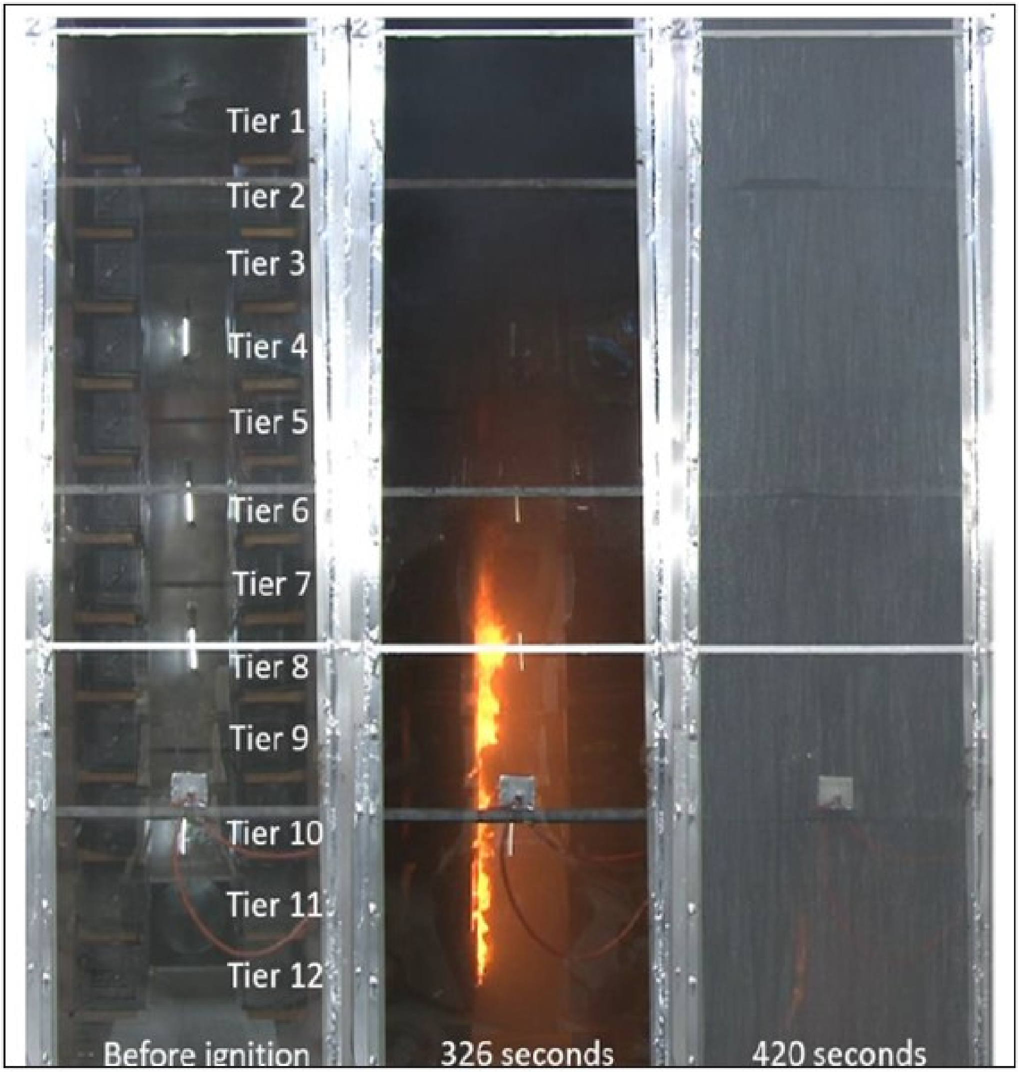


Fig. 3.3.4.3.1-2. Three side-by-side views from the east end of the stocker through the transparent wall: before ignition (left image), shortly before sprinkler activation (middle image), and seven minutes after ignition (right image) when peak temperatures were measured from the fiberoptic cables.

Figure 3.3.4.3.1-3 shows an instant after the sprinkler activated to illustrate the smoke exiting the stocker through the exhaust on the floor. Not all smoke exiting the stocker from the exhaust was ventilated through the Fire Products Collector (FPC) system. Therefore, the total smoke generated can only be estimated. The figure is provided for qualitative purposes.

Fig. 3.3.4.3.1-3. Smoke generation post sprinkler activation from the stocker setup

3.3.4.3.2 Full Scale Fire Test Results for Offset Sprinkler Location

In the second full-scale fire test, the sprinkler was moved to the offset location, 2 ft (0.61 m) north of the center sprinkler location, to examine the impact on sprinkler protection performance. The same ignition scenario as the center sprinkler location was used for this test. The sprinkler activated six minutes and seven seconds after ignition. Upon sprinkler activation, the water discharge cooled the inside of the stocker and controlled the fire. The test ended 30 minutes after ignition. However, final extinguishment was achieved via manual intervention.

The fiberoptic cables for temperature measurements were kept in the same location as in the first test to track the fire growth. The recorded temperature profiles, which are shown for each tier in Figure 3.3.4.3.2-1, were obtained at two different times: 367 seconds (blue line) and 480 seconds (red line), corresponding to the approximate sprinkler activation time and the peak temperature observed via the fiberoptic cable, respectively. No fire jump occurred from the ignition side to the target array. However, thermally degraded FOUPs on the target array across the ignition area are shaded in blue in Figure 3.3.4.3.2-1.

Post-fire test analysis included physical examination for thermal damage of the FOUPs inside the stocker. The increased heat release rate and temperatures seen inside the stocker caused thermal degradation in some of the FOUPs on the target array as shown in the left image of Figure 3.3.4.3.2-2. The extent of thermal damage on the ignition side of the FOUP array is shown in the right picture of the same figure.

In addition to the fiberoptic cable measurements, an infrared camera was also used to monitor the ignition side wall temperatures for tracking fire growth (see Figure 3.3.4.3.2-3). The IR camera was angled to clearly view the ignition side of the stocker. The left-most image of the figure shows that one minute after ignition, flames are still attaching to the front of the FOUPs on Tier 12 and have no heat signature detectable from the

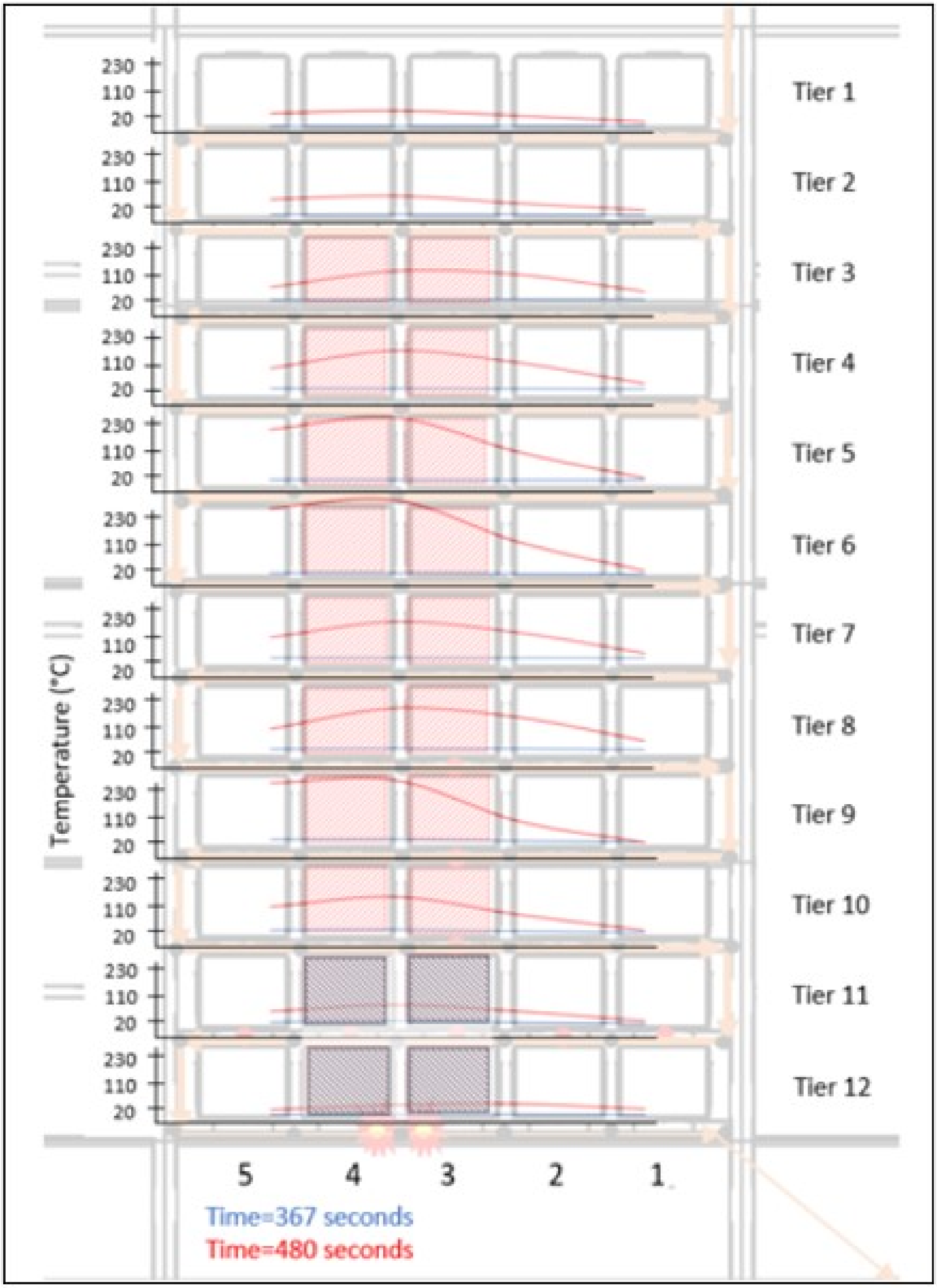


Fig. 3.3.4.3.2-1. Fiberoptic cable temperature measurements shown along with the thermally damaged FOUPSs for offset sprinkler configuration. Red shaded boxes indicate thermally damaged FOUPs on the ignition array side, and blue shaded boxes indicate FOUPs on target array with minor surface deformation.

outside. Subsequent images to the right are taken one minute apart from each other, except for the right-most image taken immediately after sprinkler activation. Maximum wall temperatures are shown above each image. The maximum wall temperature measured was 212° F (100° C), which immediately decreased upon sprinkler activation.

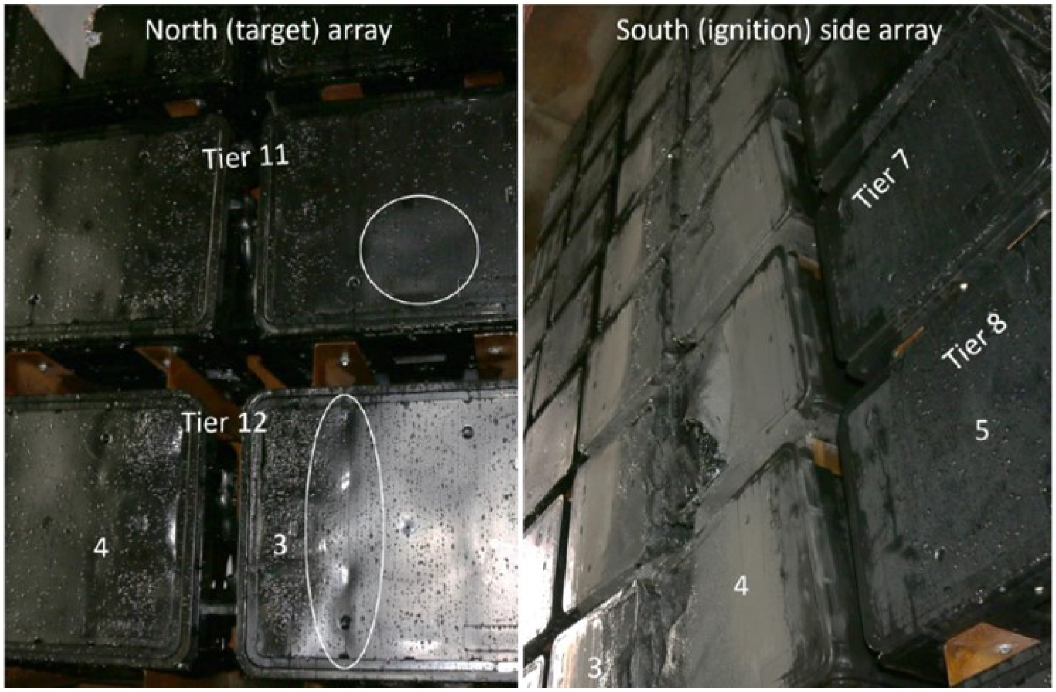


Fig. 3.3.4.3.2-2. Extent of the thermal damage on the FOUPs shown on the ignition side (right), and minor thermal damage shown on the target array (north side of the stocker) for offset sprinkler configuration.

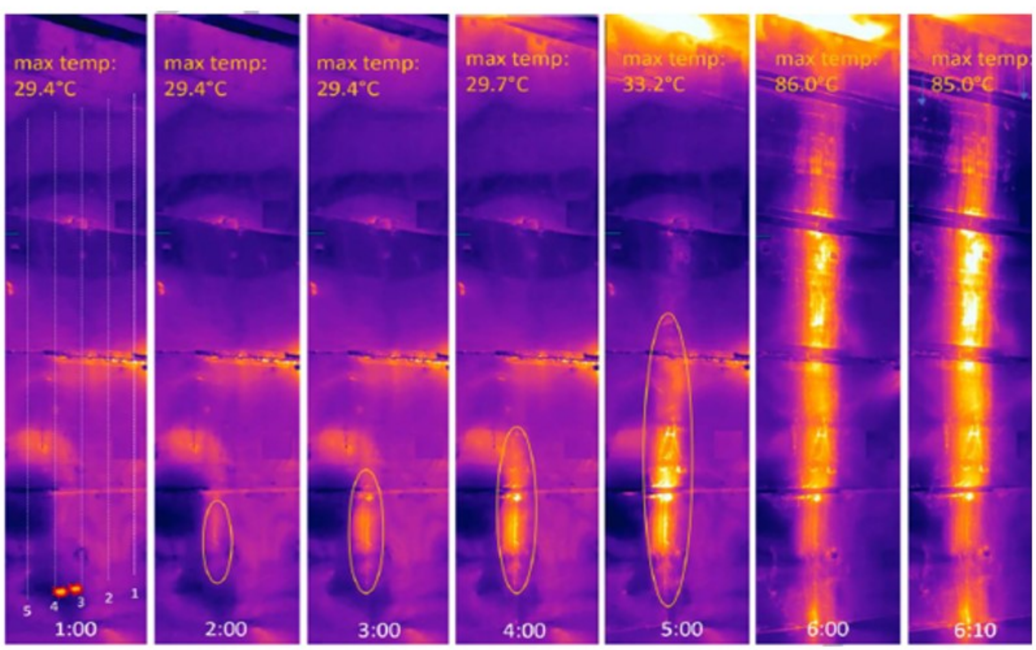


Fig. 3.3.4.3.2-3. IR camera instances from the FLIR T1030, tracing the heat outside the south wall of the stocker for offset sprinkler configuration

3.3.4.3.2 Summary

The key findings from the two full-scale fire tests include the following:

A. The fire was completely extinguished with the sprinkler in the center location but was only controlled with the sprinkler in the offset location, which required final extinguishment by manual intervention.

B. In both tests, fire grew at a much faster pace vertically than horizontally, triggering sprinkler activation prior to fire spreading to the adjacent FOUPs in any tier.

C. The outside wall temperatures were lower than 212° F (100° C), confirming the low likelihood of fire spreading to adjacent stockers.

D. At least 7 oz (200 grams) of smoke generation was estimated for the offset sprinkler configuration, compared to 3 oz (90 grams) for the test with the center sprinkler configuration. This difference is due to the delayed sprinkler operation in the offset scenario, causing more FOUPs to be involved in the fire.

3.4 Equipment and Processes

3.4.1 Process Liquid Heating

An industry standard on process liquid heating is SEMI S3, *Safety Guidelines for Process Liquid Heating Systems*. This document is very comprehensive and used by third-party reviewers to assess the risks associated with heating systems for liquid process chemicals.

3.4.2 IPA Vapor Dryer

IPA vapor dryers are preferred over older technology due to their superior Marangoni drying method after rinsing, which yields wafers that are spotless and watermark-free.

A small amount of isopropyl alcohol (IPA) is bubbled with nitrogen to form a very effective drying agent. The concentration of IPA in the carrier gas is kept as low as possible.

The IPA container for the dryer is typically constructed of stainless steel and located in a stainless-steel cabinet outside the tool enclosure. Ventilation and liquid containment are usually provided.

3.4.3 Vacuum Pumps

Four basic types of vacuum pumps are available: mechanical, diffusion, cryogenic and turbo-molecular. Mechanical pumps may have oil lubrication, and diffusion pumps operate by vaporizing heated oil. Any time combustible oils are used in vacuum pumps, the potential exists for an upset condition that could result in an explosion.

3.5 Process Gases: Storage and Handling

3.5.1 Gas Dopant Sources

A sub-atmospheric gas system (SAGS) reduces the risk, rate and magnitude of gas releases. With SAGS, a vacuum (sub-atmospheric) condition is required to induce gas flow from the cylinder. An accidental opening of the valve under atmospheric conditions will result in little or no gas release.

Fire codes differentiate SAGS based on the internal (storage) pressure of the gas. In a Type 1 SAGS, the pressure is removed by adsorbing the gas on a solid.

A Type 2 SAGS contains gas at pressures ranging from 200 to 1500 psig (14 to 100 barg) where the pressure driver is mechanically controlled via a normally closed, internal regulator system that requires a vacuum condition to open.

Toxic and corrosive dopants are used in a wide range of process applications. Larger cylinders containing 2 to 6 lb (0.9 to 2.7 kg) of hazardous material are being used, with four to six cylinders per tool. Because of its improved safety features, SAGS should be used instead of standard high-pressure cylinder gas wherever process compatibility allows.

3.5.2 Liquid Dopant Sources

Liquid sources are normally used with bubblers. Bubblers are quartz flasks that hold the liquid sources and that can be heated. They are used to convert the liquid source to a vapor by flowing an inert carrier gas (such as N_2) through the heated liquid dopant, held at a constant temperature. The bubbles of the carrier gas pick up the dopant vapor and carry it into the diffusion furnace or epitaxial reactors.

The bubbler temperature determines the vapor pressure of the liquid source and thus the concentration of dopant reaching the wafer. The process is easily controlled by starting and stopping the gas-flow to the bubbler.

3.5.3 Forming Gas

A forming gas system consists of a mixing station, hydrogen gas storage and distribution piping. Nitrogen gas is vaporized from a liquid nitrogen storage tank by a vaporizer. Mixers are used to produce the forming gas. The supply pressure of the forming gas is in the range of 87 psi (6 bar). Forming gas mixtures (H_2/N_2) below 10% hydrogen by volume are nonflammable. Pre-mixed forming gas in trailers, and compressed cylinders are also available (instead of onsite mixing).

3.5.4 Pyrophoric and Reactive Liquids

These liquids are used in chemical vapor deposition (CVD) metallization and metal organic chemical vapor deposition (MOCVD) processes. Atomic layer deposition (ALD) using trimethylaluminum (TMA) is ideal to deposit ultrathin films. LED fabrication relies heavily on MOCVD process.

TMA is a clear liquid that burns spontaneously upon contact with air and reacts violently with water. TMA handling requires extreme care and should be performed only by qualified personnel.

The liquids are dispensed from metallic containers known as ampoules or bubblers (0.1 to 2 kg), cylinders (1 to 10 kg), canisters (1 to 20 kg), and bulk supply tanks (10 to 100 kg). Ampoules are typically used on the tools. Bubblers may be used as described in Section 3.5.2.

3.6 Loss History

3.6.1 FM Loss Experience

3.6.1.1 General

Table 3.6.1.1-1 provides the FM loss experience for process-related losses in the period from January 1, 2012 to January 31, 2022. The time element amount of the loss is separated from the property damage amount to illustrate that the secondary loss leader is downtime of the facility during recovery from an incident (for cleanup, recommissioning, etc.). Interruption of power continues to be a frequent event at fabs. Several significant outages have occurred over the past several years that resulted in considerable process interruption and work-in-process (WIP) damage.

Table 3.6.1.1-1. FM Reported Losses, 2012-2022

Peril	*% of Losses by Value*	*Average % of Loss due to Property Damage*	*Average % of Loss due to Time Element*	*Median Loss Value*
Service Interruption - Utility	69%	8.2%	91.8%	$5M
Fire	17%	35.4%	64.6%	$13M
Escaped Liquids Damage	7%	14.3%	85.7%	$1M
Electrical Breakdown	5%	89.8%	10.2%	$1M
Sprinkler Leakage	1.9%	75.1%	24.9%	$1M
Pressure Equipment Breakdown	0.1%	9.1%	90.9%	$1M

3.6.1.2 Service Interruption - Utility

The Service Interruption - Utility losses reported during this period are associated with utility equipment failures outside of the insured facility not directly caused by natural hazard events. The utilities included are electrical services, water/sewer services and nitrogen plants. Breakdown of individual transformers or pieces of electrical equipment within the facility is not included (see Section 3.6.1.5).

3.6.1.3 Fire

A majority of fire losses reported during this period occurred outside of the clean room envelope. However, these losses resulted in damage to critical equipment that was difficult to replace in a timely manner, resulting in prolonged production outages.

In general, fire loss experience in the semiconductor industry has improved significantly over the last 25 years due to a number of factors, primarily the following:

A. Widespread use of FM 4910 listed plastic for tool construction

B. Widespread use of non-fire-propagating fume exhaust ductwork (FM 4922 Approved fume/smoke exhaust duct for use in cleanrooms)

C. Improved process liquid heating methods

D.Third-party review (SEMI S2, SEMI S14 and FM 7701) of process tools and associated support equipment

While the frequency of fire associated with combustible tools and ducts has been reduced, incidents involving silane continue to be an area of concern.

3.6.1.4 Escaped Liquids Damage

Water from cooling loops and scrubbers continues to be the most common escaped liquids damage. However, significant losses were reported involving process liquids being released within the cleanroom envelope due to human error. Regardless of the type of escaped liquid, the time element for cleanup was the driving factor in these losses.

3.6.1.5 Electrical Breakdown

Electrical breakdown losses reported during this period are related to breakdown of individual pieces of electrical equipment, including switchgear, circuit breakers and electrical buses. The breakdowns resulted in loss of power to individual tools or relatively small areas of the facility, and downtime was minimized.

3.6.1.6 Sprinkler Leakage

Sprinkler leakage losses reported during this period were equally attributed to contractor error during repair or commissioning and accidental discharge due to sprinkler malfunction. As with escaped liquids, sprinkler leakage resulted in significant cleanup and production outage.

3.6.2 Natural Hazards Losses

Table 3.6.2-1 shows natural hazard losses reported during the period from 2012-2022. These losses are a significant improvement over previous years, but natural hazards continue to represent a significant risk to semiconductor facilities.

Table 3.6.2-1. Natural Hazards Losses, 2012-2022

Peril	*% of Total Losses by Value*	*Average % of Loss due to Property Damage*	*Average % of Loss due to Time Element*	*Median Loss Value*
Service Interruption - NatHaz	92%	32.0%	68.0%	$83M
Water – Liquid Damage	4%	70.4%	29.6%	$4M
Earthquake	3.5%	0.0%	100.0%	$21M
Wind and Hail	0.3%	100.0%	0.0%	$0.3M
Collapse	0.1%	0.0%	100.0%	$0.6M
Flood	0.1%	87.7%	12.3%	$0.2M

3.6.2.1 Service Interruption NatHaz

Service Interruption NatHaz losses are those where a utility interruption occurred that was directly related to a natural hazard event, such as snow, wind, freeze or flood. It does not include direct damage to an insured facility by the same event. Utilities in this category include electrical service, water/sewer service and nitrogen plants.

3.6.2.2 Water Liquid Damage

Liquid damage in this category refers to rain infiltration due to roof damage.

3.6.2.3 Earthquake

Earthquake losses reported during this period were associated with minor building damage or damage to equipment that was not properly secured.

3.6.2.4 Wind and Hail

The majority of wind and hail losses reported during this time period were associated with temporary structures and barriers erected during construction.

3.6.2.5 Collapse

Collapse losses reported during this time period were associated with heavy rooftop snow loading.

4.0 REFERENCES

4.1 FM

Data Sheet 1-2, *Earthquakes*
Data Sheet 1-11, *Fire Following Earthquake*
Data Sheet 1-20, *Protection Against Exterior Fire Exposure*
Data Sheet 1-22, *Maximum Foreseeable Loss*
Data Sheet 1-28, *Wind Design*
Data Sheet 1-29, *Roof Deck Securement and Above-Deck Roof Components*
Data Sheet 1-40, *Flood*
Data Sheet 1-44, *Damaging-Limiting Construction*
Data Sheet 1-53, *Anechoic Chambers*
Data Sheet 1-54, *Roof Loads for New Construction*
Data Sheet 1-56, *Cleanrooms*
Data Sheet 1-57, *Plastics in Construction*
Data Sheet 1-62, *Cranes*
Data Sheet 2-0, *Installation Guidelines for Automatic Sprinklers*
Data Sheet 2-1, *Corrosion in Automatic Sprinkler Systems*
Data Sheet 2-8, *Earthquake Protection for Water-Based Fire Protection Systems*
Data Sheet 2-81, *Fire Protection System Inspection, Testing and Maintenance*
Data Sheet 3-26, *Fire Protection for Nonstorage Occupancies*

Data Sheet 4-0, *Special Protection Systems*
Data Sheet 4-2, *Water-Mist Systems*
Data Sheet 4-11N, *Carbon Dioxide Extinguishing Systems*
Data Sheet 5-1, *Electrical Equipment in Hazardous (Classified) Locations*
Data Sheet 5-4, *Transformers*
Data Sheet 5-11, *Lightning and Surge Protection for Electrical Systems*
Data Sheet 5-12, *Electric AC Generators*
Data Sheet 5-17, *Motors and Adjustable Speed Drives*
Data Sheet 5-19, *Switchgear and Circuit Breakers*
Data Sheet 5-20, *Electrical Testing*
Data Sheet 5-23, *Design and Protection for Emergency and Standby Power Systems*
Data Sheet 5-28, *DC Battery Systems*
Data Sheet 5-30, *Power Factor Correction and Static Reactive Compensator Systems*
Data Sheet 5-32, *Data Centers and Related Facilities*
Data Sheet 5-33, *Lithium-Ion Battery Energy Storage Systems*
Data Sheet 5-48, *Automatic Fire Detection*
Data Sheet 5-49, *Gas and Vapor Detectors and Analysis Systems*
Data Sheet 6-11, *Thermal and Regenerative Catalytic Oxidizers*
Data Sheet 7-2, *Waste Solvent Recovery*
Data Sheet 7-6, *Plastic and Plastic-Lined Tanks*
Data Sheet 7-9, *Dip Tanks, Flow Coaters and Roll Coaters*
Data Sheet 7-29, *Ignitable Liquid Storage in Portable Containers*
Data Sheet 7-31, *Storage of Aerosol Products*
Data Sheet 7-32, *Ignitable Liquid Operations*
Data Sheet 7-35, *Air Separation: Oxygen and Nitrogen*
Data Sheet 7-43, *Process Safety*
Data Sheet 7-45, *Safety Controls, Alarms and Interlocks (SCAI)*
Data Sheet 7-50, *Compressed Gases in Portable Cylinders and Bulk Storage*
Data Sheet 7-59, *Inerting and Purging Vessels and Equipment*
Data Sheet 7-72, *Reformer and Cracking Furnaces*
Data Sheet 7-76, *Prevention and Mitigation of Combustible Dust Explosions and Fires*
Data Sheet 7-78, *Industrial Exhaust Systems*
Data Sheet 7-88, *Outdoor Ignitable Liquid Storage Tanks*
Data Sheet 7-91, *Hydrogen*
Data Sheet 7-95, *Compressors*
Data Sheet 7-98, *Hydraulic Fluids*
Data Sheet 7-108, *Silane*
Data Sheet 7-110, *Industrial Control Systems*
Data Sheet 8-9, *Storage of Class 1,2,3,4 and Plastic Commodities*
Data Sheet 8-33, *Carousel Storage and Retrieval Systems*
Data Sheet 8-34, *Protection for Automatic Storage and Removal Systems*
Data Sheet 9-0, *Asset Integrity*
Data Sheet 9-16, *Burglary and Theft*
Data Sheet 10-1, *Pre-Incident and Emergency Response Planning*
Data Sheet 10-5, *Disaster Recovery Planning*
Data Sheet 10-8, *Operators*

FM Approval Standards

Approval Standard 4882, *Class 1 Interior Wall and Ceiling Materials or Systems for Smoke Sensitive Occupancies*
Approval Standard 4910, *Cleanroom Materials Flammability Test Protocol*
Approval Standard 4911, *Wafer Carriers for Use in Cleanrooms*
Approval Standard 4920, *Filters Used in Clean Room Facilities*
Approval Standard 4922, *Fume Exhaust Ducts or Fume and Smoke Exhaust Ducts*
Approval Standard 4924, *Pipe and Duct Insulation*
Approval Standard 6933, *Transformer Fluids*
Approval Standard 7701, *Tools Used in the Semiconductor Industry*

4.2 Other

American Society of Civil Engineers (ASCE). ASCE 7, *Minimum Design Loads and Associated Criteria for Buildings and Other Structures.* 2016.

American Society of Mechanical Engineers (ASME). ASME 31.3, *Process Piping.* 2018.

American Society of Mechanical Engineers (ASME). *Boiler and Pressure Vessel Code.* 2019.

International Code Council (ICC). International Fire Code, Chapter 27, *Semiconductor Fabrication Facilities.* 2018.

IEEE Standards Association (IEEE). IEEE C57.12.10, *Standard Requirements for Liquid-Immersed Power Transformers*.

National Fire Protection Association (NFPA). NFPA 12, *Standard on Carbon Dioxide Extinguishing Systems*.

National Fire Protection Association (NFPA). NFPA 55, *Compressed Gases and Cryogenic Fluids Code*.

National Fire Protection Association (NFPA). NFPA 262, *Standard Method of Test for Flame Travel & Smoke of Wires and Cables for use in Air-Handling Spaces*.

National Fire Protection Association (NFPA). NFPA 318, *Semiconductor and Related Facilities*.

National Fire Protection Association (NFPA). NFPA 704, *Standard System for the Identification of the Hazards of Materials for Emergency Response*.

Semiconductor Equipment and Materials International (SEMI). SEMI S2, *Environmental, Health, and Safety Guideline for Semiconductor Manufacturing Equipment*.

Semiconductor Equipment and Materials International (SEMI). SEMI S3, *Safety Guideline for Process Liquid Heating Systems*.

Semiconductor Equipment and Materials International (SEMI). SEMI S10, *Safety Guideline for Risk Assessment and Risk Evaluation Process*.

Semiconductor Equipment and Materials International (SEMI). SEMI S14, *Safety Guidelines for Fire Risk Assessment and Mitigation for Semiconductor Manufacturing Equipment*.

Semiconductor Equipment and Materials International (SEMI). SEMI F47-0706, *Specification for Semiconductor Processing Equipment Voltage Sag Immunity*.

Underwriters Laboratories (UL). UL 94, *Standard for Tests for Flammability of Plastic Materials for Parts in Devices and Appliances*.

Underwriters Laboratories (UL). UL 586, *Standard for Safety for High-Efficiency, Particulate, Air Filter Units*.

Underwriters Laboratories (UL). UL 900, *Standard for Air Filter Units*.

Underwriters Laboratories (UL). UL 910, *Standard Method of Test for Flame Travel and Smoke of Wires and Cables for Use in Air-Handling Spaces*.

Underwriters Laboratories (UL). UL 2360, *Standard for Test Method for Determining the Combustibility Characteristics of Plastics Used in Semiconductor Tool Construction*.

APPENDIX A GLOSSARY OF TERMS

Backend: Also known as assembly and test, it is comprised of steps leading to the final finished product, including wafer test, wafer sawing, die (chip) separation, die attach, wire bolding, packaging and final testing. Typically done in Asia by contract manufacturers.

Central source nitrogen supply system: A system comprised of a nitrogen source (such as air separation plant, liquefied nitrogen supply or gaseous nitrogen supply), vaporizers (as applicable) and purifiers (as applicable).

Cleanroom: An enclosed area in which the amount and size of particulate matter in air, temperature, humidity and pressure are closely controlled.

Cleanroom envelope: The area of the fab where clean/conditioned air circulates (includes clean subfabs and plenum areas, but not dirty subfabs).

Clean subfab: The area located underneath the fab processing floor that contains support equipment (pumps, etc.) for processing tools and in which clean/conditioned air circulates.

Cycle time: The length of time required for a wafer to complete a specified process or set of processes.

Dirty subfab: The area located underneath the fab processing floor that contains support equipment (pumps, etc.) for processing tools and in which clean/conditioned air does not circulate.

Epitaxial process: A process that involves growing a thin layer of silicon crystals over a crystalline substrate. The crystal development is controlled, so the substrate crystal structure has a dominant orientation. This process is the only affordable method of high-quality crystal growth for semiconductor materials.

Equipment contingency plan (ECP): A section of a business continuity plan that documents the intended response to recover from an unplanned outage of equipment that results in significant interruption to key site processes, including production, utility and support systems. This plan is a systematic, strategic assessment of site processes and systems to identify equipment considered key for the continuity of site operations. It includes evaluating the breakdown scenarios and exposures for this equipment.

Fab: The main manufacturing facility for processing semiconductor wafers.

Fabless: Companies who design semiconductors and send the designs to a foundry for fabrication. The foundry labels the semiconductor device with the name of the fabless company.

Flame oxidation: The oxidation of waste gas using a flame created by the combustion of hydrogen, natural gas or propane with air.

FM 4910 Listed: Plastic material that has been tested in accordance with FM Approval Standard 4910, Cleanroom Materials Flammability Test Protocol. FM4910 materials are listed in the Specification Tested Section of the *Approval Guide*, an online resource of FM Approvals.

FM 4911 Approved: Wafer carriers that have been tested in accordance with FM Approval Standard 4911, Wafer Carriers in Use in Cleanrooms. FM 4911 wafer carriers are listed in the Wafer Carrier for Use in Cleanroom Occupancies in the Semiconductor Industry section of the *Approval Guide*, an online resource of FM Approvals.

FM 4920 Approved: Filters tested in accordance with FM Approval Standard 4920, Filters Used in Cleanroom Facilities. FM 4920 filters are listed in the Air Handling, System Components - Filers/Cleanroom section of the *Approval Guide*, an online resource of FM Approvals.

FM 4922 Approved: Fume exhaust ducts and fume, and smoke exhaust ducts that have been tested in accordance with FM Approval Standard 4922, Fume Exhaust Ducts or Fume and Smoke Exhaust Ducts. FM 4922 ducts are listed in the Duct Systems - Commercial (Class Number 4922) section of the *Approval Guide*, an online resource of FM Approvals.

FM 4924 Approved: Pipe and duct insulation tested in accordance with FM Approval Standard 4924, *Pipe and Duct Insulation*. FM 4924 pipe and duct insulations are listed in the Pipe and Duct Insulation (FM Approval Class Number 4922) section of the *Approval Guide*, an online resource of FM Approvals.

Front opening unified pod (FOUP): A specialized plastic enclosure designed to hold silicon wafers securely and safely in a controlled environment, and to allow the wafers to be removed for processing or measurement by tools equipped with appropriate load ports and robotic handling systems.

Foundry: A company that manufactures semiconductors on a contract basis.

Front end: The first portion of the semiconductor fabrication process where the individual devices (transistors, capacitors, resistors, etc.) are patterned on the wafer. The front end process ends with wafer probe.

Hazardous production material (HPM): A solid, liquid, or gas associated with semiconductor manufacturing that has a Class 3 or 4 degree of hazard rating in health, flammability or instability as ranked by NFPA 704, and that is used directly in research, laboratory or production processes that have materials that are not hazardous as their end product.

High voltage: See voltage.

Integrated device manufacturer (IDM): A company that designs, manufactures and labels its own semiconductors.

Interstitial: Also known as a plenum or return air plenum (RAP), it is the space directly above the cleanroom ceiling grid that is used for cleanroom air return.

Life safety system (LSS): A monitoring and control system, independent of process controls, used for detecting and alarming conditions that present a hazard to personnel and initiating process shutdown as appropriate.

Low pressure gas: Materials that are gases at ambient temperature (68°F [20°C]) and pressure (14.7 psi [1 bar]). These are Class 2 gases under 49 CFR 173.115, U.S. Department of Transport Code of Federal Regulations.

Low voltage: See voltage.

Mask: A pattern that can be transferred to an entire wafer in one exposure.

Medium voltage: See voltage.

Pyrophoric liquid: A liquid capable of spontaneously igniting in air at or below a temperature of 130°F (54.4°C).

Reticle: A mask that contains the pattern to be reproduced on a substrate; the image may be equal to or larger than the final projected image.

Stacked fab: Multiple levels of front-end fabrication cleanrooms, each separated by a subfab level.

Subatmospheric gas storage and delivery source (SAGS) Type 1: A gas source package that stores and delivers gas at subatmospheric pressure and includes a container (e.g., gas cylinder and outlet valve) that stores and delivers gas at a pressure of less than 14.7 psia (1 bara) at standard temperature and pressure (STP).

Subatmospheric gas storage and delivery source (SAGS) Type 2: A gas source package that stores compressed gas and delivers gas at subatmospheric pressure and includes a container (e.g., gas cylinder and outlet valve) that stores gas at a pressure greater than 14.7 psia (1 bara) at STP and delivers gas at a pressure of less than 14.7 psia (1 bara) at STP.

Subfab: The area below the cleanroom production area. It can consist of a single level or multiple levels and may or may not be clean.

Third party: A person qualified through training, education, and experience who can perform a compliance and hazard analysis of processing equipment.

Tool: A piece of semiconductor fabrication or inspection equipment designed to process wafers into chips.

Unstable materials: As defined in NFPA 704: Materials that may decompose, condense, become self-reactive or otherwise undergo a violent chemical change under conditions of shock, pressure or temperature.

UPW: Ultra-pure water.

Voltage: No widely accepted definition of Low Voltage, Medium Voltage, or High Voltage is available. For the purpose of this document, Low Voltage is defined as less than 1,000 V, Medium Voltage is defined as greater than 1,000 V and less than 100,000 V, High Voltage is defined as greater than 100,000 V. These definitions align with the definitions used in International Electrical Testing Association ANSI/NETA MTS-2015, Standard for Maintenance Testing Specifications.

Wafer: The silicon or compound semiconductor disk on which integrated circuits or chips are manufactured.

Wafer starts: The number of new wafers introduced into the manufacturing process. Typically expressed as wafer starts per week (WSPW) or wafer starts per month (WSPM).

Yield: The percentage of semiconductor devices produced in an operation or process that confirm to specifications.

APPENDIX B DOCUMENT REVISION HISTORY

The purpose of this appendix is to capture the changes that were made to this document each time it was published. Please note that section numbers refer specifically to those in the version published on the date shown (i.e., the section numbers are not always the same from version to version).

April 2025. This document has been completely revised. Significant changes include the following:

A. Recommendations redundant to other FM Data Sheets were removed, including fire protection inspection and testing, control room protection and electric utility system studies.

B. The recommendation to retain a consulting firm specializing in seismic design for seismic zones was removed, because it is a building code requirement in those areas.

C. Recommendations related to sprinkler installation around ceiling obstructions for waffle-style ceilings were revised for clarity.

D. The recommendation for manual fire extinguishers was removed, because the need and location should be established in the facility emergency response plan (ERP).

E. The recommendation on location of zero footprint storage was removed, because relocating is generally impractical and does not have a significant impact on the loss scenario.

F. A recommendation was added to arrange switchgear in a way that allows inspection, testing and maintenance (ITM) without defeating interlocks.

G. The recommendation for independent HVAC units for each fab area was removed, because ballroom fabs don't require a dedicated unit for each fab area to prevent smoke/air migration or loss of airflow.

H. Recommendations related to steam, hot water and chilled water equipment were removed because they were redundant with Asset Integrity recommendations.

I. A recommendation was added to provide a hard-wired interlock that automatically switches over the backup nitrogen supply if the primary supply deviates from specified purity limits.

J. Recommendations related to reprocessors were removed, because that equipment is not used in current fab operations.

K. Recommendations related to facility security were removed, because modern fabs are tightly controlled facilities.

L. The recommendation for metal trash containers was removed, because small plastic trash receptacles are not a significant hazard in the fab area.

January 2024. Interim revision. The document was revised to address fire protection for work-in-process (WIP) in combustible wafer boxes and reticle jewel cases.

July 2023. July 2023. This document has been completely revised. Significant changes include the following:

A. Updated liquid leakage recommendations to refer to Data Sheet 1-24, *Protection Against Liquid Damage*.

B. Added recommendation to evaluate freeze exposure in accordance with Data Sheet 9-18, *Prevention of Freeze-Ups*.

C. Added recommendations for sprinkler installation where solid ceiling structural members are more than 24 in. (0.6 m) deep.

D. Revised recommendation for infrared thermal scans to clarify what equipment should be scanned.

E. Removed recommendation related to smoke control systems due to the variation in design criteria provided by design consultants. FM engineers cannot fully evaluate these systems, and therefore they are not credited

F. Replaced scrubber protection recommendations with reference to Data Sheet 7-78, *Industrial Exhaust Systems*.

G. Removed recommendation for labeling tools of FM 4910 construction.

H. Removed recommendation for FM Approved FOUPS, because, while they displayed superior fire performance, there were material aspects related to off-gassing that make them nonviable for use in 300 mm semicon fabrication facilities. In addition, there are no FOUPs currently Approved.

I. Removed recommendation for sprinkler protection in reticle stockers , because water damage from accidental discharge or leakage is unacceptable due to the sensitivity and high concentration of value in the reticle stocker.

J. Replaced HPM gas cutoff room construction recommendations with reference to Data Sheet 7-50, *Compressed Gases in Portable Cylinders and Bulk Storage*.

K. Added recommendation to separate ignitable liquid storage from other process material storage and dispensing areas.

L. Removed recommendation for excess flow valves in HPM liquid piping.

M. Added reference to Data Sheet 7-32, *Ignitable Liquid Operations*, for leak detection in HPM liquid piping.

N. Updated Loss History.

April 2021. Interim revision. Significant changes include the following:

A. Added guidance for end-users regarding training related to central source nitrogen supply systems.

B. Clarified recommendation on automatic valve maintenance provisions in nitrogen supply systems to better reflect intent.

C. Revised control bypass recommendation for nitrogen supply systems to specifically address nitrogen purity analyzers.

D. Added UPS recommendation for gas analysis equipment in nitrogen supply systems.

E. Removed recommendation for location of switchover valve in nitrogen supply systems.

F. Revised capacity recommendation for backup nitrogen supply to cover ASU maintenance outage instead of specific number of days.

G. Added recommendation to provide emergency power to backup nitrogen system.

July 2020. Interim revision. The following changes were made:

A. Updated equipment contingency planning and sparing guidance.

B. Added service interruption planning guidance.

C. Revised facility protection guidance regarding sprinkler K factor.

D. Revised stocker protection guidance.

October 2019. The following changes were made:

A. Expanded scope to include allied processes, such as LCD and OLED fabrication (Section 1.0).

B. Restructured Section 2.0 to co-locate design and protection recommendations for buildings, equipment, and process fluids.

C. Removed recommendation for a ventilation hood over cabinets containing or dispensing pyrophoric or reactive liquids.

D. Added recommendation to develop a process safety program (Section 2.2).

E. Added recommendation for functional testing of safety interlocks (Section 2.3.1.3).

F. Added recommendation for minimum K8 (K115) sprinklers (Section 2.3.4.1).

G. Reorganized and updated electrical system recommendations (Section 2.3.5.2).

H. Expanded and updated recommendations on nitrogen supply systems (Section 2.3.5.8).

I. Added recommendation for a cyber risk security assessment (Section 2.4.1.2).

J. Recognized the use of pre-action sprinkler systems over sensitive equipment (Section 2.4.6.5.2).

K. Updated loss experience (Section 3.7).

L. Added guidance material on process safety program applications (Appendix D).

M. Added background material on LCD and OLED manufacturing (Appendix E).

N. Relocated "Assembly and Testing" to separate appendix (Appendix F).

October 2018. Interim revision. The following changes were made:

A. Added recommendations for hydrogen monitoring around extreme ultraviolet (EUV) equipment (Section 2.3.1.9.4).

B. Added recommendations for operations and maintenance procedures for nitrogen supplies and air-separation plants (Section 2.6.5).

C. Added recommendations for operations procedures for cranes (Section 2.6.6).

D. Added recommendations for backup nitrogen supplies (Section 2.8.14).

E. Added recommendations for contingency plans specific to nitrogen supplies and air-separation plant outages (Section 2.9).

F. Added support for recommendations for EUV equipment (Section 3.4.5).

G. Added support for recommendations for air-separation plants (Section 3.6.3).

April 2015. Minor editorial changes have been made to Appendix C to better clarify the intent of the recommendations relating to the design of detection and suppression systems within wet benches and other processing tools.

January 2015. Interim revision. Section 3.2.1 on gas dopant sources was revised to remove confusion on the differences between Type 1 and Type 2 sub-atmospheric gas systems (SAGS).

April 2014. This data sheet has been completely revised. Significant changes include the following:

A. Moved information relating to silane to new Data Sheet 7-108, *Silane.*

B. Relocated fire detection and suppression design criteria for wet benches and other processing tools to Appendix C.

C. Added new sections on pyrophoric and reactive liquids, AMHS, epitaxial reactors, extreme ultraviolet (EUV) lithography, assembly and test (i.e., backend), multi-level stockers, under/side track storage, and 450 mm fabrication facilities.

D. Changed the criteria for using tools made of non-FM 4910 listed plastic. Non-FM 4910 listed plastic is now limited to no more than 1 lb/ft^2 (5 kg/m^2) of the tool footprint (previous criteria was no more than 1% by weight of the total plastic used).

E. Removed reference to FM 200 protection for wet benches and other processing tools. Also removed references to gaseous suppression and water mist protection for stockers because these protection schemes are rarely used.

F. Revised terminology and guidance related to ignitable liquids to provide increased clarity and consistency with regard to FM Global's loss prevention recommendations for ignitable liquid hazards. This includes replacing references to "flammable" and "combustible" liquids with "ignitable" liquids throughout the document.

G. Updated the loss experience section to reflect the most recent ten-year period of FM Global's loss experience involving semiconductor fabrication facilities.

H. Removed the recommendation for electrical systems with secondary selective schemes. Closed bus ties are now recommended for power supply reliability.

I. Emphasized the importance of power quality as well as power reliability; added information on how to evaluate power quality and reliability.

May 2010. Minor editorial changes were made for this revision.

September 2004. References to FM Global earthquake zones have been modified for consistency with Data Sheet 1-2, *Earthquakes*.

January 2003. This edition contains major new or revised recommendations under the following sections:

2.2.10 New recommendation and additional information has been added for dopant gas sources.

2.2.11.1.7 Revision to recommendations for Tube Trailer Systems.

2.2.17 Revision to recommendations for Valve Manifold Boxes.

2.2.20 Additional recommendations provided for Effluent Treatment Systems.

2.2.21 New section added ''Acid Waste Neutralization Systems''.

2.2.25 Additional information provided for Vacuum Pumps.

2.5.8 Distinction for new and existing steppers eliminated.

2.5.9 Revisions to Pass-Through Cabinets recommendations.

2.5.11 Revised recommendations for wafer tracks.

2.5.15.2.4 Linear heat detection (LHD) requirements revised for fire detection system for wet bench subsurface.

2.5.16 Revised and added new recommendations for stocker fire protection.

May 2001 Changes.

Editorial changes only were made to this data sheet.

January 2001 Changes.

The January 2001 edition of Data Sheet 7-7/17-12 contains changes in recommendations under the following sections:

2.2.2.5 & 2.2.2.7 Recommendations from May, 2000 version have been combined and revised to clarify functional testing requirement.

2.2.5.6 Revised recommendation for chemical transportation carts.

2.2.5.7 Revised recommendation for storage within plastic wet benches.

2.5.8 Revised recommendations for Step and Repeat exposure systems.

2.5.11.3 Revised recommendation sections a, b, c to clarify requirements for storage and distribution cabinets.

2.5.12 Ion implanter recommendations. Complete revision of this section. Requirements for electrical protection of existing oil filled transformers have been provided.

2.5.15.2 Fire Detection and Alarm Systems. This section has been revised to include allowances for using linear heat detection.

2.5.15.4.4 Revised recommendation for tools provided with mini-environment enclosures.

September 1999 Changes.

The September 1999 edition of Data Sheet 7-7/17-12 contains minor editorial changes to various sections.

January 1997 Changes.

This document was completely rewritten January, 1997.

APPENDIX C DESIGNING FIRE DETECTION AND SUPPRESSION FOR WET BENCHES AND OTHER PROCESSING TOOLS

C.1 General

C.1.1 Provide FM Approved fixed fire suppression systems specifically evaluated for semiconductor tool application. Use Figure C.1.1-1 to help determine which system to install.

C.1.2 Design the suppression system to discharge with ventilation and exhaust systems in continuous operation. Interlock filter units supplying air to mini-environments to shut down supply air on fire detector activation while maintaining tool exhaust.

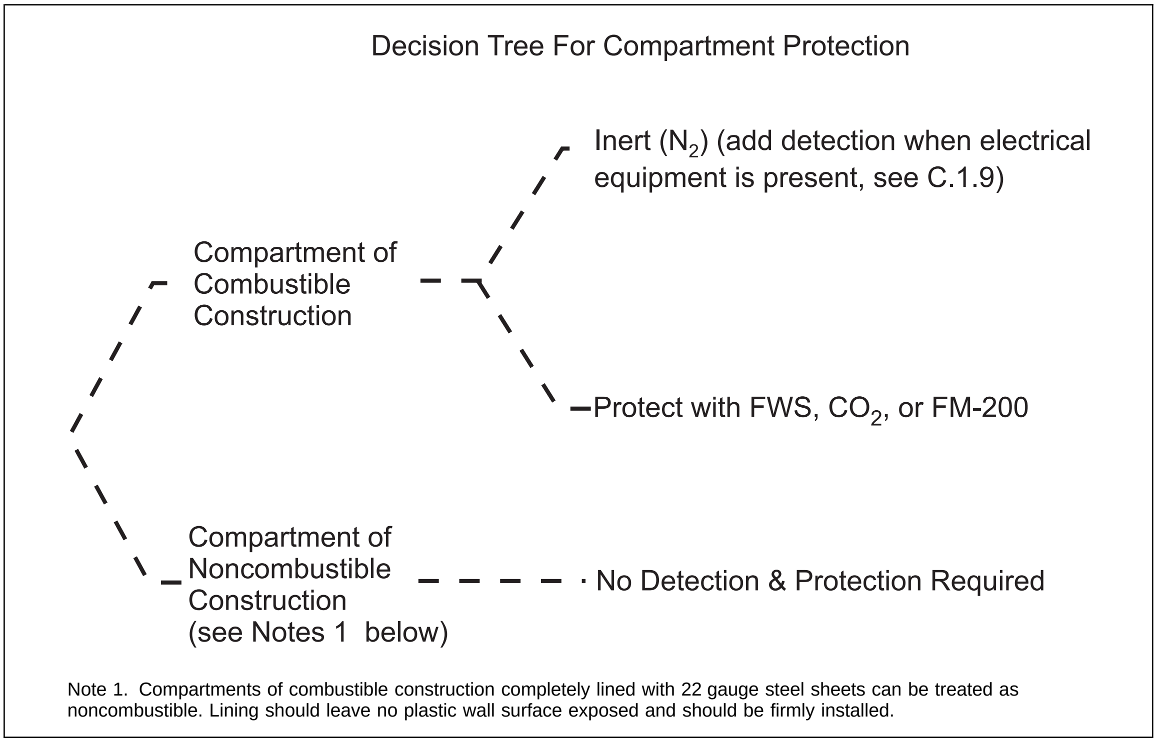


Fig. C.1.1-1. Decision tree for compartment protection

C.1.3 Interlock electrical power to the tool to shut down on system discharge (except for the electrical power necessary to keep the exhaust in operation). Isolate external ignitable liquid supplies on system discharge.

C.1.4 Base the suppression agent supply quantity on one discharge throughout the processing equipment for the recommended discharge duration of the specific agent used, per the relevant section of this data sheet.

C.1.5 Provide each tool with an individual fire suppression system. A single CO_2 system is acceptable to protect a group of processing equipment if the agent supply is sized for the largest hazard, and an equally-sized, connected reserve supply is provided.

C.1.6 When CO_2 is the extinguishing agent, a connected reserve supply is not needed for individual extinguishing systems, provided the tool is not operated until the agent supply is restored after the discharge.

C.1.7 For suppression systems that provide agent to separate zones in processing equipment (i.e., one zone protecting the working surface and subsurface of a wet bench and a separate zone protecting the headcase and other compartments of the same bench), the tool can exceed 8 ft (2.4 m) in length. Provide each zone with a separate agent supply and connected reserve, or size the system for the entire tool and provide an equally sized connected agent reserve. Provide physical barriers separating multiple zones.

C.1.8 A maximum 30-second time delay (after fire detection) is acceptable prior to discharge of the extinguishing system over the working surface of an open wet bench or other processing tool. The delay allows the working surface to be prepared for system discharge. A 30-second time delay can also be accepted in other areas of a tool (subsurface, headcase, etc.) in a single protection zone system.

C.1.9 Automatic fire detection/suppression systems are not needed in individual tool compartments constructed of combustible materials or that contain combustible materials if the compartments are inerted with nitrogen to a maximum oxygen concentration of five percent, per Data Sheet 7-59, *Inerting and Purging Vessels and Equipment*. In addition, do all of the following:

A. Provide fire detection (smoke detection or linear heat detection) in compartments containing electrical equipment.

B. Provide a low-pressure alarm for the processing equipment compartments with notification locally at the tool and at a constantly attended location.

C. Interlock the low-pressure detection to shut down the electrical power to the processing equipment.

C.1.10 Provide stainless steel tubing/piping and corrosion resistant nozzles for fixed fire suppression systems in tools handling corrosive chemicals.

C.1.11 Provide each system with a clearly identified and readily accessible means of manual operation in conjunction with automatic operation for fire detection.

C.2 Fire Detection and Alarm Systems

C.2.1 General

This section covers general requirements for fire detection and alarm systems used with fire suppression systems FM Approved for the protection of wet benches and other processing tools.

C.2.1.1 Use FM Approved fire detectors arranged to alarm at the tool and at a constantly attended location. Acceptable detectors include optical flame detectors, smoke detectors and linear heat detection (LHD). Provide components and systems per Data Sheet 5-48, *Automatic Fire Detection*.

C.2.1.2 Use optical flame detectors that are FM Approved for the flame signatures of the fuels and combustibles present within the tool. Position the detectors (using the center axis of their field of view) so they respond to a fire within five seconds. Information on the fuels and combustibles to which the detectors will respond can be found in the *Approval Guide* listing or the manufacturer's specification sheet.

C.2.1.3 Locate detectors to eliminate obstructions that block the field of view of the hazard. Do not install detectors to view through clear materials (e.g., Plexiglas, Lexan) that filter the full range of electromagnetic radiation necessary for the operation of the detectors. Consult the manufacturer of the detector to determine if such partitions will constitute an obstruction for its operation.

C.2.1.4 Install detectors with a direct view of the hazard. Do not consider indirect reflective radiation from a fire as a source of actuation for optical flame detectors.

C.2.1.5 Install detectors per the manufacturer's written instructions regarding spacing, distance to the hazard, fuel type, field of view and detection capabilities for direct and off-angle viewing.

C.2.2 Detector Types and Locations

C.2.2.1 Tool working surfaces: Provide optical flame detectors located so a fire in any part of the working surface area of the processing equipment is in the field of view of at least one detector.

C.2.2.2 Tool subsurface (plenum) areas: Provide optical flame detectors located so a fire in any part of the compartment is in the field of view of at least one detector. (Refer to Figure C.2.2.2-1.)

C.2.2.3 Tool enclosed compartments other than the subsurface areas (e.g., headcase, auxiliary electrical compartments, etc.): Provide optical flame detection, linear heat detection, or air-sampling/addressable spot-type smoke very early warning fire detection (VEWFD). In areas subject to migration of corrosive fumes that can impair smoke detection or subject the system to false alarms, use linear heat or optical flame detection.

C.2.3 Linear Heat Detection (LHD)

C.2.3.1 Provide digital (two wire) linear heat detection cable with an alarm temperature rating of 155°F (68°C), or 20°F (11°C) above the ambient temperature, whichever is higher.

C.2.3.2 Where optical flame detection is recommended by this data sheet, and the compartment exhaust rate does not exceed one air change per minute, linear heat detection is acceptable as an alternative to optical flame detection. Locate the heat detection cable across the centerline of all exhaust openings and around the top perimeter of the compartment.

C.2.3.3 Commission fire detection systems to determine correct operation, including a trial period before final connection of the suppression agent supply, during which activation of the fire detection system will be locally alarmed and logged for troubleshooting in the event of anomalous operation (false alarms, non-operation in the presence of a fire source).

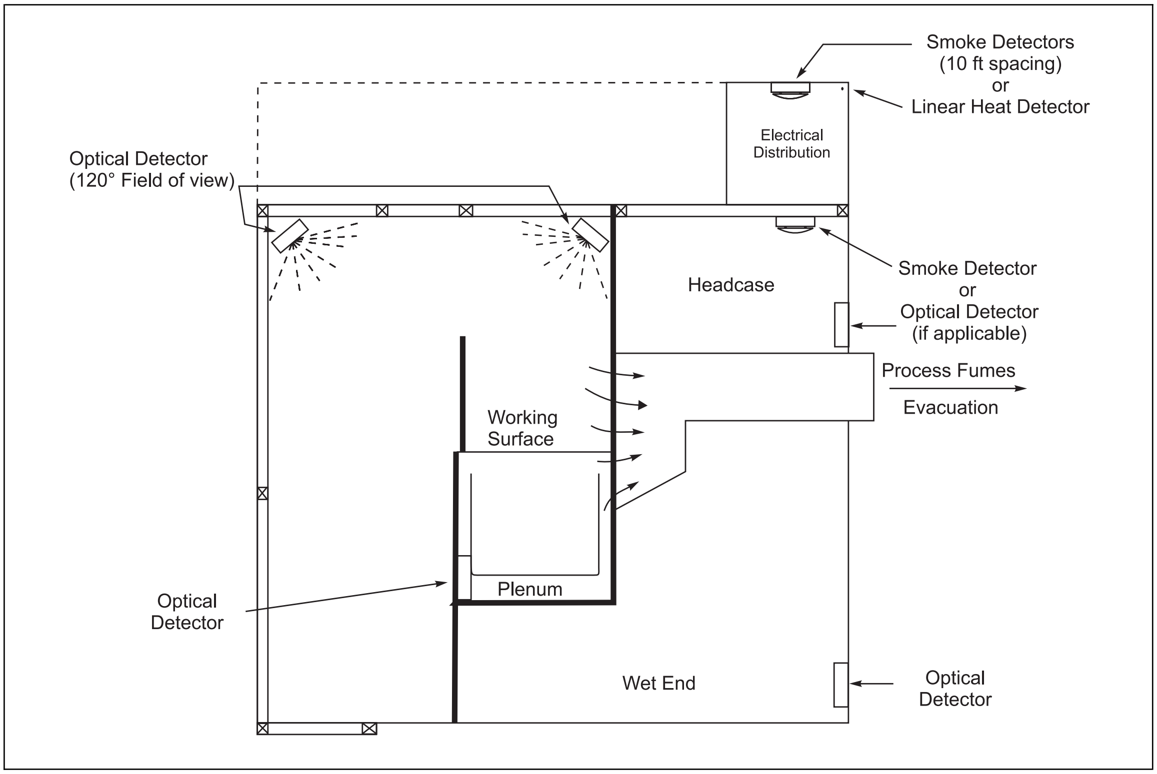


Fig. C.2.2.2-1. Wet processing tool detection arrangements

C.3 Carbon Dioxide (CO_2) Suppression Systems

C.3.1 General

C.3.1.1 Provide high-pressure or low-pressure carbon dioxide (CO_2) extinguishing systems and components that are FM Approved and listed in the *Approval Guide* specifically for this application.

Exception: Processing equipment enclosed within mini-environments, or other fully enclosed hazards, can be protected with FM Approved CO_2 systems that have not been specifically listed for semiconductor processing equipment if all of the following criteria are met:

A. A total CO_2 flooding design is provided, and compensation has been made for processing equipment ventilation and leakage through unclosable openings in the enclosure during the system discharge period.

B. Nozzles are located a sufficient distance from exhaust openings and process baths, so that agent discharge is not directly vented and does not cause liquid baths to splash.

C. A complete discharge test is performed in the protected tool with the processing equipment ventilation system in full operation to verify the required minimum gas concentration is achieved throughout the protected volume.

In contrast to local application systems, total flooding systems do not require specific FM Approval for protection of wet benches and other processing equipment. However, a full discharge test is needed to verify the system can reach the required design concentration throughout the protected volume within one minute, as recommended in this data sheet.

C.3.1.2 In addition to the requirements of this data sheet, provide carbon dioxide system design, installation and maintenance per Data Sheets 4-0, *Special Protection Systems*; 4-11N, *Carbon Dioxide Extinguishing Systems*; and 2-81, *Fire Protection System Inspection, Testing and Maintenance*.

C.3.2 Protection of Working Surfaces

C.3.2.1 For hazards that are not fully enclosed, design CO_2 systems on a local application basis using rate-by-volume (RBV) method for a minimum discharge time of 30 seconds. The basic system discharge rate of 1 lb/min/ft^3 (16 kg/min/m^3) of assumed volume may be proportionately reduced to account for barriers that surround the working surface, such as side panels, back walls and headcases (do not account for unenclosed areas on open tools), in accordance with NFPA 12, *Carbon Dioxide Extinguishing Systems*. Determine the assumed volume enclosing the working surface as outlined in NFPA 12.

C.3.2.2 Shut down supply air (e.g., shut the fan or close the dampers) to processing equipment upon fire detector activation.

C.3.2.3 For hazards that are fully enclosed, (e.g., mini-environment enclosures, interior compartments) design the CO_2 system on a total flooding basis to achieve a minimum concentration of 50% within one minute. Provide a total quantity of CO_2 that compensates for exhaust and unclosable openings. Maintain full processing equipment exhaust operation. If the supply air cannot be shut down, provide a total amount of CO_2 that compensates for the greater of (a) the exhaust flow rate, or (b) the supply air flow rate.

C.3.2.4 Center CO_2 nozzles over the working surface of the processing equipment and orient them vertically to project the discharge downward to the working surface of the processing equipment. Provide unobstructed discharge over the entire working surface. Include the height of the nozzle above the working surface and the nozzle discharge pattern and spray angle when determining the number of nozzles and their locations, positions and orientation. Locate and orient nozzles to prevent CO_2 from splashing exposed liquids on the working surface during discharge.

C.3.3 Protection of Other Compartments, Including Subsurface (Plenum) and Headcase

C.3.3.1 Design the CO_2 system on a total flooding basis to achieve a minimum concentration of 50% within one minute. Provide a total quantity of CO_2 that compensates for exhaust and unclosable openings.

C.3.3.2 When the CO_2 system is arranged to protect the working surface area and plenum simultaneously, provide the agent discharge rate for the plenum per NFPA 12.

C.3.3.3 Determine the size and required number of nozzles based on the total required discharge rate of CO_2 and the discharge characteristics of the nozzle selected. Provide FM Approved discharge nozzles listed for total flooding application. If possible, center nozzles on the lateral side walls, and arrange them to discharge longitudinally towards the center of the plenum.

C.4 Water Mist Systems

C.4.1 General

C.4.1.1 Provide water, and air or N_2, from sources having a reliability commensurate with that of the fire suppression system. Do not provide water from a source that is not dedicated to fire protection (e.g., the facility domestic water system) unless the supply connection from that source is not subject to routine domestic impairments. A water supply connection at or near the main incoming domestic supply point is acceptable if all control valves in the supply lines are locked, supervised and inspected in accordance with Data Sheet 2-81, *Fire Protection System Inspection, Testing and Maintenance*.

If provided and maintained per the above, sources of water, and air or gas can be one of the following:

A. A self-contained source of air or N_2, and water.

B. The plant fire protection (or DI/domestic water) system and plant air (or N_2) system.

C. A combination of (A) and (B) above (e.g., water from the sprinkler system and air taken from a pressurized tank).

D. Facility ultrapure water (UPW) and facility N_2 if facility systems are in continuous operation; and loss of pressure, flow, or shutdown of the system initiates a fire alarm trouble signal.

C.4.1.2 Provide FM Approved water mist systems for wet bench protection per Data Sheet 4-2, *Water Mist Systems*.

C.4.1.3 Provide detection and controls arranged to activate the suppression system automatically in the event of fire detector activation. Provide a minimum discharge time of 120 seconds. Base the system demand on the operation of all nozzles within the tool.

C.4.2 Protection of Working Surface

C.4.2.1 Center water mist nozzles over the working surface of the processing equipment (see Figure C.4.2.1-1) and orient them vertically to project the spray downward to the working surface of the processing equipment. Provide unobstructed spray over the entire working surface.

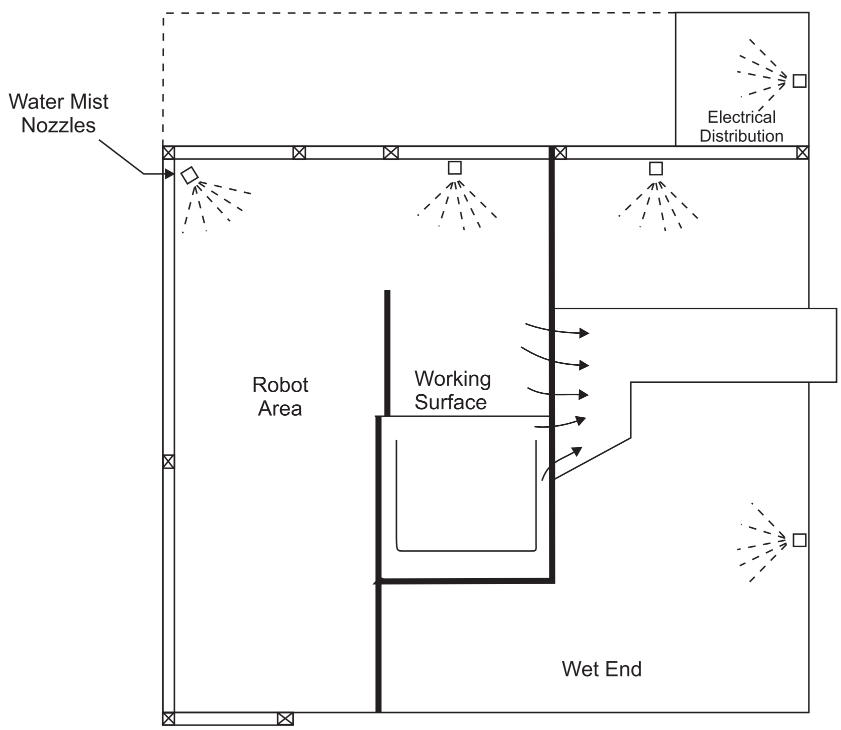


Fig. C.4.2.1-1. Wet processing tool water mist suppression arrangements

C.4.3 Protection of Other Compartments, Including Subsurface (Plenum) and Headcase

C.4.3.1 Locate and position water mist nozzles inside the subsurface area (plenum) to provide unobstructed spray over the entire internal volume of the compartment, including the compartment walls.

APPENDIX D PROCESS SAFETY APPLICATIONS IN SEMICONDUCTOR FABRICATION FACILITIES

D.1 Management Commitment

A statement should be developed, outlining how aspects of process safety are integrated into the company culture. This statement is typically contained within the corporate environmental health and safety policy.

D.2 Process Knowledge

Compile all information needed to understand the hazards and ensure the safe and reliable operation of the plant, including all information required to complete a process hazard analysis. This information must be updated and maintained to ensure its accuracy. Key elements consist of:

- Piping and instrumentation diagrams (P&ID)
- Specifications for design, construction, fabrication and installation of production and support equipment

- Information on hazardous materials, including safety data sheets (SDS) and maximum intended inventory
- Electrical classification
- Critical utilities and support systems, including utility demand trends
- Safety systems design basis and capabilities, including process gas and liquid leak detection, UVIR flame detection, purifier interlocks, purity monitoring on bulk gases, emergency switchover interlocks for bulk gasses, hydrocarbon monitoring of the reboiler at air separation plants that produce liquid oxygen, boiler combustion safeguards, abatement unit combustion safeguards, etc.
- Relief system design and design basis
- Reactive chemical hazards, including chemical and material compatibilities

D.3 Process Hazard Analysis (PHA)

Originating in the chemical industry, a PHA is a systematic approach for the identification, evaluation and control of hazards associated with a process. The intent of a PHA is to determine the potential causes and consequences of events (e.g., fires, explosions, releases of hazardous chemicals) and evaluate factors which may affect the process. By completing a PHA, potential failure points, methods of operations and other contributing factors that can lead to loss incidents can be identified and mitigated.

Applying PHAs to all systems in a semiconductor facility would be cumbersome and of little value (e.g., a PHA conducted on a metrology tool with no hazardous gases). A risk matrix screening process should be developed to identify the processes that pose significant hazards or risk.

PHAs are now a routine tool used by numerous industries to identify and mitigate a wide range of process and equipment hazards that could adversely affect their operations, personnel or environment. Many semiconductor operators and tool manufacturers perform analyses in accordance with SEMI S2, the *Environmental Health and Safety Guideline for Semiconductor Equipment*. SEMI S2 evaluations incorporate process hazard analyses.

Varying methodologies can be used to complete the PHA (Checklist, What If, HAZOP, FMEAs, etc.). Any of these methodologies are adequate for the semiconductor industry. The following should be addressed in the PHA:

- Start-up and shut-down
- Process deviations
- Utility/facility failures
- Control failures
- Safety bypasses
- Procedural changes

A formal PHA review should be conducted and attended by all critical departments, including engineering, production, operators, safety, environmental, etc. In addition, the facilitator of the PHA should receive training from a process safety professional. Another option is to hire process safety professionals to facilitate the PHA.

A system should be established to prioritize and address PHA findings. Track all findings to resolution within an appropriate timeframe as defined by the organization's PHA policy. Revalidation of PHAs is unlikely at semiconductor facilities, because processes rarely remain static for five years.

D.4 Management of Change (MOC)

The purpose of a management of change (MOC) process is to prevent unrecognized hazards from being introduced during a change. The process includes evaluating, as early as possible, every change to technology, facilities or personnel for its potential impact. Any change from original design intent represents a deviation. If the impact of this deviation is not fully understood, the change, even if minor, can cause a significant incident.

A management of change (MOC) program should be developed that includes the following elements:

A. Formal, documented procedures to manage change in processes, equipment, technology, protection, facilities and personnel

B. Review and approval by competent supervisors/management of all system changes, permanent or temporary. Identify the personnel and/or departments responsible for reviewing and approving changes. Using a single reviewer for simple changes is acceptable; but large, complicated changes require a more complex process.

C. A method for identification and tracking of changes that are subject to the MOC procedures

D. Documentation of the process and mechanical design basis for proposed changes. The change request should clearly identify what the change is and the technical basis for the change.

E. Review of potential hazards associated with the change, including the effects of the proposed change on upstream and/or downstream facilities, processes and equipment, using an appropriate hazard analysis methodology,

F. Determination of the maximum allowable duration for any temporary or emergency change. Provide a means for tracking the duration of such changes. Those that go beyond the maximum allowable duration need to be revalidated, following the normal MOC process.

G. Relevant administrative procedures established (e.g., documentation and/or checklists that cover hazards, maintenance requirements, records of personnel skills, responsibilities and training) to provide clear communication of the change and consequences to affected personnel, such as maintenance engineers, operators, safety and emergency response staff.

The modifications to the operating procedures, P&IDs, asset integrity program, personnel training, etc. should be finalized post-change as needed.

A pre-startup safety review (PSSR) should be performed prior to use of the system/process components for new or modified facilities whenever the modification is significant enough to require a change in the process safety information. This review includes ensuring all recommendations developed during the MOC process have been addressed.

- All updates to operating procedures, personnel training, diagrams, drawings, etc., required as part of the MOC process, should be completed prior to commissioning.
- The PSSR should be conducted prior to introducing chemicals and/or energy into the process.
- Final documentation may be created post startup.

D.5 Asset Integrity (AI)

A well-defined and properly executed inspection, testing and maintenance (ITM) program is necessary to ensure equipment operates as designed, avoiding production interruptions or upsets. The ITM program should include the following at a minimum:

A. Maintenance program

1. A specific process should exist to ensure protection considered in the PHA is included in the ITM program.
2. The maintenance backlog should have a specific target threshold.
3. The program performance should be regularly compared with the established target thresholds to ensure the effectiveness of the program.
4. Overdue and superseded maintenance items for critical equipment should be reviewed and appropriate action taken.
5. Maintenance tasks should have written instructions that include acceptable ranges for measured parameters. Records of past testing should be maintained for reference.

B. Instrumentation and controls (I&C)

1. A documented program should exist for the calibration and functional testing of important indicators and interlocks.

2. At a minimum, the following equipment should be included in the program if present at the facility:

- Purity monitoring on bulk gases
- Emergency switchover interlocks for bulk gasses
- Hydrocarbon monitoring of the reboiler at air separation plants that produce liquid oxygen
- Boiler combustion safeguards (these items can also be included in the boiler's maintenance instructions)
- Abatement unit combustion safeguards (these items can also be included in the abatement unit's maintenance instructions)

C. Electrical

The following equipment should be maintained in accordance with FM Property Loss Prevention Data Sheets and the manufacturers recommendations:

- Major transformers (transformers from the utility connection to the final distribution switchgear)
- Major breakers (breakers from the utility connection to the main, and tie breakers on the final distribution switchgear)
- Automatic transfer switches
- Emergency generators
- Uninterruptable power supplies (UPS)
- Switchgear batteries (see Data Sheet 5-28 or 5-33, as applicable)

D. Mechanical

1. Overpressure protection devices for boilers, pressure vessels and steam reducing stations should be included in a formal inspection and testing program.
2. Boilers should be included in a documented inspection program. At locations with mandatory compliance programs, these programs are typically reviewed by an inspector commissioned by the authority having jurisdiction.
3. Vibration monitoring should be performed on rotating equipment that has a potential to affect fab operations should it fail. This equipment can include exhaust fans, make up fans, scrubber fans, abatement fans, process cooling water pumps, etc.

D.6 Incident Investigation

Failures in process safety programs often result in incidents and near misses. To fully understand what went wrong and how to prevent recurrences, a comprehensive incident investigation program must be in place.

An incident investigation program should be created that includes the following elements, at a minimum:

A. A formal process for investigating incidents and near misses. Investigations should include all deviations from the normal process, including loss of containment, fires, utility interruption, unintentional releases of process materials, activation of safety devices, and quality excursions in production

B. An investigation team with appropriate expertise (i.e., relevant operational, maintenance, and engineering expertise), led by a trained incident investigator

C. A formal methodology to guide the investigative process (e.g., root cause analysis [RCA]). Establish benchmarks to ensure the timely completion of tasks.

D. All recommendations should be documented and a process to ensure completion of the recommendation should be developed.

E. The findings should be shared with all applicable members of the organization.

F. Incident trending: Use trending incident data for identification and correction of recurring incidents, including reviews within the process hazard analysis.

Personnel should be encouraged to include reports of all unusual occurrences to determine whether an incident has occurred. Establish a simple process for prompt reporting, with training provided to employees on what should be reported.

APPENDIX E EXTREME ULTRAVIOLET (EUV) LITHOGRAPHY

The difference between EUV tools and others in the cleanroom is the value. The latest tools cost in the range of US$200 to US$300 million, without the wafer tracks that are usually installed very close or attached to the EUV tool (US$40 to US$50 million per tool). However, infrastructure changes associated with initial installations can increase the installed cost from US$300 to US$400 million.

E.1 Background

The wavelength of light used for the lithography process is known by the initialism EUV (extreme ultraviolet radiation) or by XUV (high-energy ultraviolet). Line widths below 10 µm, the current, cutting-edge, high-volume manufacturing (HMV) line width, are becoming harder to achieve using the common (as of 2018) photo lithographic techniques. Line width shrinkage by use of EUV technology will not only result in smaller, faster, more power-efficient devices, but also provide a significant reduction in the process steps needed to make advanced semiconductors.

EUV tools are significantly larger than most other tools in a fab; they can be approximately 9 to 12 ft (3 to 4 m) in height, with a footprint of approximately 25 x 12 ft (8 x 4 m) for the scanner tool only. The actual tool containing the source vessel and the scanner volume sits at the fab level. As with other scanners, the EUV is attached to a wafer track where the wafers are coated with the photoresist. The rest of the control systems, power systems, CO_2 laser, beam transfer system (BTS), etc., are in the subfab. Approximately one-quarter of the tool is in the fab; the remainder is in the subfab. Therefore, approximately 4300 to 5400 ft^2 (400 to 500 m^2) of space is needed in the subfab area to support each tool. Subfab support areas may necessitate a cleanroom environment.

Due to the weight and vibration sensitivity of the tool, significant structural work is required to prepare an existing fab floor for the installation. The tool sits on a vibration-eliminating and structurally complex steel frame attached to the concrete fab deck. Cranes are needed above the machines for the routine maintenance of the tool, specifically to lift out the source vessel and the ellipsoidal mirror.

E.2 Process Description

Traditional photolithography uses light at wavelengths of around 193 µm. EUV uses light generated at a wavelength of 13.5 µm, which is part of the electromagnetic spectrum. EUV is the most highly absorbed component of the electromagnetic spectrum. As such, it cannot be transmitted or focused through lenses like UV light can. The light source is focused by reflecting it off mirrors with incredibly fine surface finishes. Due to the properties of the light used, the technology for EUV is very different from that of UV lithography.

EUV equipment can be split into four distinct processes or sections:

- Laser and light generator, including beam transport, used when vaporizing metals to form the plasma
- Source vessel
- Scanner volume containing focus optics
- Wafer stage where the wafer is positioned and exposed to light

E.2.1 Laser and Light Generator

To artificially produce EUV light, a generator produces a high-powered pulsed CO_2 laser. The laser generator is located in the subfab; therefore, the laser light (10.6 µm wavelength) has to be directed and focused to the source vessel inside the EUV tool. This focus is accomplished via a series of beam transport tubes (BTT) with the light directed by mirrors. The beam transport tubes operate under a vacuum to transport the pulsed beam without distortion. The CO_2 pulsed laser beam is used to evaporate a tin droplet, heating the vapor to a critical temperature at which electrons are shed. The ions left behind are further heated until they start producing photons. The light emitted from this process is collected and reflected on an ellipsoidal collector. The EUV light is then focused and reflected off a turning mirror to transmit the light into the scanner volume that contains the focusing optics.

EUV light is readily absorbed by the mirrors used for its reflection; typically, a reflection rate of h70% is achieved. The power requirements for the EUV light source to overcome these high losses is significant. To achieve throughput rates of 100 wafers per hour (wph), the EUV source power to the exposure tool should be greater than 200 W. By comparison, 193 µm light lithography requires a source power of 90 W for 200 wph.

E.2.2 Source Vessel

The source vessel is a critical part of the EUV process as it contains the ellipsoidal collector (a highly polished dished mirror approximately 3 ft [1 m] in diameter), the laser droplet generator, metrology and systems associated with focusing and controlling the laser strike on the droplet, and the mirrors and focusing systems used to produce the beam of EUV light to be focused. The source vessel is constructed of special materials to withstand the high vacuum pressures and temperatures generated during the EUV process. The vessel is cooled using the fab process cooling water system. The module is highly sensitive to shock and moisture due to very tight tolerances of the equipment mounted externally to the chamber and the internal components.

The basic optical element is the ellipsoidal multi-layer mirror (MLM). MLM consists of approximately 50 bi-layers of molybdenum/silicon that are 6.7 nm thick, with the outermost layer being a protective layer that is 1.5-2 nm thick. Temperature control is essential to ensure stability of the mirror. As such, cooling the rear element of the mirror is critical to ensure a tight temperature tolerance, which is challenging due to the energy produced by the plasma.

Ultra-pure hydrogen is pumped into the source vessel low-vacuum chamber, serving three purposes:

- Cool the region near the plasma
- Stop fast tin ions
- Effectively etch the tin from the collector surface

E.2.3 Scanner Volume

The scanner volume contains the optics to focus and reflect the EUV light onto the reticle. It projects the pattern from the reticle through the projection optics onto the wafer stage, where the photoresist is exposed on the wafer to form the desired pattern. As with the source vessel and the ellipsoidal mirror, these processes are conducted under extreme vacuum; and hydrogen is used to cool and clean the lenses. The process inside the EUV tool has four distinct stages:

- Illuminator
- Reticle stage
- Projection optics
- Wafer stage

Ultra-pure hydrogen is used to protect the scanner volume (focus optics) from debris generated in the source. The scanner element has many optical surfaces that are very sensitive to contamination and extremely expensive to replace.

E.3 Hazards

E.3.1 Hydrogen

Hydrogen is used extensively in the EUV process, both in the source vessel and the scanner volume. These areas of the tool operate under high levels of vacuum, lessening the risk of hydrogen leaving the operating chambers. The complexity of the process necessitates process conditions are rigidly controlled in the tool. The measurement of vacuum conditions, gas pressure and flow rates in the source vessel and scanner volume is critical to ensure the longevity of the mirrors and the maintenance of process conditions.

Depletion of the reflective surface would reduce light reflection, slowing down the process or cause process errors.

Due to the purity of the gas required for the EUV scanners, numerous cleaning and purification processes are needed before use. Therefore, the EUV will likely be supplied from a system separate from the usual hydrogen supply. Contamination of the gas supply would cause significant damage to the internal components of the EUV tool. The semiconductor industry will likely want to clean and recycle the hydrogen used in the EUV process due to the volumes that will be needed for multiple tools. At the present time, little information is available about the recycling techniques used. However, recycling will likely not be performed at the point of use but rather, outside the fab envelope; and techniques will develop over time as the tools become more mainstream and numerous.

Storage of liquid hydrogen is needed to support the large hydrogen usage by EUV. Weekly deliveries of liquid hydrogen will likely be the norm, and hazards associated with liquid hydrogen transfer from the transport vehicles to the fixed holding tanks should be reviewed and understood. Other process gases such as argon, nitrogen and ultra-high purity compressed air represent little hazard compared to hydrogen. However, as with hydrogen, contamination of the supply is an issue. “Dirty” gases would seriously damage the tool. Because human error can result in contamination from improper connection of lines during hook-up and maintenance, some risk is associated with these tasks. The likelihood of error is no greater than for other tools, but the consequences are magnified due to the values involved.

E.3.2 Combustible Load

The tools have a significant combustible load within the enclosures due to the complex, substantial wiring looms. An electrical fault would cause significant smoke and possible fire from the plastics contained in the wiring loom. The cabling used is mostly low-smoke, halogen-free (LSHF) cable. However, the potential for wires to overheat still exists, causing the casing to melt and smoke. In addition, due to the large power usage at the tool, multiple levels of stacked cable trays in these areas are common, potentially obstructing the overhead sprinkler systems.

E.3.3 Temperature Criticality

Temperature regulation in and around the EUV tool is critical to its continued operation and performance. Loss of cleanroom conditions, particularly temperature variation, would cause key components to fall out of tolerance and fail. Should the tool be shut down in a controlled manner prior to loss of conditions, requalification would be required. The mini-environment would cushion the equipment for some time before temperature out of tolerance would compromise operation.

E.3.4 Impact Sensitivity

Numerous components are sensitive to impact shock, especially the source vessel containing the ellipsoidal mirror. The general maintenance of elements and mirrors requires them to be removed for cleaning. They must be lifted from the heart of the machine, and minor errors could result in damage to these extremely expensive components.

E.3.5 High Energy Usage

EUV tools use around 2 MW of power per unit. As multiple tools will likely be used in the fab, the electrical infrastructure enhancements required to ensure the correct operation of the equipment may be significant. Power reliability and N+1 availability need to be carefully considered by the design teams. The increased power requirements and amount of equipment associated with EUV substantially increase the amount of cabling required, adding to the combustible load of the subfab area around the EUV support equipment.

E.3.6 Cranes

EUV machines will have cranes/crane tracks located above them for the initial installation and for major overhauls where large pieces of the tool must be removed. These overhauls are expected to be an infrequent occurrence. A hazard associated with dropping equipment from a crane, either onto the fab floor or onto the EUV equipment, can result. Special lifting equipment for each component is provided as part of the tool maintenance package.

E.3.7 Human Element

EUV tools require a higher frequency and more complex maintenance to remain operational, specifically associated with the dismantling and reassembly of large elements of the tool. The increased amount of maintenance work for these tools increases the risk of a loss caused by human error.

APPENDIX F OVERVIEW OF LIQUID CRYSTAL DISPLAY (LDC) AND ORGANIC LIGHT EMITTING DIODE FABRICATION

F.1 Thin Film Transistor Liquid Crystal Display (TFT LCD)

A TFT LCD uses thin-film-transistor (TFT) technology to improve image qualities such as addressability and contrast. A TFT LCD is an active-matrix LCD.

TFT LCDs are used in appliances, including television sets, computer monitors, mobile phones, handheld devices, video game systems, personal digital assistants, navigation systems, projectors and car instrument clusters.

A TFT-LCD panel has a sandwich-like structure filled with liquid crystal between two glass substrates. The front glass substrate (Color Filter [CF] glass) and the rear glass substrate (TFT glass) are produced in different production lines. In most cases, several displays are produced on one glass substrate. Glass substrate size varies, and the largest substrate in the industry is 2,940 mm x 3,370 mm (the 10.5 generation substrates).

The fab contains three major process areas: Thin Film Transistor (TFT), Color Filter (CF) and Cell (also called Liquid Crystal). The panels are then packaged into modules for shipping by attaching polarizers and printed circuit boards.

F.1.1 Thin Film Transistor (TFT)

The TFT process (Figure F.1.1-1) is similar to the semiconductor fabrication process. The TFT process includes cleaning, photo process (i.e., photo resist coating, exposure and developing), etching (dry and wet), photo resist stripping, inspection and deposition (sputtering and CVD).

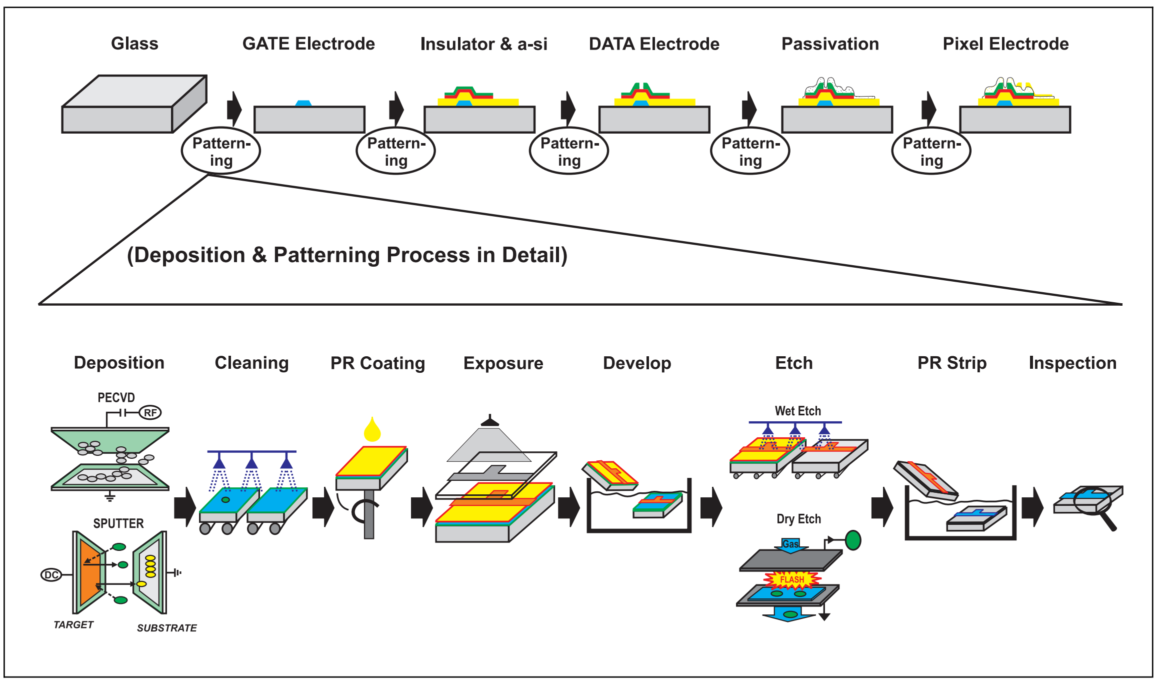


Fig. F.1.1-1. Typical TFT fabrication process

Ignitable liquids such as photoresist, thinner and stripper are used for photo, stripping and coating processes. Pyrophoric and flammable gases such as silane, hydrogen, and phosphine are used for CVD.

F.1.2 Color Filter

The front glass plate consists of Color Filter layers: red, green, blue, and black matrices. The Color Filter process (Figure F.1.2-1) includes cleaning, photo process (i.e., photo resist coating, exposure and developing), etching (dry and wet), photo resist stripping, inspection, Indium Tin Oxide (ITO) deposition, and overcoat lamination.

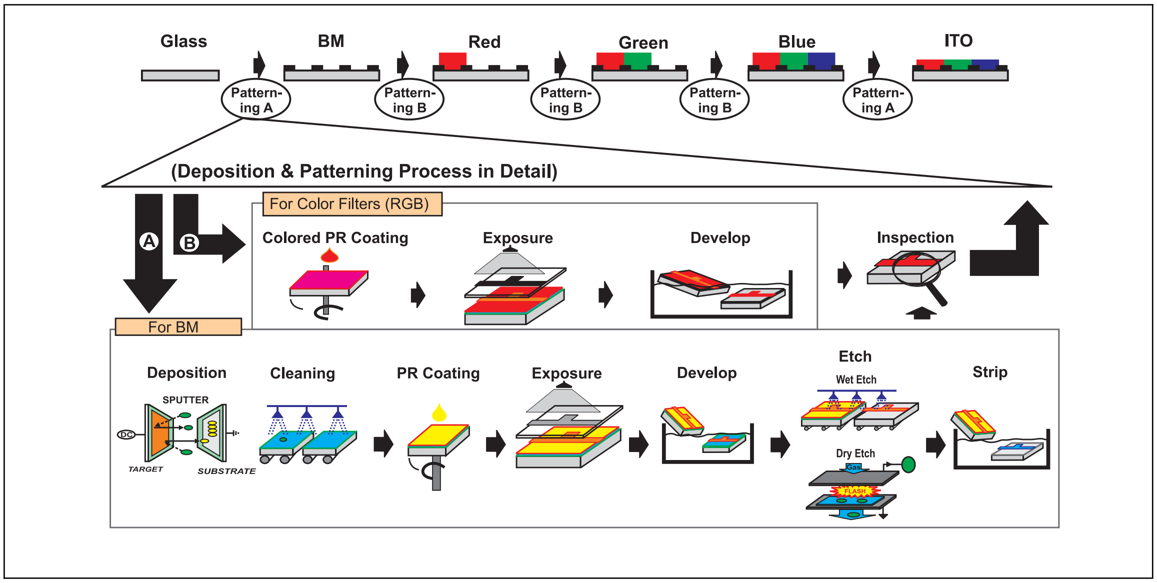


Fig. F.1.2-1. Typical color filter process

F.1.3 Cell (Liquid Crystal)

The cell process (Figure F.1.3-1) begins with polyimide printing on both of the TFT glass and Color Filter glass. This step is followed by column spacer dispensing, assembly and liquid crystal injection.

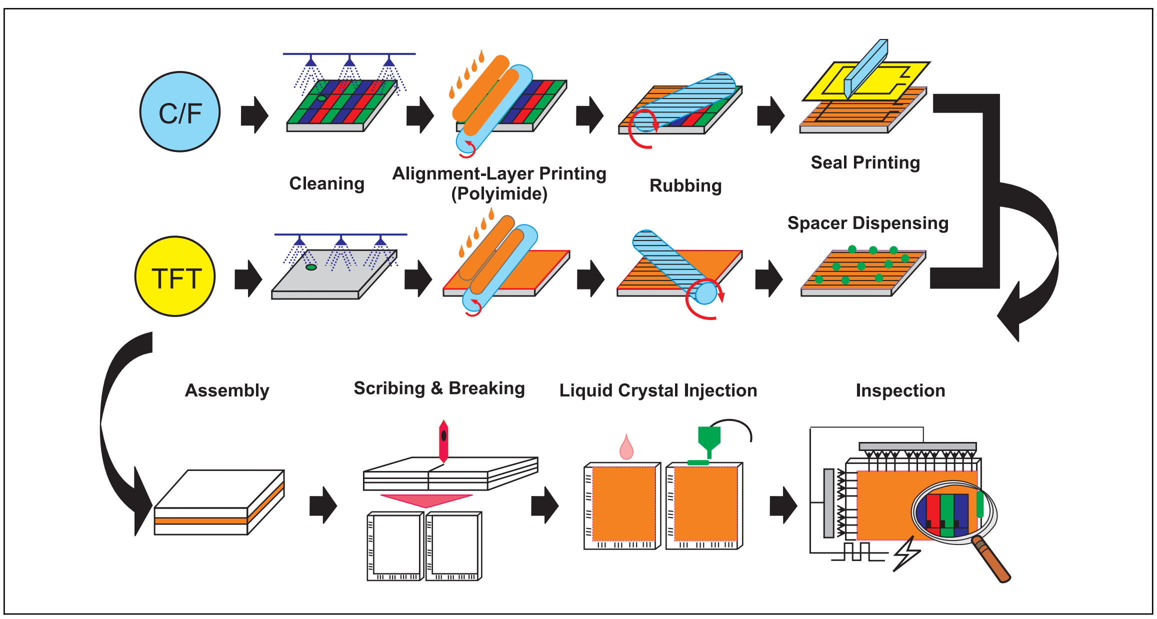


Fig. F.1.3-1. Typical Cell Process

F.2 Glass Organic Light Emitting Diode (OLED) and Plastic OLED

OLED is an emerging display technology that is fast becoming mainstream in many markets. One of the benefits of OLED over the competing LCD design is that these light emitters can be switched completely off, giving the technology deep blacks and an excellent contrast ratio. OLED enables display panels to offer the best image quality and accommodating design as they can be made flexible and transparent (Figure F.2-1).

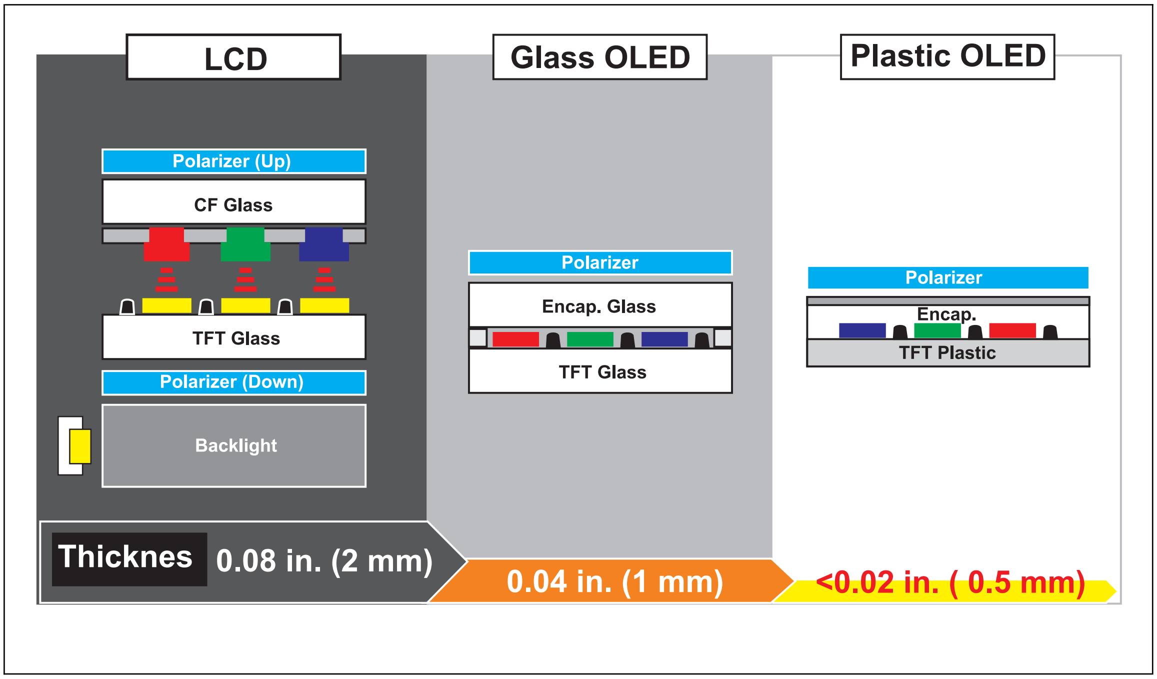


Fig. F.2-1. Comparison of cell layers (LCD and OLED)

Like LCD, Glass OLED also has a sandwich-like structure. The front glass substrate and the rear glass substrate are produced in different production lines. In most cases, several displays are produced on one glass substrate. Glass substrate size varies, and the largest substrate can be 7.2 ft x 8.2 ft (2,200 mm x 2,500 mm).

For plastic OLED (POLED), polyimide is coated on a glass substrate first. TFTs are formed on the polyimide, then the organic layers and the encapsulation layers are deposited. Finally, the glass is removed (delaminated), making the panel flexible. A "back plate" may be added to the flexible panel to make it stronger. The fab contains three major process areas: Low Temperature Polycrystalline Silicon (LTPS), Evaporation and Encapsulation (EVEN) and Cell. The OLED panels are then packaged into modules in a process similar to that of a semiconductor back-end facility.

F.2.1 Low Temperature Polycrystalline Silicon (LTPS)

The LTPS process for OLED is similar to an LCD's TFT process, but more and thinner layers are required. Therefore, more advanced process technology is used. One major difference is the presence of a doping process using ion implanters and additional hazardous gas (e.g., phosphine). LPTS consists of the following processes: Wet Etch, Polyimide (PI), Excimer Laser Annealing (ELA), Sputtering, CVD, Dry Etch and Doping.

Ignitable liquids such as photoresist, thinner, stripper and polyimide are used for photo, stripping and coating processes. Pyrophoric and flammable gases, including silane, hydrogen and phosphine (1% PH_3/H_2), are used for CVD.

F.2.2 Evaporation and Encapsulation (EVEN)

In the evaporation (EV) process, organic material is deposited on the glass substrate by evaporation, using fine metal mask (FMM). The evaporation is completed in an OLED Evaporator.

Masks used for the EV process are sent to mask cleaners utilizing ignitable liquids, ethyl alcohol and NMP (F.P. around 190°F-210°F [90C° - 100C°]).

Encapsulation (EN) is a process to provide a protective shield against oxygen and moisture using CVD. (See Figure F.2.2-1.)

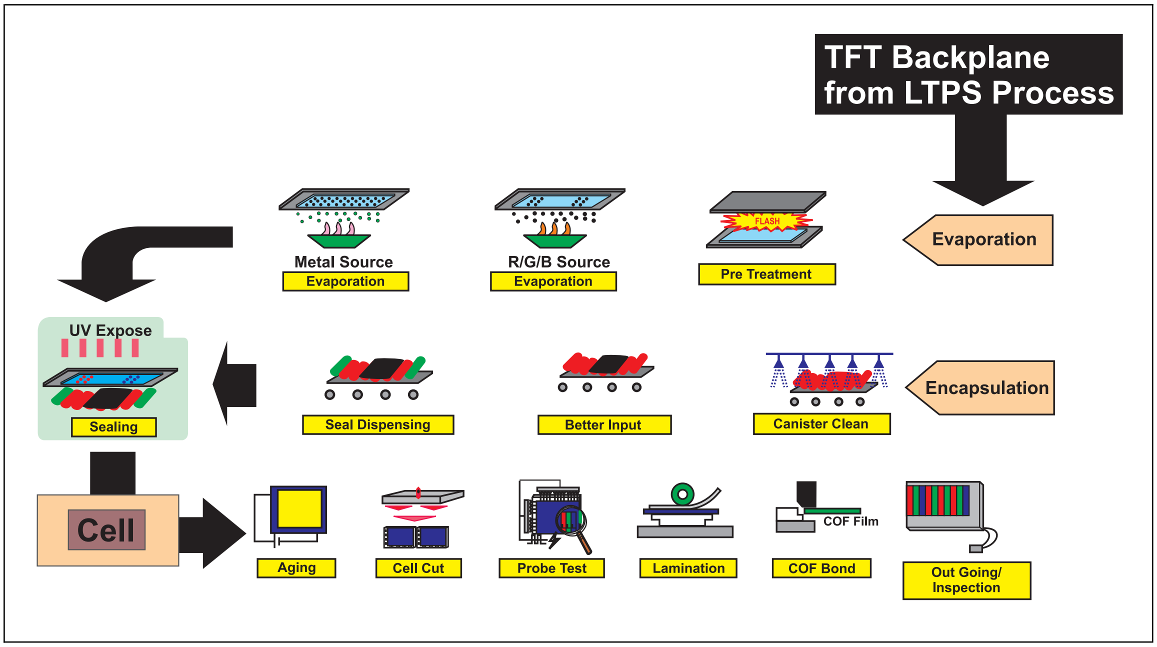


Fig. F.2.2-1. EVEN and cell processes

F.2.3 Cell

The cell process consists of aging, cell cut, test, lamination, etc. No chemicals or gases are used. AMHS and stockers storing cells in plastic cases are used in the process. (See Figure F.2.2-1.)

F.3 Hazards

The majority of LCD and OLED fabs are in Asia, and stacked fabs are very common. Each fab consists of a cleanroom and a clean-sub fab.

In the cleanroom envelope, the major differences in hazards from a typical 300 mm semiconductor fab are as follows:

A. Sprinkler obstructions in the cleanroom

Glass substrates are transferred via conveyers (at least 3 m wide) installed above fab tools such as wet benches. In addition, many fab tools such as wet benches and coater/developers are enclosed in plastic panels. This arrangement is similar to the ′mini-environment′ in a semiconductor fab, but the enclosures are much bigger due to the size of the fab tools. The presence of conveyers and the tools' plastic enclosures can cause the ceiling sprinklers to be significantly obstructed in some areas, such as wet benches where ordinary plastic panels are concentrated. Sprinkler obstructions can be eliminated by using an overhead transportation (OHT) system instead of conveyors.

B. Use of immersion heaters for heating chemicals

Immersion heaters (plug heater and quartz heater) are widely used for wet benches (wet etchers for corrosive liquid and stripper for ignitable liquid) and coaters/developers (developer for alkali) due to the size of the chemical tank (approximately 500 liter). Replacement of the heater with other types would not be practical, especially for the existing tools. If the necessary safety features are in place (low level liquid interlock, independent high-temperature cut-off switch, overcurrent protection for heaters, etc.) the likelihood of a fire from the heater would be very low. However, as mentioned above, if the plastic tank and panels around were to ignite, a large fire would result.

C. Larger ignitable liquid hazards in the cleanroom envelope

A large amount of ignitable liquid is present inside the cleanroom envelope. For example, ignitable liquid in a wet bench bath for a semiconductor fab can be up to 13 gal (50 L), whereas some wet benches could contain approximately 530 gal (2,000 L). A photoresist container in a semiconductor fab is 1 gal (3.8 L), whereas the containers for wet benches could be 53 gal (200 L) drums.

D. More ordinary plastic panels in the cleanroom

Ordinary plastic panels are widely used for tools, robot areas, stockers, etc. This usage contributes significantly to fire loads in the cleanroom and would also contribute to fire spread. Sprinklers in the cleanroom are typically designed for cleanroom occupancies (i.e., 0.2 gpm [8 mm/min] over 3,000 ft^2 [280 m^2]). Consider whether the sprinkler design should be based on Hazard Category 3 due to significant amounts of plastic.

E. Expanded-plastic (EP) box for new glass substrate

In some cases, glass substrate is stored in an expanded-plastic box. The substrate is transferred to a loading area and then to a cleanroom for inspection. However, use of metal crates is becoming a common practice because of greater storage capacity and smaller footprint.

APPENDIX G ASSEMBLY AND TEST

The following information is provided for analysis of assembly and test (back-end) semiconductor facilities.

G.1 Construct cleanrooms in accordance with Data Sheet 1-56, *Cleanrooms*, and Section 2.4.3 of this data sheet.

G.2 Treat wafer bump and diamond-like carbon processes similar to front-end semiconductor fabrication, and provide protection in accordance with this data sheet.

G.3 Arrange and protect data centers in accordance with Data Sheet 5-32, *Data Centers and Related Facilities*.

G.4 Arrange and protect laboratories (work benches, hot plates, and ignitable liquid handling and storage) in accordance with Data Sheet 7-29, *Ignitable Liquid Storage in Portable Containers*; Data Sheet 7-32, *Ignitable Liquid Operations*; and Sections 2.6.4 and 2.9 of this data sheet.

G.5 Arrange and protect wet process tools used in plating in accordance with Section 2.7 and Data Sheet 7-6, *Plastic and Plastic-Lined Tanks*.

G.6 Arrange and protect equipment with hydraulic oil in accordance with Data Sheet 7-98, *Hydraulic Fluids*.

G.7 Use and protect fume exhaust ductwork in accordance with Sections 2.5.3.4 and 2.5.8.1.

G.8 Assess and protect against dust hazards in accordance with Data Sheet 7-76, *Combustible Dusts*.

G.9 Evaluate ammonia cracking in accordance with Data Sheet 7-72, *Reformer and Cracking Furnaces*.

G.10 Arrange and protect hydrogen usage hazards in accordance with Data Sheet 7-91, *Hydrogen*.

G.11 Arrange and protect forming gas mixing, storage, and distribution in accordance with Section 2.8.10 and Data Sheet 7-91, *Hydrogen*.

G.12 Arrange and protect cryogenic gases in accordance with Data Sheet 7-91, *Hydrogen*.

G.13 Protect wave solder units in accordance with Data Sheet 7-9, *Dip Tanks, Flow Coaters and Roll Coaters*.

G.14 Protect solder paste machines and associated screen-cleaning equipment in accordance with Data Sheet 7-32, *Ignitable Liquid Operations*.

G.15 Locate and protect solvent recovery systems in accordance with Data Sheet 7-2, *Waste Solvent Recovery*.

G.16 Protect the storage of finished wafers, work-in-process (WIP) and finished product in accordance with Section 2.7 and Data Sheet 8-9, *Storage of Class 1, 2, 3, 4 and Plastic Commodities*.

G.17 Arrange and protect the handling of gold and precious materials, as well as finished goods storage, in accordance with Data Sheet 9-16, *Burglary and Theft*.

G.18 Protect anechoic chambers in accordance with Data Sheet 1-53, *Anechoic Chambers*.