SILANE

Table of Contents

Page

List of Figures

List of Tables

1.0 SCOPE

This data sheet applies to hazards associated with silane gas storage and dispensing to process equipment at end-user facilities, such as manufacturing of semiconductors, photovoltaic cells, flat panel displays, other specialty glass and fibers, and experimental installations in laboratories. Recommendations are provided to help prevent the accidental release of silane, and to mitigate property damage if a release does occur and results in a fire or explosion.

Also consult local code requirements and industry standards for silane installations. Code compliance is outside the scope of this data sheet.

1.1 Changes

April 2014. Silane hazards and safeguards were previously addressed in DS 7-7, *Semiconductor Fabrication Facilities.* Data Sheet 7-108 has been created because silane usage has expanded in recent years to industries beyond semiconductor manufacturing. Many recommendations pertaining to silane have been transferred from DS 7-7 to this data sheet. Key changes to the recommendations previously published in DS 7-7 include the following:

1.1.1 Added new recommendations for a more comprehensive approach to the prevention of accidental silane releases.

1.1.2 Revised separation distances between outdoor silane containers and main buildings based on studies and silane explosion modeling performed by FM Global.

1.1.3 Deleted former Recommendation 2.2.11.1.7(f) for installation of pressure relief devices on silane tubes (to reflect current industry and code trends).

2.0 LOSS PREVENTION RECOMMENDATIONS

2.1 Introduction

Accidental releases of silane from storage containers, dispensing systems, and end-use equipment have resulted in severe explosion and fire damage to exposed buildings and their contents. The majority of property loss can be prevented by following these basic safeguards:

- Implement robust containment design.
- Provide effective personnel training.
- Strictly adhere to safe operating and maintenance procedures.

2.2 Construction and Location

2.2.1 Cylinders

The term “cylinder” refers to individual containers of up to 13 gal (50 L) water capacity. Larger capacity containers or groups of interconnected (manifolded) cylinders, also called “cylinder packs,” are addressed as “bulk containers” (see Section 2.2.2).

2.2.1.1 Strictly limit the number of silane cylinders on site and keep them in designated areas that provide ready access for emergency responders.

2.2.1.2 Locate silane cylinders outdoors and at least 50 ft (15 m) away from main buildings, outdoor equipment, and important utilities (see Figure 1, location I).

Note: An explosion hazard is present when silane is stored or dispensed outdoors. Space separation of 50 ft (15 m) is expected to help mitigate property loss in the event of relatively small releases of silane, assuming the cylinders are fitted with restrictive flow orifices (RFOs) per Section 2.5.3. Severe local blast damage may occur in the dispensing or storage area under some release conditions, even if RFOs are present.

2.2.1.3 Where an indoor location is unavoidable, use small, detached buildings of damage-limiting wall and roof construction per DS 1-44, *Damage-Limiting Construction,* (locations I and II in Figure 1).

2.2.1.4 Where it is not possible to locate cylinders outdoors or in a detached building, provide a cut-off room at grade level along an outside wall with direct access from outside the main building (location III or IV in Figure 1). Determine the design strength of pressure-resistant and relieving walls using DS 1-44, based on the hydrogen criteria.

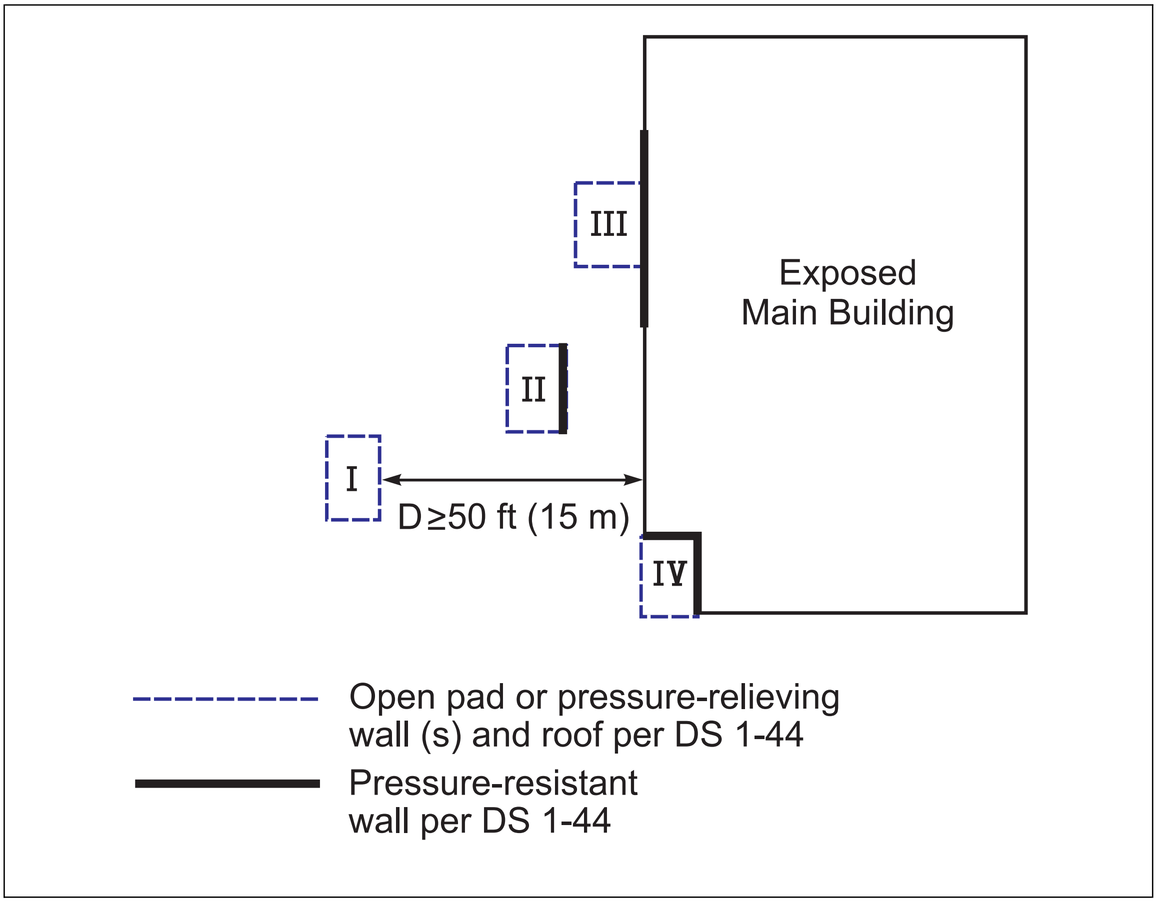

Fig. 1. Silane cylinder storage and dispensing locations

Note: An explosion hazard is present when silane is stored or dispensed indoors. Damage-limiting construction (DLC) may help mitigate property loss in the event of explosion following relatively small releases of silane, assuming the cylinder is fitted with an RFO. Severe local blast damage may occur under some release conditions, even if an RFO and DLC are provided as recommended.

2.2.1.5 Isolate outdoor cylinder pads and detached buildings from potential external fire exposures, including vegetation, combustible construction, outdoor transformers, ignitable liquid storage, ignitable liquid processes, oxidizers and other hazardous materials, idle pallets, and bulk combustible yard storage.

2.2.1.6 Install indoor dispensing cylinders inside ventilated gas cabinets arranged in accordance with this data sheet (Section 2.5.4).

2.2.1.7 Provide controls to prevent authorized acess to cylinder storage and dispensing installations.

2.2.2 Bulk Containers

For the purposes of this data sheet, “bulk containers” are individual and manifolded containers, including cylinder packs and tube trailers, with aggregate water capacity exceeding 13 gal (50 L).

2.2.2.1 Locate bulk silane containers outdoors in open areas and at least 50 ft (15 m) away from main buildings, outdoor equipment, and important utilities.

Note: The recommended 50 ft (15 m) separation distance assumes an explosion following an unconfined outdoor release that is limited by a 1/8 in. (3.2 mm) diameter or smaller RFO (or equivalent flow restriction) located upstream of the release point. For larger diameters, or for releases into enclosed or partially enclosed spaces, such as multisided weather enclosures, greater distances may be needed as outlined in Sections 3.2.1.3 and 3.2.1.4.

2.2.2.2 Isolate bulk containers from potential external fire exposures such as combustible construction, outdoor transformers, cooling towers, ignitable liquid storage and processes, oxidizers and other hazardous materials, idle pallets, and other bulk combustible storage.

2.2.2.2.1 Ensure that any exposing ignitable liquid storage and process areas are provided with spill containment and emergency drainage to a safe location.

2.2.2.3 Separate bulk containers from each other and from the regulator station by 2-hour fire-rated walls extending at least 3 ft (1 m) above the containers (see Figure 2).

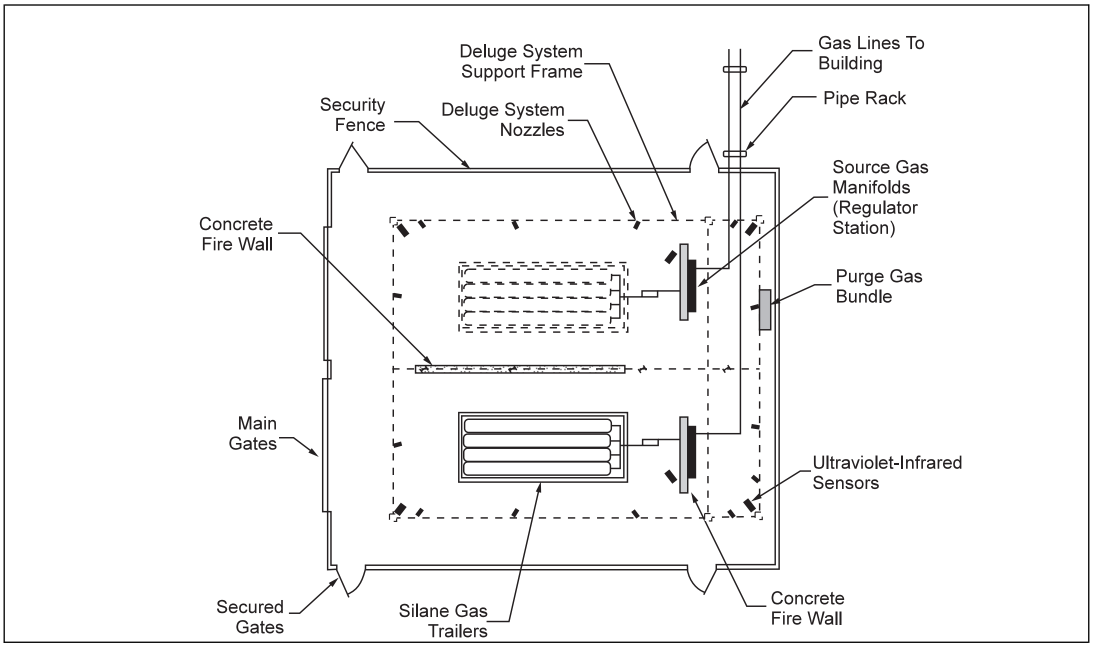

Fig. 2. Bulk silane storage facility

2.2.2.4 Provide open chain link fencing to help restrict unauthorized access to bulk installations.

2.2.3 Weather Protection

2.2.3.1 Where weather protection is needed for outdoor installations, use light, noncombustible, pressure-relieving roof and wall panels designed per DS 1-44, *Damage-Limiting Construction.*

2.2.3.2 Provide water spray on the containers, or deluge protection under the roof in accordance with Section 2.4.2.

2.2.4 Separation from Walls and Fire Barriers

2.2.4.1 Locate cylinder packs, bulk containers, and open cylinder racks at least 10 ft (3 m) from walls and fire barriers, or provide forced mechanical ventilation over mechanical connections in accordance with Section 2.3.4.

2.2.4.2 Provide forced mechanical ventilation in accordance with Section 2.3.4 for pressure-reducing systems that are mounted on a wall or fire barrier.

2.2.5 Seismic Hazards

Apply the following recommendations to silane installations located in FM 50-year through 500-year earthquake zones, as defined in Data Sheet 1-2, *Earthquakes.*

2.2.5.1 Perform a seismic loading analysis based on ASCE 7 or other recognized code to ensure that supports for cylinders, gas cabinets, bulk containers, and delivery piping have been designed to resist the anticipated seismic loads. (See also “Equipment Restraint/Location and Nonstructural Component Anchorage” in DS 1-2, Appendix C.3.3, “Meeting and Exceeding Minimum Building Code Provisions”).

2.2.5.2 Determine horizontal seismic forces in accordance with the requirements of the local building code, but use a minimum horizontal force equal to 50% of the weight of the equipment acting on the equipment’s center of gravity.

2.2.5.3 Provide the following seismic safeguards for piping:

A. Provide seismic shut-offs on silane supplies in accordance with DS 1-11, *Fire Following Earthquake.*

B. Use welded piping systems, and provide clearance where piping passes through foundations, walls, and floors in accordance with DS 1-11.

C. Refer to DS 2-8, *Earthquake Protection for Water-based Fire Protection Systems,* for seismic design of water spray fire protection systems.

2.2.6 Flood Hazards

2.2.6.1 Consult DS 1-40, *Flood,* to evaluate and protect against flood exposures for the location.

2.2.6.2 Locate silane installations on elevations that are at least 2 ft (0.6 m) higher than the predicted 500-year flood elevation and at least 500 ft (152 m) from direct wave impacts and or high flood-flow velocities (i.e., above 7 fps [2 m/s]).

2.2.6.3 Where cylinders and bulk containers are located in flood-prone areas, provide anchorage and foundations to resist the forces of buoyancy, moving water, and wave impact.

2.3 Occupancy

2.3.1 Inherently Safer Installations

2.3.1.1 Strictly control the number and the location of silane containers in accordance with a documented siting plan.

2.3.1.2 Use restrictive flow orifices or equivalent flow-limiting design on silane piping where applicable, as determined by process hazards analysis (Section 2.5.2).

2.3.2 Container Receiving, Storage, and Handling

2.3.2.1 Check silane containers for leaks and verify proper fitting of RFOs prior to allowing entry onto the site.

2.3.2.2 Check cylinder and bulk storage/dispensing areas for leaks, poor housekeeping, and other unsafe conditions on a weekly recorded basis.

2.3.2.3 Provide basic handling safeguards for cylinders in accordance with Data Sheet 7-50, *Compressed Gases in Portable Cylinders and Bulk Storage.*

2.3.3 Room Exhaust Ventilation

2.3.3.1 Install continuous mechanical exhaust ventilation in rooms and detached buildings occupied for silane storage in cylinders. Provide a rate of 1 cfm/ft^2 (0.3 m^3/min/m^2) or six air changes per hour, whichever is greater.

Note: This ventilation rate will prevent buildup of silane concentration in the event of very small leaks. It is not intended to provide protection against accumulation of flammable atmosphere in case of large releases, such as full flow through an RFO.

2.3.3.2 Design air intakes and exhaust outlets to ensure proper circulation and eliminate stagnant zones within the room.

2.3.3.3 Monitor and alarm the ventilation system at a control room or other constantly attended location.

2.3.3.4 Use noncombustible exhaust ductwork.

2.3.3.5 Provide an emergency power supply in accordance with Data Sheet 5-23.

2.3.4 Forced Mechanical Ventilation

2.3.4.1 Provide forced mechanical ventilation over unenclosed potential release sources, such as pigtail and unwelded pipe connections, and pressure-reducing stations.

2.3.4.2 Provide outside air at a flow rate sufficient to limit the maximum average concentration of silane to 0.4% in the event of a release as calculated in Section 3.3.2.

2.3.4.3 Monitor and alarm the ventilation system at a control room or other constantly attended location.

2.3.4.4 Provide safety interlocks to activate the emergency isolation system (Section 2.5.5) on loss of ventilation.

2.3.4.5 Provide an emergency power supply in accordance with Data Sheet 5-23.

2.4 Protection

2.4.1 Indoor Installations

2.4.1.1 Install a 165°F (74°C) rated, quick response automatic sprinkler inside each silane gas cabinet. Design to flow a minimum of 30 gpm (114 L/min).

2.4.1.2 Provide a deluge system or automatic ceiling sprinkler system in silane storage and dispensing areas. Design for a density of 0.30 gpm/ft^2 (12 mm/min) over the most hydraulically remote 3000 ft^2 (280 m^2) or the room area, whichever is smaller. Where sprinklers are provided, use a 165°F (74°C) temperature rating.

2.4.2 Outdoor Installations

2.4.2.1 Provide automatic fixed deluge protection under any roof canopy. Design the system to provide a density of 0.30 gpm/ft^2 (12 mm/min) over the canopy footprint.

2.4.2.2 Provide FM Approved automatic fixed water spray protection for the tube trailers, designed to provide a density of 0.30 gpm/ft^2 (12 mm/min) over the external tank surface area.

2.4.2.3 Provide FM Approved fixed water spray protection for cylinder pack and 450 L (“tonner”) storage containers. Design to provide a density of 0.30 gpm/ft^2 (12 mm/min) over the cylinder pack system or tonner surface, plus a 10 ft (3 m) wide perimeter area on all sides.

2.4.2.4 Provide fixed automatic protection for associated pressure-reducing and control panel areas.

2.4.2.5 Activate all deluge and water spray protection by optical flame detection systems in accordance with Section 2.5.8.

2.4.2.6 Provide remote manual activation of all deluge and water spray systems from the control room or other location that will be accessible in the event of an emergency.

2.4.2.7 Provide water supplies for a duration of 60 minutes, including a hose stream of 250 gpm (950 L/min) for cylinders, and 500 gpm (1890 L/min) for bulk containers.

2.5 Equipment and Processes

2.5.1 Materials of Construction

2.5.1.1 Use cylinders, bulk containers, piping, and components suitable for silane service and design conditions in accordance with applicable codes and industry standards such as CGA G-13, AIGA (052/08), and EIGA (160/10/E).

2.5.1.2 For greater resistance to external fire exposure, use cylinders constructed of steel.

2.5.1.3 If aluminum cylinders are used, limit them to 6061 alloy individual cylinders (not cylinder packs).

2.5.1.4 Provide a 0.25 in. (7 mm) thick steel partition between aluminum cylinders located in a common gas cabinet.

2.5.1.5 In open manifold racks, provide a steel partition between the silane cylinders as follows:

A. Use a 0.25 in. (7 mm) thick steel plate partition extending 3 in. (76 mm) beyond the footprint of the cylinder.

B. Extend the plate from the top of the purge panel to 12 in. (305 mm) below the cylinder valve.

2.5.1.6 Construct ventilation ducts of noncombustible materials.

2.5.2 Process Hazards Analysis (PHA)

2.5.2.1 Perform a documented process hazards analysis (PHA) to identify conditions that could result in accidental loss of containment of silane during storage, dispensing, end use, line and equipment purging, and waste treatment.

2.5.2.2 Use a recognized PHA methodology (“HAZOP,” “What-if,” “Checklist,” etc.) to help identify critical process deviations, including but not limited to the following:

A. Pipe breaks, leaking connections and other equipment malfunctions

B. Operator error, such as during change-out or purging

C. Sudden interruption of services such as process water, cooling water, steam, ventilation, instrument air, and/or electric power

D. Contamination

E. Line heater failure “on” or “off”

F. Upsets that may be caused by emergency shutdown

G. Logic controller failures

2.5.2.3 Evaluate adequacy of basic process controls, administrative controls, and safety interlocks to respond to potential deviations and prevent releases, or at least limit the amount of silane if a release should occur.

2.5.2.4 Implement additional safeguards to address exposures, if appropriate (as determined by the PHA).

2.5.2.5 Update the PHA in case of process changes, accidents or near misses, and review it at least every three years.

2.5.2.6 Have PHA documentation accessible for review during managing change and loss prevention audits.

2.5.3 Restrictive Flow Orifices (RFOs)

2.5.3.1 Provide restrictive flow orifices (RFOs) on silane containers.

2.5.3.2 Provide RFOs in delivery piping to protect valve manifold boxes and end-use equipment if warranted based on process hazards analysis (PHA).

2.5.3.3 Size the RFO to limit maximum flow rates to that needed for production requirements.

2.5.3.4 Document the maximum required silane flow rates and the location and diameter of respective RFOs.

2.5.3.5 Estimated flow rates for RFOs are given in Section 3.3.1.

2.5.4 Gas Cabinets and Valve Manifold Boxes

2.5.4.1 Provide the following safeguards for silane cylinder cabinets:

A. At least 12 gauge (0.097 in., 2.5 mm) metal construction, and a self-closing, self-latching door.

B. Automatic sprinkler protection per Section 2.4.1.1

C. RFO on silane cylinder valve per Section 2.5.3

D. Emergency isolation system per Section 2.5.5

E. Purge gas system per Section 2.5.6

F. Gas and flame detection per Section 2.5.8

G. Exhaust ventilation per Section 2.5.9

H. Electrical hazardous area rating per Section 2.10.2

2.5.4.2 Limit the number of silane cylinders in the gas cabinet to no more than two, plus a purge gas cylinder.

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

2.5.4.4 Provide the following safeguards for valve manifold boxes (VMBs)

A. Noncombustible construction

B. Emergency isolation system per Section 2.5.5

C. RFO if appropriate per Section 2.5.3

D. Gas detection per Section 2.5.8

E. Exhaust ventilation per Section 2.5.9

2.5.5 Emergency Isolation Systems

The goal of this section is to prevent or at least limit the duration of accidental releases of silane in the dispensing and end-use equipment areas.

2.5.5.1 Provide automated cylinder valves (ACVs) on the cylinder and bulk container outlets to isolate the supply in the event of detected upset conditions.

2.5.5.2 Provide an emergency isolation system capable of closing the ACV on the source container(s) and other isolation valves (as determined by the PHA) in the event of any of the following:

A. Optical silane flame detection

B. Silane gas leak detection for indoor dispensing systems and end-use areas

C. Loss of exhaust ventilation or low flow for cabinets and enclosures

D. Loss of room exhaust ventilation or forced mechanical ventilation

E. Excess flow of silane

F. Critical process upsets (deviations) in end-use equipment, such as excess pressure or temperature

G. Water flow in the water spray, sprinkler, or deluge systems in the dispensing and end-use areas

H. Manual ("push button") activation at the dispensing area, point of use, and in one or more remote locations that will be accessible to operation by emergency responders

2.5.5.3 Arrange alarms and automatic emergency trips of end-use equipment as follows:

A. Use hard-wired safety interlocks or a separate programmable electronic system ("safety PLC") where feasible.

B. If critical safety interlock logic is integrated with basic process controls, such as a distributed process control system (DCS), provide safeguards to minimize the potential for hardware or software problems that may result in critical process upsets and also compromise the automatic safety interlock system ("common cause failures;" see Data Sheet 7-45, *Instrumentation and Control in Safety Applications)*.

C. Connect all critical alarms to a constantly attended location.

D. Establish alarm settings that allow sufficient time for operators to intervene to avert further deviation prior to an automatic trip of the process.

E. Provide alarms and emergency automatic trip devices with reliability and redundancy levels commensurate with the criticality of identified process upsets (as identified in the process hazard analysis).

F. Provide device redundancy with a voting protocol, where appropriate, to minimize unnecessary or nuisance trips.

2.5.5.4 For each end-use process, provide a manual emergency shutdown system that meets the following criteria:

A. Capable of isolating the silane supply and initiating a controlled process shutdown in the event of alarms or other conditions indicating imminent critical upsets as identified in the process hazards analysis.

B. Capable of activation at remote locations that will be accessible to operators and emergency responders during a fire or other emergency in the process area.

C. Functionally independent to ensure operators can achieve a controlled shutdown in the event of software or hardware malfunctions in the basic process control system (PLC or DCS).

2.5.5.5 Document the emergency isolation system by means of schematics and narrative for use in training, emergency drills, loss prevention audits, and management of changes.

2.5.6 Purge Systems

2.5.6.1 Provide dedicated inert gas and vacuum sources for purging of silane piping and end-use equipment.

2.5.6.2 Provide redundant backflow and isolation valves to prevent contamination of purge gas cylinders with silane.

2.5.6.3 Use purge gas at higher pressure than the silane system pressure, where feasible.

2.5.6.4 Provide loss of vacuum and low-pressure alarms for vacuum and inert gas purges, respectively.

2.5.6.5 Provide a continuous flow of purge gas for the vent line, with monitoring and interlocks to prevent venting if the purge gas flow is restricted or interrupted, as determined by PHA.

2.5.6.6 Arrange purge gas vent lines to discharge independently of other vent systems to a treatment system or to a safe outdoor area and directed away from any rooftops or building walls.

2.5.7 Pressure-Relief Devices

Where pressure-relief devices are installed on containers, arrange them as follows:

A. Use a combination fusible plug and burst disk (CG-4 type).

B. Arrange tube trailer PRDs to discharge into stacks discharging above the trailer, or manifold them to a main release stack located away from the tube trailer, so a gas flare resulting from a PRV release will not impinge on adjacent tubes, piping, or control systems.

C. Provide relief vent stacks with vertical upward discharge with blow-off caps or other means of preventing rain and other foreign material from entering the stacks.

D. Arrange to discharge vertically upward and above the level of the roof. Provide weather caps on the discharge end, and do not gooseneck the discharge pipe.

2.5.8 Gas and Fire Detection

2.5.8.1 Provide FM Approved silane gas and optical flame detection systems in cabinets, enclosures, and rooms as well as outdoor dispensing and storage areas.

2.5.8.2 Use optical flame detection systems that are FM Approved for silane flames.

2.5.8.3 Arrange gas and flame detectors to close automated cylinder valves on the source containers as well as activate deluge and water spray systems.

2.5.8.4 Locate and install detectors in accordance with manufacturers' instructions.

2.5.9 Mechanical Exhaust Ventilation for Gas Cabinets and Enclosures

Explosion hazards are present where silane is dispensed in gas cabinets and handled in enclosures, such as valve manifold boxes, in the event of releases from potential sources such as leaking valves, gauges, regulators, and unwelded piping connections.

2.5.9.1 Provide continuous mechanical exhaust ventilation systems for gas cabinets and enclosures. Size these systems to limit the average concentration to 0.4% by volume, based on a continuous release of silane at a standard volumetric flow rate as determined by the size of the RFO in the discharge line and the maximum cylinder pressure.

Further guidance and example safety ventilation calculations are provided in Section 3.3.1.

2.5.9.2 Monitor the exhaust ventilation and interlock it with the emergency shutdown system in accordance with Section 2.5.5.2.

2.5.9.3 Provide emergency backup power for the cabinet ventilation system.

2.5.10 Equipment Commissioning and Documentation

2.5.10.1 Prior to the startup of a new or modified installation, implement a documented commissioning protocol to ensure compliance with the requirements of applicable codes, manufacturers' instructions, and the following recommendations:

A. Inspect and test all piping and equipment.

B. Perform pressure testing using hydrostatic methods or pneumatic testing with nonflammable gas.

C. Proof-test all manual and automatic emergency isolation safeguards.

D. Verify that as-built site and installation drawings are complete and accurate.

2.5.10.2 Document the detailed equipment specifications, including materials of construction, applicable pressure vessel and piping codes, and process and instrumentation diagrams.

2.5.10.3 Keep all original equipment documentation, including purchase specifications, "as-built" drawings, and photographs, on file and readily accessible to authorized personnel for emergency response, loss prevention audits, and management of changes.

2.6 Operations and Maintenance

2.6.1 General

2.6.1.1 Establish administrative controls and designate responsible personnel to ensure employees and contractors adhere to established operating and maintenance procedures.

2.6.1.2 Use qualified employees and/or contractors to supervise and perform all operation and maintenance duties for silane storage and dispensing.

2.6.1.3 Maintain documented operating procedures, including the following:

A. Normal startup and shutdown

B. Container change-out

C. Supervision during normal operation

D. Emergency isolation system

2.6.1.4 Establish documented preventive maintenance procedures in accordance with facility experience and equipment manufacturers' guidelines.

2.6.1.5 Conduct regular recorded maintenance and inspection of silane installations according to industry guidelines, manufacturers' directions, and facility experience. Conduct visual monthly recorded inspections of housekeeping and other general conditions in silane storage, delivery, and end-use areas.

2.6.1.6 Establish procedures to report and take prompt corrective action to address equipment failures, leakage, corrosion, operator error, near-misses, and other deviations from normal conditions.

2.6.2 Safeguard Testing

2.6.2.1 Test the performance of all manual and automatic emergency shutoff valves and actuators annually, or more frequently if recommended by the device manufacturer or facility experience warrants it.

2.6.2.2 Test excess-flow valves and switches for closing action as recommended by the equipment manufacturer.

2.6.2.3 Replace or recondition all safety devices based on manufacturers' recommendations, or when necessary due to damage or other poor condition.

2.7 Training

2.7.1 Employee Training

2.7.1.1 Create a training program for employees who have access to silane installations, including operators, emergency responders, and maintenance and security personnel. Include at least the following subjects in the training program:

A. The hazards created by silane storage and use.

B. Proper operation and shutdown of equipment under normal and emergency procedures.

C. Location of all local and remote shutoff stations.

2.7.1.2 Provide initial and regular, periodic refresher training.

2.7.2 Contractor Training

2.7.2.1 Ensure contractors have adequate training in silane hazards and the performance of their assigned duties in supplying or maintaining the installation.

2.7.2.2 Train contractors to follow facility procedures for notification and response to silane emergencies.

2.8 Human Factor

2.8.1 Property Conservation

2.8.1.1 Address silane hazards and prevention of accidental releases as part of a documented property conservation program in accordance with DS 9-7, Property Conservation, including the following steps:

A. Prepare a written property conservation policy.

B. Establish authority and responsibilities.

C. Organize responders to handle emergencies.

D. Educate and train.

E. Audit and update.

2.8.2 Emergency Response and Pre-Fire Planning

2.8.2.1 Establish a plan for emergency response to accidental silane releases that includes at least the following elements:

A. Refer to Data Sheet 10-1, *Pre-Incident Planning,* for general guidelines on establishing and maintaining an emergency response plan.

B. Site plan showing the location of all silane containers and emergency isolation stations

C. Authorization for designated responders to activate the emergency isolation system when warranted based on judgment

D. Preplan for response by qualified, trained personnel to remove leaking containers from the site using suitable emergency containment vessels

E. Ensure availability of fire protection for cooling exposed silane containers.

F. Do not extinguish silane fires until the release source has been isolated.

2.8.2.2 Familiarize the facility's emergency response team members and the local fire service with the location of silane installations as well as the emergency response plan.

2.8.2.3 Conduct annual emergency response drills to reinforce the employee and contractor training program and to familiarize the fire service with the site layout.

2.8.3 Supervision of Loss Prevention Programs

2.8.3.1 Keep loss prevention documentation current and readily accessible at the facility for review and use in management of change, loss prevention audits, hazards assessments, and emergency response.

2.8.3.2 Ensure silane-related loss prevention programs are supervised by employees trained in silane gas handling and emergency response procedures.

2.8.4 Supervision of Contractors

2.8.4.1 Develop and implement a program to supervise contractors in accordance with the recommendations in Data Sheet 10-4, *Contractor Management,* including but not limited to, the following:

A. Draft a formal policy statement on contractor supervision, along with procedures for selecting, inducting, and supervising contractors.

B. Assign an employee to be accountable for ensuring the policy and procedures are followed, audited regularly, and updated as necessary.

C. Post the policy and ensure the information is communicated to all employees and contractors.

2.8.4.2 Perform a detailed analysis to establish the limits of the work the contractor is expected to complete.

2.8.4.3 Ensure the contract specifies the services or work expected from the contractor as well as the codes and standards the contractor must comply with in performing the work.

2.8.4.4 Identify which equipment and what activities remain the responsibility of the facility, and how facility and contractor personnel will interact.

2.8.4.5 Review completed work and records to ensure contract requirements are met.

2.9 Contingency Planning

2.9.1 Evaluate the need for an independent backup silane supply system, including containers, gas control panel, and feed piping, to help limit potential production downtime due to contamination, mechanical damage and replacement of components, or other disruption of the primary supply.

2.9.2 Determine the need for a backup supply system based on estimated production downtime in the event of contamination of the supply.

2.9.3 Establish written procedures for responding to contamination of the bulk silane delivery system as follows:

A. Address safety and production downtime concerns.

B. Limit spread of contamination.

C. Provide periodic refresher training to appropriate personnel.

2.10 Ignition Source Control

2.10.1 Hot Work

2.10.1.1 Do not allow hot work on or around silane installations. Relocate any work to a nonhazardous location.

2.10.1.2 When relocation is not possible, use a permit system in accordance with DS 10-3, *Hot Work Management,* to strictly control all hot work operations.

2.10.1.3 Issue temporary hot work permits only after conducting a thorough review of all proposed work. Document the procedure and identify the hazards in the area, as well as all precautions needed to prevent fire or explosion. If all of the requirements cannot be met, do not issue the permit and do not allow the work to be performed.

2.10.1.4 Physically manage the authorized work in the silane area using a documented hot work permit system that specifically evaluates the fire hazards involved.

2.10.2 Hazardous Area Electrical Equipment

2.10.2.1 Design electrical installations for hazardous electrical areas in accordance with the recommendations in Data Sheet 5-1, *Electrical Equipment in Hazardous (Classified) Locations,* and applicable electrical codes.

2.10.2.2 Provide rated electrical equipment in accordance with Table 1.

Table 1. Hazardous Electrical Areas for Silane Installations

Area[1]	*Class 1 Div 1 or Zone 1*	*Class 1 Div 2 or Zone 2*
Inside gas cabinet		Entire cabinet interior
Point of connection that is regularly made and opened[2]	0-5 ft (1.5 m)	5 ft (1.5 m) - 15 ft (4.6 m)
Pressure-relief device discharge path	0-5 ft (1.5 m) (not in direct path)	5 ft (1.5 m) - 15 ft (4.6 m)
Purge vent opening	0-5 ft (1.5 m) (not in direct path)	5 ft (1.5 m) - 15 ft (4.6 m)
Cylinder storage and dispensing rooms		Entire room

[1]Table shows distance in all directions from the source of release.
[2]For example, pigtail connections to cylinders and bulk containers.

3.0 SUPPORT FOR RECOMMENDATIONS

The primary goal of the recommendations in this data sheet is to prevent accidental silane releases. However, accidents cannot be ruled out, even at locations with superior loss prevention programs. Therefore, mitigation measures such as space separation, restrictive flow orifices (RFO), emergency isolation system, damage-limiting construction (DLC), and emergency response planning are also recommended to help protect high-value property and production operations against the consequences of potential releases.

3.1 Management of Loss Prevention Programs

3.1.1 Property Conservation Policy

Loss prevention programs will only be effective if corporate and local management demonstrate strong support, beginning with a written policy that clearly sets property conservation and loss prevention as goals for employees at all levels.

3.1.2 Loss Prevention Supervision and Internal Audits

Accidental silane releases that result in fire and explosion damage to facility buildings typically can be attributed to a failure to follow procedures, or other breakdown in implementation of basic loss prevention programs. Effective loss prevention requires ongoing supervision and internal audits conducted by knowledgeable and well-trained employees.

3.2 Site Selection for Outdoor Silane Installations

Silane cylinders and bulk containers are best located outdoors to help limit potential damage due to fire and explosion in case of accidental releases. In addition, physical separation is warranted because an outdoor silane release at the storage or dispensing area might cause severe explosion and/or fire damage if located too close to critical utility equipment or a main manufacturing building (see Figure 3, A and B).

3.2.1 Explosion Exposure to Main Buildings

Prompt ignition of the released silane will result in a jet flame, while delayed ignition can lead to a silane/air explosion. The probability of prompt as opposed to delayed ignition is unpredictable for practical purposes; therefore, both jet flame and blast damage should be considered as potential consequences. In most cases, for property protection purposes, explosion separation distances will exceed thermal radiation distances. Nonetheless, flame jets from PRDs, piping leaks, and broken connections can also present a substantial hazard that warrants separation from potential targets.

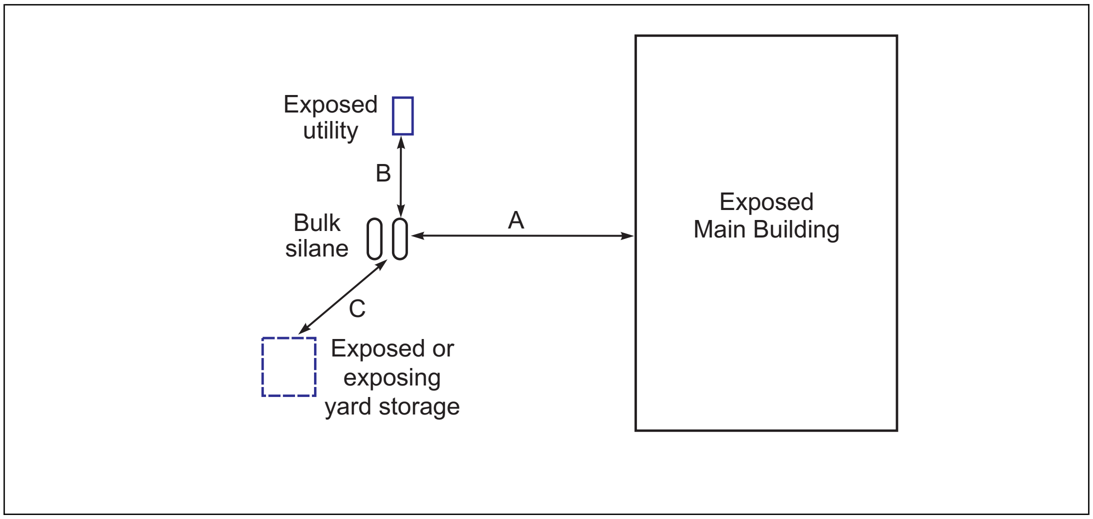

Fig. 3. Separation of exposures during site selection

The prescriptive separation distances recommended in Section 2.2 are suitable for protection against expected explosion overpressure following an unconfined outdoor release with flow rate limited by a 1/8 in. (3.2 mm) diameter RFO or equivalent. Where larger diameter release sources are present, the following methodology can help determine separation distances and evaluate alternative locations:

A. Recognize that any silane storage installation or dispensing system can experience an accidental release followed by fire and/or explosion.

B. Conduct a process hazard analysis (PHA) to identify and quantify potential credible release sources.

C. For each release source, estimate the flow rate and flammable mass in the silane gas jet or cloud.

D. Use fire and blast models to predict damage effects as a function of distance from the source.

E. Estimate the severity of consequences for each release scenario.

F. Determine tolerable levels of property damage and production outage.

G. Select an acceptable separation distance.

3.2.1.1 Release Sources

The release is typically assumed to be a silane jet flow through a full break of the largest connected pipe or pressure-relief device on the container, giving credit to an RFO if present upstream of the break point. Large releases may occur when a connection in the delivery system loosens, or a pipe is severed by impact from a heavy object, or as a result of operators not following procedures. Subsequently, the emergency isolation system on the tank or cylinder may fail to stop the flow, resulting in a sustained uncontrolled escape of silane.

3.2.1.2 Release Size and Flammable Mass

“Release size” for an explosion is primarily determined by the mass flow rate, which must be estimated using pipe flow models. The rate depends on the pressure inside the container, the size of the opening, the presence of a restrictive flow orifice, and the flow coefficients of upstream piping and valves, if any.

Where an RFO (or equivalent piping and valve flow coefficient) is provided upstream of the release source, the release size and potential consequences may be substantially reduced relative to a full flow of silane.

A worst-case scenario in terms of release size is typically the container pressure-relief device, when provided. PRD releases may result in severe blast and thermal effects, but are less likely than other sources, such as a loose connection or disconnected pigtail. For FM purposes, releases due to premature PRD activation do not need to be analyzed for determination of space separation.

“Flammable mass” is the estimated amount of silane within the flammable range in a jet or a cloud. The simplest method of determining flammable mass is based on the flow rate of an assumed quasi-steady state, free-jet release (i.e., with discharge into an unconfined and unobstructed outdoor area). If obstacles are present in the direct path of the jet, flammable mass will increase substantially compared to an unobstructed jet. A scientific basis for modeling the flammable mass of unobstructed and obstructed free-jet releases can be found in *Estimating Blast Effects from an Accidental Release of High-Pressure* Silane by J. Chao, et. al.

3.2.1.3 Explosion Damage for an Unconfined Jet Releases of Silane

Assuming a quasi-steady, free-jet release, proprietary FM software (BlastCalc©) was used to develop the following simplified formulas for use in the evaluation of separation distances for buildings exposed to outdoor silane explosions.

For unobstructed and unconfined releases, use the following formula to calculate the separation distance, *D,* at which to expect onset of minor structural damage to the exposed building.

(1) $D = Ad^n$

Where *d* is the orifice size, and *A* and *n* are coefficients specific to the building construction and release scenario. Refer to Table 2 for appropriate values of n. Tables 3 and 4 give A when d is given in mm and in., respectively.

If obstructed discharge is possible (i.e., objects are present in the path of the jet), the calculated value doubles:

(2) $D = 2Ad^n$

Provide a minimum separation of 50 ft (15 m) or *D,* whichever is greater.

Table 2. Values of n

Criterion	*Description*	*Example*	*n*
Weak building	Steel frames, siding, and roof deck	Central utility or industrial manufacturing building	1.6
Strong building	Reinforced concrete floors, roof, and walls	Semiconductor fabrication building	1.9

Table 3. Values of A (for D in Meters if d is specified in mm)

Fill Density (gram/L)	*Pressure, psi at 70°F; (bar at 21°C)*	*Weak Construction*	*Strong Construction*
193	1000 (69)	0.29	0.033
320	1500 (103)	0.46	0.057
360	1865 (129)	0.50	0.063

Table 4. Values of A (for D in Feet if d is specified in inches)

Fill Density (gram/L)	*Pressure, psi at 70°F; (bar at 21°C)*	*Weak Construction*	*Strong Construction*
193	1000 (69)	180	56
320	1500 (103)	285	92
360	1865 (129)	312	102

3.2.1.4 Partially Confined Releases

If the silane release occurs in a confined or partially confined space, such as a multisided weather enclosure, flammable mass available in the explosion may be considerably greater than the corresponding “steady state” free-jet unconfined release.

Partial confinement may cause the accumulation of substantially more flammable mass if ignition is delayed. Ignition delay is unpredictable for industrial-scale releases. Partially confined jet releases may also exhibit higher flammable mass and a more severe explosion than a partially obstructed jet release (which also assumes a quasi-steady state jet and non-accumulating flammable mass).

3.2.1.5 Example: Tube Trailer Exposure to Main Building (with RFO)

Evaluate space separation options for a proposed new silane tube trailer installation assuming the site conditions in Figure 4.

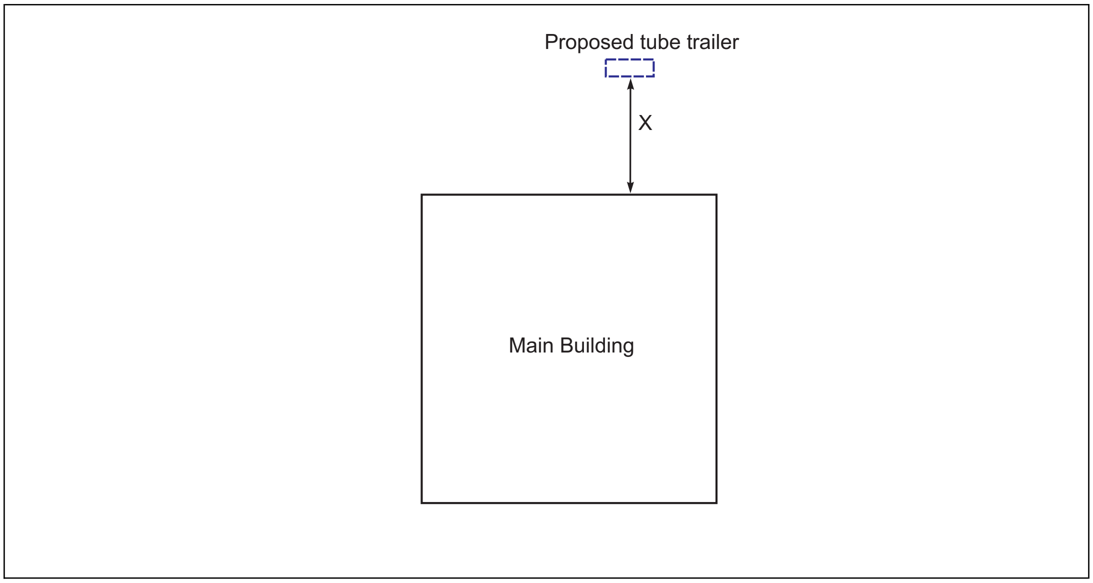

Fig. 4. Site layout for example A, proposed silane tube trailer

A. Process hazards analysis indicates the largest credible release is from a separated connection, with flow potentially obstructed and limited by a 1/8 in. diameter(3.2 mm) upstream RFO.

B. The tube trailer fill density is 320 g/L, which corresponds to a maximum pressure of 1500 psig at 70°F (103 barg at 21°C).

C. The silane tube trailer is protected by automatic water spray.

D. Main Building is of steel frame and insulated metal panel (weak) construction.

Metric Units:

Use Tables 2 and 3 to determine the coefficients for weak construction.

Because the discharge is obstructed, use formula (2):

D (in meters) = $2Ad^n = 2 \times (0.46)\ (3.2^{1.6}) = 6$ m.

Therefore, use the minimum separation distance of 15 m.

Non-Metric Units:

Use Tables 2 and 4 to determine the coefficients for weak construction.

D (in feet) = $2Ad^n = 2 \times (285)\ (0.125^{1.6}) = 20$ ft.

Therefore, use the minimum separation distance of 50 ft.

3.2.1.6 Example: Tube Trailer Exposure to Main Building (Piping Release)

Given the same hypothetical installation as in 3.2.1.5, calculate the separation distance assuming a release of 0.40 in. (10 mm) diameter is possible through a broken pipe.

Metric Units:

Use Tables 2 and 3 (for weak construction) for coefficients.

Because the discharge is obstructed, use formula (2):

D (in meters) = $2Ad^n = 2 \times (0.46)\ (10^{1.6}) = 37$ m.

Therefore, use the calculated separation distance of 37 m.

Non-Metric Units:

Use Tables 2 and 4 (for weak construction) for coefficients.

Because the discharge is obstructed, use formula (2):

D (in feet) = $2Ad^n$ = 2 x (285) ($0.4^{1.6}$) = 130 ft.

Therefore, use the calculated separation distance of 130 ft.

3.2.2 Estimating Thermal Radiation Effects

Once the flow rate and flammable mass are determined, commercially available software models can also be used to estimate damage levels versus distance from a hypothetical silane release.

3.3 Ventilation

The ventilation recommended in this data sheet performs three different functions:

A. Mechanical exhaust ventilation for gas cabinets and equipment enclosures

B. Forced ventilation over potential silane release points

C. Room exhaust ventilation

3.3.1 Exhaust Ventilation for Gas Cabinets and Equipment Enclosures

Section 2.5.9 recommends mechanical exhaust ventilation capable of limiting the average concentration of silane to 0.4% by volume. The intent is to mitigate damage following delayed ignition of released silane inside a cabinet or enclosure. Delayed ignition can occur during flow decay at the end of a release, or with the sudden shutoff of the gas flow. The maximum average concentration of 0.4% corresponds to an air flow rate equal to at least 250 times the estimated standard volume flow rate of silane.

Also note that silane concentrations at or above 4% by volume can lead to bulk autoignition of the gas and result in severe pressure development inside cabinets, enclosures, and exhaust ducts.

The basis for 0.4% concentration is testing and experiments done by FM. It was found that, even with 0.4% average silane concentration, there may still be pockets of silane that are above the LEL (1.4%) and capable of causing a partial volume deflagration (PVD) inside the cabinet or enclosure. The 0.4% limit was estimated to correspond to an overpressure that would vent the explosion by failure of the cabinet latches.

To determine the recommended ventilation rate for a cabinet or enclosure, first determine the volumetric flow rate from Figure 5a or 5b based on the size of the RFO in the discharge line and the pressure. Use the maximum pressure of the cylinder for gas cabinets, or the pressure downstream of the regulator for valve manifold boxes and other enclosures.

3.3.1.1 Ventilated Gas Enclosure Example

Consider the case of a ventilated enclosure of 25.9 ft^3 (0.73 m^3) volume, swept by a ventilation flow of 450 scfm (12,744 slpm). Silane is supplied to the enclosure by a 1/4 in. (6.3 mm) (OD) line at a regulated pressure of 50 psig (3.4 bar). This line is in turn fed from a source at 1450 psig (100 bar), through a 10 mil restricted flow orifice (RFO), located at a distance of 80 ft (24.4 m) from the ventilated enclosure. Adequacy of ventilation is determined by the ratio of the RFO-controlled silane flow relative to the ventilation in the enclosure. This ratio provides a measure of the pressure development at flow shutoff.

Determine the adequacy of the exhaust ventilation by calculating the RFO-controlled flow. From Figure 5a (5b), the flow through a 10-mil orifice from a source at 1450 psig (100 bar) is estimated to be equal to 2.4 scfm (68 L/min). Since the maximum silane flow rate that can be accepted for a ventilation of 450 scfm (12,744 L/min) is 1.8 scfm (51 L/min) (i.e., 450 x 0.004; see Recommendation 2.5.9.1), this situation is not acceptable. It would become acceptable if the ventilation flow was increased to 600 scfm (17,000 L/min) (i.e., 2.41 x 250).

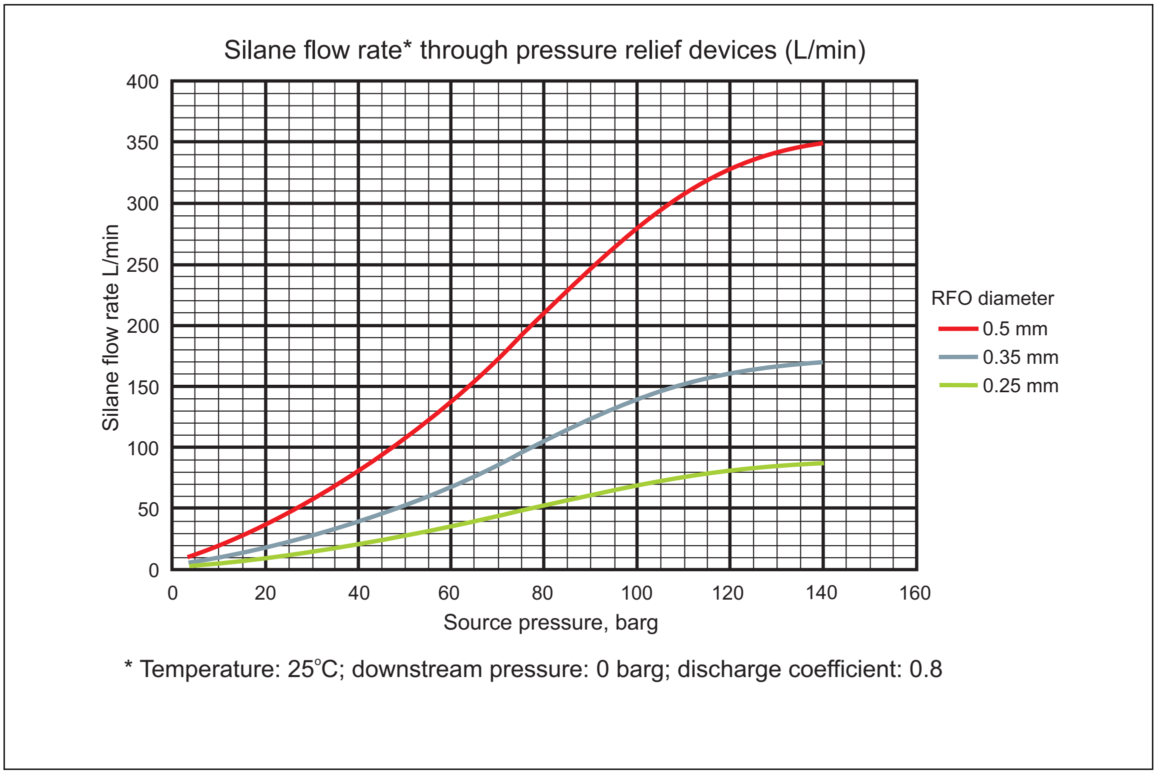

Fig. 5a. Silane flow rate through cylinder RFOs (L/min)

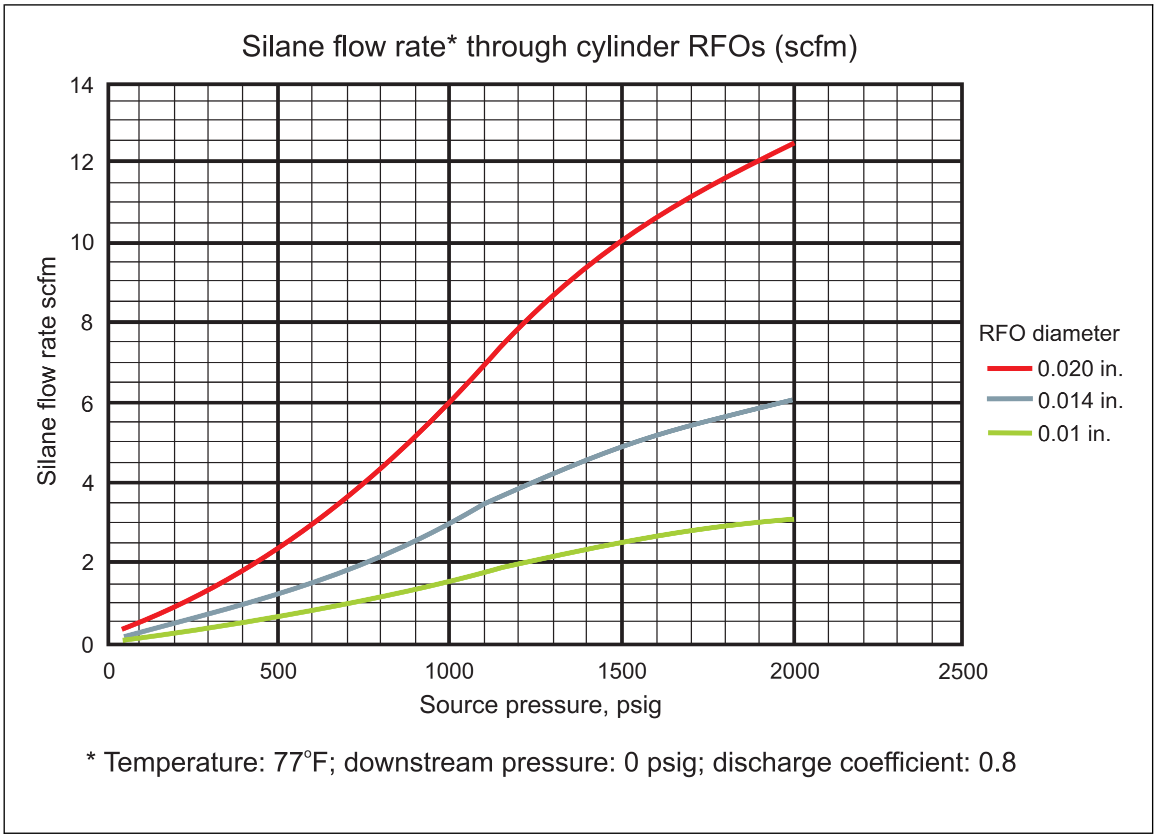

Fig. 5b. Silane flow rate through cylinder RFOs (scfm)

3.3.2 Forced Mechanical Ventilation

Forced mechanical ventilation (Section 2.3.4) is used over non-welded connections, cylinders in open racks, and pressure-reducing panels to prevent flammable silane accumulations in the event of accidental releases. The flow rate is calculated using the same methodology as that for ventilated gas cabinets (see Section 3.3.1).

3.3.3 Room Exhaust Ventilation

Provision of exhaust ventilation for silane storage and dispensing rooms is recommended (Section 2.3.3) as a means of preventing accumulation of silane as a result of small leaks. The recommended ventilation rate will not prevent the formation of a flammable silane cloud in the event of larger releases, such as from a loose connection or a severed line.

3.4 Illustrative Losses

The following are summaries of losses that have been reported in engineering journals and other reliable public sources.

3.4.1 Failure of a Silane Gas Cylinder Valve

Failure of a manual valve on a silane gas cylinder reportedly resulted in loss of containment and an explosion in the gas room at a silicon thin-film photovoltaic module fabrication plant. The explosion caused a fatality and severely damaged the gas room. Subsequently, the fire spread through polypropylene exhaust ductwork into fume exhaust scrubbers and wastewater treatment facilities, which were also severely damaged. The investigators recommended three key safeguards to prevent recurrences:

A. A gas detector arranged to alarm in the event of a small leak from the valve retainer or connection.

B. An automated cylinder valve (ACV) to help prevent operator error and lower the likelihood of an operator's exposure to a silane release.

C. Strictly enforced operating procedures that require two operators to double-check all actions.

3.4.2 Silane Explosion in Experimental Apparatus

An explosion occurred in a laboratory using a silane cylinder to supply an experimental chemical vapor deposition (CVD) system. The seal on a backflow check valve failed and allowed nitrous oxide to flow into the silane cylinder. The backflow created an unstable mixture that reacted and caused the silane container to explode, killing two students and injuring five others.

4.0 REFERENCES

4.1 FM

Data Sheet 1-2, *Earthquakes*
Data Sheet 1-11, *Fire Following Earthquake*
Data Sheet 1-40, *Flood*
Data Sheet 1-44, *Damage-Limiting Construction*
Data Sheet 2-8, *Earthquake Protection for Water-Based Fire Protection Systems*
Data Sheet 5-1, *Electrical Equipment in Hazardous Locations*
Data Sheet 5-23, *Design and Protection for Emergency and Standby Power Systems*
Data Sheet 7-7, *Semiconductor Fabrication Facilities*
Data Sheet 7-43, *Process Safety*
Data Sheet 7-45, *Instrumentation and Control in Safety Applications*
Data Sheet 7-50, *Compressed Gases in Portable Cylinders and Bulk Storage*
Data Sheet 9-7, *Property Conservation*
Data Sheet 10-1, *Pre-Incident Planning*
Data Sheet 10-3, *Hot Work Management*
Data Sheet 10-4, *Contractor Management*

Chao, J., et. al. *Estimating Blast Effects from an Accidental Release of High-Pressure Silane.* 23rd ICDERS, Irvine CA, USA. July 24-29, 2011.

4.2 Others

Asia Industrial Gases Association (AIGA). *Storage and Handling of Silane and Silane Mixtures.* AIGA 052/08.

Chang, Y. Y., et. al. "Revisiting a Silane Explosion in a Photovoltaic Fabrication Plant." *Process Safety Progress* (2007): 155-158.

Chen, J. R., et. al. "Analysis of a Silane Explosion in a Photovoltaic Fabrication Plant." *Process Safety Progress* (September 2006): 237-244.

Compressed Gas Association (CGA). *Silane.* G132006.

European Industrial gases Association (EIGA). Code of Practice: *Silane.* IGC Doc 160/10/E.

Nakao, Masayuki. "Silane Gas Explosion at Osaka University." Failure Knowledge Database. Hatamura Institute for the Advancement of Technology. http://www.sozogaku.com/fkd/en/cfen/CA1000614.html (accessed December 5, 2013).

Peng, D. J., et. al., "Failure analysis of a silane gas cylinder valve: A case study", Engineering Failure Analysis, 15 (2008) 275-280.

APPENDIX A GLOSSARY OF TERMS

Approval Guide: An online resource of FM Approvals that lists FM Approved products and services.

Automatic cylinder valve (ACV): A pneumatic, normally closed valve that is mounted by the silane supplier directly onto a cylinder or larger container. Also called an "automated" cylinder valve.

Bulk container: Individual or manifolded containers with greater than 13 gal (50 L) water capacity.

Contractor: Outside firms and their employees who deliver silane to the site and/or install, maintain, inspect, and test silane storage and equipment.

Cylinder: A pressure vessel with a water capacity of 13 gal (50 L) or less.

Cylinder bundle (or cylinder pack): Several cylinders manifolded together and moved about as a single unit.

Distributed control system (DCS): A network of programmable electronic systems performing monitoring, controlling, safeguarding, and archival (database) functions via common communication links for one or more processes that are being managed. The DCS does not require the redundancy and reliability of a safety system. When safety functions are controlled by a DCS, additional reliability is needed (see DS 7-43).

FM Approved: The term "FM Approved" is used to describe a product or service that has satisfied the criteria for Approval by FM Approvals. Refer to the *Approval Guide* for a complete list of products and services that are FM Approved.

Pigtail: Flexible piping used to connect a gas cylinder to piping and other components that are rigidly attached to a building or wall structure. A pigtail normally provides sufficient flexibility to accommodate a slight variation in the location of the cylinder valve. The end of the pigtail that connects to the cylinder terminates in a Compressed Gas Association (CGA) connector.

Silane dispensing system: The piping and components used to transfer silane from a supply source to piping supplying the end-user equipment. The dispensing system begins at the connection to the container shutoff valve and ends at the inlet isolation valve for the end-use equipment.

Storage: Silane in containers not connected to a delivery system.

Weather enclosure: A covered outdoor pad with less than 25% of the perimeter enclosed by a wall extending from the pad to the roof. The walls can be on more than one side of the pad, as long as the 25% area limit is not exceeded. If the wall area exceeds 25% of the perimeter, the term "multisided weather enclosure" is used.

APPENDIX B DOCUMENT REVISION HISTORY

April 2014. Silane hazards and safeguards were previously addressed in DS 7-7, *Semiconductor Fabrication Facilities.* Data Sheet 7-108 has been created because silane usage has expanded in recent years to industries beyond semiconductor manufacturing. Many recommendations pertaining to silane have been transferred from DS 7-7 to this data sheet. Key changes to the recommendations previously published in DS 7-7 include the following:

1.1.1 Added new recommendations for a more comprehensive approach to the prevention of accidental silane releases.

1.1.2 Revised separation distances between outdoor silane containers and main buildings based on studies and silane explosion modeling performed by FM Global.