STORAGE AND HANDLING OF SILANE AND SILANE MIXTURES

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NOTE—Appendices A and B (Informative) are for information only.

NOTE—Appendices C and D (Normative) are requirements.

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1 Introduction

The use of the pyrophoric gas silane as a source of silicon has grown with its consumption by semiconductor manufacturers, producers of solar cells, and allied technologies. Systems once imagined to be rare are now commonplace and are in use worldwide. The hazards of this material are noteworthy due to the ability of the material to self-ignite with visible flame upon release, or in other cases to be released with either no ignition or delayed ignition. The material has been the subject of technical study by users and suppliers [1].[1] Studies conducted by the Compressed Gas Association (CGA) of the release of both large and small-scale quantities of silane have produced new technical data [2]. The data have been used to establish minimum separation distances for delivery system installations as well as for the storage of this material. Distance limitations are used to minimize risk to property and personnel in the event of an inadvertent release. The distances determined recognize the probability for immediate ignition as well as the probability of latent ignition with its potential explosive effects. Although the uncontrolled release of compressed gas is a cause for concern, it is the application of engineering and administrative controls to prevent the release of material that allows the users to handle this material at a reduced level of risk. Suppliers and users have contributed to the development of the controls presented in this standard as a means to provide reasonable safeguards for handling this unique material that is characterized by its chemical and physical nature.

CGA G-13 supersedes and replaces CGA P-32. The revision has taken into account the comments received from the American National Standards Institute (ANSI) canvass of CGA P-32. Comments received from users, producers, and regulatory officials were evaluated by CGA's technical committee and modifications were made to address technical issues and concerns raised in the evaluation process. There were a number of changes made to this edition to eliminate permissive language so the document can be used as a regulatory tool. Provisions that were in need of clarification have been edited to clarify the intent of the technical committee. There were several questions common to a number of those that reviewed the first edition during the ANSI review phase. A question was raised as to whether or not the standard applied to manufacturers as well as users. The scope section has been clarified to show that the standard applies universally to silane and silane systems regardless of the location in which they are found. A second concern was whether the standard applies to cylinder systems in lieu of "large scale" uses. It is intended that the standard applies to silane storage and use regardless of the size of the container with the exception of small containers of 0.5 standard cubic feet (scf) or less that are commonly found in laboratory operations.

2 Scope and purpose

2.1 Scope

This standard governs the installation of systems and sources that are used to store, transfer, or contain silane or silane mixtures. The scope of this standard includes guidance for siting, design of equipment, piping and controls, and the fabrication and installation of silane gas storage and closed-use systems. Additional guidance on operational steps associated with the use of silane and silane mixtures as well as fire protection, gas monitoring, ventilation, and related safeguards are provided.

2.1.1 Application

The requirements of the standard apply to pure silane and silane mixtures with a silane content greater than 1.37% [3]. A concentration of 1.37% has been chosen as it represents the lower flammable limit (LFL) for the material in air under conditions of normal temperature and pressure. Silane containers include tube trailers, ISO modules, cylinder packs with manifolded cylinders, and individual cylinders.

2.1.2 Limitations

This standard is not intended to provide requirements beyond the first point of control within a user's facility where connections are made to piping systems associated with internal transmission and/or use of this material.

[1] References are shown by bracketed numbers and are listed in order of appearance in the reference section.

The following subjects are outside the scope of the standard:

- Equipment downstream of a gas cabinet with the exception of valve manifold boxes (VMBs) when VMBs are used;
- Off-site transportation of compressed gases regulated by the national government; and
- Requirements within the jurisdiction of national regulatory authorities with laws or regulations that preempt the provisions of this standard. When such is the case, it is recommended that the authority having jurisdiction be guided by this standard in determining requirements.

A full risk management program is comprised of a hazard assessment, a management system, a prevention program, and an emergency response program. Such programs and assessments must be developed on a case-by-case basis in response to the requirements of the relevant risk management programme at the respective country and the circumstances found at each individual company where silane is stored or used.

2.2 Purpose

The purpose of this standard is to prescribe the controls for the installation of silane systems and the recommended methods for storage or transfer of silane or its mixtures from a source of supply to a point of use to provide protection against injury, loss of life, and property damage.

2.3 Equivalency

Nothing in this standard is intended to prevent the use of systems, methods, or devices of equivalent or superior quality, strength, fire resistance, effectiveness, durability, and safety over those prescribed by this standard. Systems, methods, or devices to be used as equivalents shall be supported by technical documentation that demonstrates equivalency. The use of equivalencies shall be subject to approval by the authority having jurisdiction.

3 Definitions

For the purpose of this standard, the following definitions apply.

3.1 Barricade construction

Room, building, or enclosed structure of such type, size, and construction as to limit in a prescribed manner the effect of an explosion on nearby buildings or within the building in which an explosion occurs.

3.2 Barrier, shield

Partition constructed of materials in such a manner so as to isolate the hazard from contact with personnel (see Appendix A for information on personnel protection).

NOTE—Barriers are designed with structural strength and arranged in such a way to resist physical forces.

3.3 Burning velocity

Intrinsic property of burning gases or vapors expressed as the motion of the flame relative to the motion of the unburned gas.

3.4 Container

3.4.1 Cylinder

Pressure vessel designed for pressures higher than 40 psia (276 kPa) and having a circular cross section with an internal water volume not exceeding 16 ft^3 (450 L) or a water capacity of 1000 lb (454 kg).[2] It does not include a portable tank, multiunit tank car tank, cargo tank, highway tank, or tank car.

[2] kPa shall indicate gauge pressure unless otherwise noted as (kPa, abs) for absolute pressure or (kPa, differential) for differential pressure. All kPa values are rounded off per CGA P-11, *Metric Practice Guide for the Compressed Gas Industry* [4].

3.4.2 Cylinder pack

Arrangement of cylinders into a cluster where the cylinders are confined into a grouping or arrangement with a strapping or frame system and connections are made to a common manifold. The frame system is allowed to be on skids or wheels to permit movement.

NOTE—Six-packs and twelve-packs are terms used to further define cylinder packs with a specific number of cylinders involved. The characteristic internal water volume of individual cylinders in a cylinder pack ranges from 1.52 ft^3 to 1.76 ft^3 (43 L to 50 L) or a water capacity of 95 lb to 110 lb (43 kg to 50 kg).

3.4.3 ISO module

Assembly of tubular cylinders permanently mounted in a frame conforming to International Organization for Standardization (ISO) requirements. The characteristic internal water volume of individual tubular cylinders is 43 ft^3 (1218 L) or a water capacity of 2686 lb (1218 kg). The frame of an ISO module and its corner castings are specially designed and dimensioned for use in multimodal transportation service on container ships, special highway chassis, and container-on-flatcar railroad equipment.

3.4.4 Mobile supply unit

Any silane supply source equipped with wheels so it is able to be moved. Examples include ISO modules, tube trailers, and cylinder packs.

3.4.5 Tube trailer

Truck or semi trailer on which a number of tubular cylinders have been mounted and manifolded into a common piping system. The characteristic internal water volume of individual tubular cylinders ranges from 43 ft^3 to 93 ft^3 (1218 L to 2633 L) or a water capacity of 2686 lb to 5803 lb (1218 kg to 2632 kg).

3.5 Deflagration

Exothermic reaction, such as extremely rapid oxidation of a flammable dust or vapor in air, in which the reaction progresses through the unburned material at a rate less than the velocity of sound. A deflagration will have an explosive effect.

3.6 Detonation

Exothermic reaction characterized by the pressure of a shock wave in material that establishes and maintains the reaction. The reaction zone progresses through the material at a rate greater than the velocity of sound. The principal heating mechanism is one of shock compression. A detonation will have an explosive effect.

3.7 Exhausted enclosure

Appliance or piece of equipment that consists of a top, a back, and not more than two sides providing a means of local exhaust for capturing gases and vapors.

3.8 Explosion control

Means to either prevent or mitigate the effects of an explosion. Deflagration venting, containment barricades, analogous construction, or other means including fuel reduction and oxidant reduction are used to protect buildings against the effects of an explosion.

3.9 Face seal fitting

Threaded joints in which the tightness of the joint is provided by a sealing surface other than the threads such as a union comprised of male and female ends joined with a threaded union nut or other construction.

NOTE—The sealing surface is typically a metal gasket when used in high purity applications.

3.10 Fire barrier

Fire-resistance rated vertical or horizontal assembly of materials designed to restrict the spread of fire in which openings are protected.

3.11 Fire partition

Vertical assembly of materials designed to restrict the spread of fire in which openings are protected.

3.12 Flame speed

Extrinsic property of burning gases or vapors that describes the motion of the flame relative to a stationary reference.

3.13 Flammable limits

Minimum and maximum concentrations of flammable gas in a homogeneous mixture with air (or other oxidizing gas or gas mixture) that will propagate a flame when ignited.

3.14 Gas cabinet

Fully enclosed, noncombustible enclosure used to provide an isolated environment for compressed gas cylinders in storage or use. Doors and access ports for exchanging cylinders and accessing pressure-regulating controls are allowed to be included.

3.15 Gas filling room

Separately ventilated, fully enclosed room used for cylinder filling operations in which only compressed gases and associated equipment and supplies are stored or used.

3.16 House gas

Source of gas either originating at a bulk source or generated on site where the gas is used to supply multiple systems for uses across the site.

3.17 Incompatible materials

Materials that when mixed have the potential to react in a manner that generates heat, fumes, gases, or byproducts that are hazardous to life or property.

3.18 Instrument nomenclature

See Figure 1.

3.19 Laminar burning velocity

Velocity at which a flame reaction front moves into the unburned medium as it chemically reacts to transform a fuel and oxidant mixture into combustion products. Burning velocity is only a fraction of the flame speed. The fundamental burning velocity is the burning velocity for laminar flame under stated conditions of composition, temperature, and pressure of the unburned gas. The combustion wave in a laminar stream of uniform velocity is said to occur under laminar conditions when every portion of the wave in the plane of combustion remains uniform.

3.20 Location

3.20.1 Outdoor

Location that is either:

- outside the confines of a building; or
- one that is sheltered from the elements by overhead cover and is protected from weather exposure by not more than one exterior wall that obstructs not more than one side with the other sides unobstructed and open to the atmosphere.

3.20.2 Indoor

Locations that do not meet the definition of outdoor shall be defined as being indoor locations.

3.21 Nitrogen, facility or house

Supply of nitrogen that is used for utilities and general purposes. It is usually industrial grade (99.998% pure) and supplied from an on-site air separation plant, liquid nitrogen tank, or other sources. It is piped to use points throughout the facility.

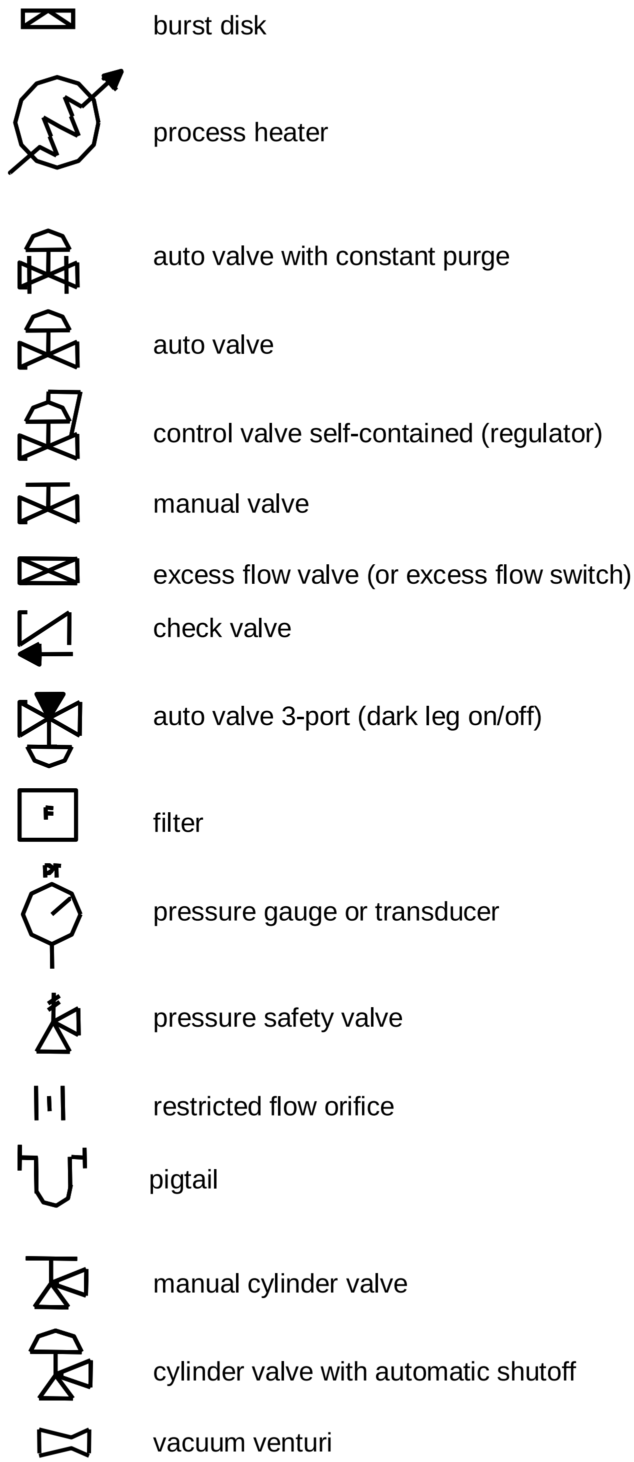


Figure 1—Instrument nomenclature

3.22 Operations

3.22.1 Operations, attended
Operations where an operator is physically present and responsible for the control of the operation or transfer process throughout the period of time where the operation occurs.

3.22.2 Operations, transfer
Operations where silane is transferred from one container to another for the purpose of filling, processing, evacuating, or otherwise preparing containers that are used to contain silane that will be delivered to an end user.

3.22.3 Operations, unattended
Operations where silane is connected for use, other than those conducted by the silane supplier or manufacturer, where the use is not constantly attended by operators involved in the process of transfer or use.

3.23 Panel

3.23.1 Panel, control
A panel-mounted arrangement of electrical components including power supplies, programmable logic controllers, and other instrumentation necessary to determine process parameters associated with the delivery of silane to the piping system.

3.23.2 Panel, process
A panel-mounted arrangement of manually or automatically operated pressure-regulating or control equipment, control valves, check valves, pneumatic controls, and interconnecting piping that is used to control the delivery of silane gas.

3.23.3 Panel, purge
A panel-mounted arrangement of manually or automatically operated pressure-regulating or control equipment and interconnecting piping designed to deliver a purge gas to the process gas panel for purging atmospheric gases and/or silane from the process gas panel.

3.24 Part per million (ppm)
A term used to express the concentration of a gas in parts per million as opposed to expressing the concentration in terms of volume or mol percent. One molar ppm or one ppm by volume is equal to 0.0001%.

3.25 Physical hazard
A chemical for which there is evidence that it is a combustible liquid, compressed gas, flammable or oxidizing cryogenic fluid, explosive, flammable gas, flammable liquid, flammable solid, organic peroxide, oxidizer, pyrophoric, unstable-reactive, or water-reactive material.

3.26 Pigtail
A relatively short and semi flexible section of connecting piping or tubing that is used to connect a compressed gas source to the control system. A pigtail contains a fitting to mate with the outlet of the control valve at the source at one end with the opposite end being connected into a manifold or control panel. The purpose of the pigtail is to accommodate slight variations in height or position presented by the use of moveable containers.

3.27 Piloted ignition
The ignition by application of a pilot flame. By comparison, ignition without a pilot energy source is referred to as autoignition, self-ignition, or spontaneous ignition.

3.28 Pressure relief device
A pressure- and/or temperature-activated device used to prevent the pressure from rising above a predetermined maximum, and thereby preventing rupture of a normally charged cylinder when subjected to a standard fire test as required by 49 CFR 173.301(f). The term “pressure relief device” is synonymous with “safety relief device”.

3.29 Purging
The replacement of the atmosphere in a piping system or enclosure used to house mechanical or electrical connections by the introduction of a controlled atmosphere consisting of an unreactive gas or fresh air.

3.30 Rack system
An unenclosed silane process gas panel and purge gas panel mounted to a support structure used with silane cylinders. It is designed for unconfined open ventilation, as opposed to the confinement provided in ventilated gas cabinets.

3.31 Remotely located, manually activated shutdown control
A control system that is designed to initiate shutdown of the flow of gas and is activated from a point located some distance from the delivery system.

3.32 Shall
Indicates a mandatory requirement.

3.33 Silane systems and sources

3.33.1 Silane
Silane and silane in combination or mixed with other gases where the concentration of silane exceeds 1.37% by volume.

3.33.2 Silane delivery system
A system used to transfer silane from a source of supply to a point where connections are made to piping systems associated with internal transmission and/or use of this material. The piping and components that make up the silane gas delivery system include:

– container connections;

– process control panel and integral components;

– purge gas panel and integral components;

– piping between the process gas panel and the purge gas panel; and

– output piping from the process control panel terminating at the point where the gas either enters the building piping system or the outlet from a valve manifold box (VMB) when VMBs are used as a means to supply individual points of use.

The delivery system does not include:

– silane containers (cylinders, tubes, etc.);

– gas cabinets;

– gas disposal equipment; or

– auxiliary equipment related to a silane installation.

3.33.3 Silane, bulk source
A container or interconnected group of containers with a water volume exceeding 8.8 ft^3 (250 L).

3.33.4 Silane, nonbulk source
A container or interconnected group of containers with a water volume not exceeding 8.8 ft^3 (250 L).

3.34 Site
A location on a premise from which distances to exposures are measured.

3.35 Storage
The keeping or retention of material in bulk sources connected to a piping system or in nonbulk source systems or bulk sources that are not connected to a piping system other than piping systems integral to the source.

3.36 Ultra high integrity service (UHIS)
An acronym used for outlet connections designed for ultra high integrity service.

NOTE—In 1989, CGA approved a new group of cylinder valve outlet connections commonly referred to as the CGA 630/710 series. This series was conceived to provide "higher purity and leak integrity" than previous connections. The connection is distinctive in appearance and uses a sealing mechanism that is common to high purity applications. See CGA V-1, *Standard for Compressed Gas Cylinder Valve Outlet and Inlet Connections* [6].

3.37 Use
The placement of material into service by connecting to a piping or pressure control system or by using the product in process operations.

3.38 Valve

3.38.1 Valve, automatic
A valve designed to be operated by pneumatic pressure or other power source other than manual means.

3.38.2 Valve, check
A valve designed to provide for flow in one direction. The internal components of the valve are designed to prevent flow in the reverse direction. Check valves are not viewed as safety devices.

3.38.3 Valve, pressure relief
A valve designed to open if a predetermined pressure is exceeded. Pressure relief valves are commonly referred to as pressure safety valves with the recognition that relief is provided to prevent a dangerous condition due to overpressurizing a system or container.

3.38.4 Valve manifold box (VMB)
A fully enclosed, ventilated enclosure of limited size used to house valves, fittings, pressure regulating, monitoring, and flow control systems suitable for the distribution of gases in closed piping systems to one or more tools or workstations.

3.39 Vapor cloud explosion
An explosion occurring outdoors that results in damaging overpressure . It is initiated by the unplanned release of a large quantity of flammable vaporizing liquid or high pressure gas from containers including but not limited to a storage container, delivery system, process vessel, or piping system.

4 Physical and chemical properties

4.1 Description

Silane is a colorless, pyrophoric gas that is able to burn at concentrations from 1.37% to 96% volume in air [3]. At concentrations between 1.37% and about 4.5%, mixtures can react if an ignition source is provided. When the silane concentration in air is greater than about 4.5%, the mixture is metastable and will undergo bulk autoignition after a certain delay with shorter ignition delays at higher concentrations [1]. Due to the nature of the reaction, it does not always ignite when vented to the atmosphere. It has been reported to have a repulsive odor that is able to be physiologically detected well below the Threshold Limit Value–Time-Weighted Average (TLV®–TWA) concentration of 5 parts per million by volume (ppmv); however, odor is not to be relied upon as a means to indicate the absence of a hazardous material [7]. Notwithstanding reports regarding odor, the reported odor for silane is believed to be a characteristic of burning silane rather than of the material itself.

4.2 Properties

Fundamental physical and chemical properties of silane are noted in Table 1.

4.3 Pyrophoric nature of silane

Silane is pyrophoric; however, it does not always ignite when vented to the atmosphere. Lack of instantaneous ignition can lead to delayed ignition resulting in fireballs or vapor cloud explosions, which can range in character from deflagration to detonation. It is important to understand the pyrophoric nature of silane and conditions surrounding ignition.

Table 1—Physical and chemical properties of silane

Parameter	Value
Chemical name	Silane
Synonyms	Silicon tetrahydride, silicane, monosilane, silicon hydride
Chemical formula	SiH_4
Chemical Abstracts Service (CAS) registration number	7803-62-5
Appearance	Colorless gas
Boiling point	–169 °F (–112 °C)
Melting point	–300.5 °F (–184.7 °C)
Gas density at 1 atm and 68 °F (20 °C)	0.084 lb/ft^3 (1.35 kg/m^3)
Specific gravity (liquid) at 301 °F (–185 °C)	0.711
Specific gravity (gas) at 1 atm and 70 °F (21.1 °C)	1.12 (Air = 1)
Specific volume at 1 atm and 70 °F (21.1 °C)	12.0 ft^3/lb (0.75 m^3/kg)
Vapor pressure at 68 °F (20 °C)	Gas
Molecular weight	32.12
Solubility in water	Negligible. Slowly decomposes
Critical temperature	25.8 °F (–3.4 °C)
Critical pressure	702.5 psia (4 844 kPa, abs)
Critical density	15.4 lb/ft^3 (0.247 g/cm^3)
Compressibility	See Appendix B
Heat of combustion	19 076 Btu/lb (44 370 kJ/kg)
Flammable limits in air	1.37% to 96%
Autoignition temperature	–58 °F (–50 °C)
ACGIH TLV–TWA	5 ppm
Acute toxicity	Inhalation rat LC_{50} – 9600 ppm/4 hr [8]

4.3.1 Ignition and combustion

The ignition and combustion characteristics of 100% silane release have been the subject of major studies [1, 2, 3]. Based on these studies, the LFL of silane in air has been established as 1.37%. Concentrations from 1.37% to 4.5% in air are able to be ignited by an external source (piloted ignition) resulting in deflagration with laminar burning velocity reaching 5 m/sec (985 linear ft/min). When the silane concentration is greater than 4.5% in air, the mixture is metastable and is capable of autoignition after a certain delay, with shorter ignition delays at higher concentrations. Test results also have shown that silane air mixtures do not always autoignite, even at higher concentrations. A delayed ignition is capable of resulting in a deflagration or a detonation [1].

4.3.2 Combustion reaction

The stoichiometric combustion reaction of silane in air is expressed as follows:

$$SiH_4 + 2\ O_2 + 7.52\ N_2 \rightarrow SiO_2\ (s) + 2\ H_2O + 7.52\ N_2$$

The stoichiometric mixture contains 9.51 volume percent silane [3]. Large quantities of amorphous silica are formed during the combustion of silane. For each 1.0 lb (0.45 kg) of silane completely burned, approximately 1.87 lb (0.85 kg) of amorphous silica is formed.

4.4 Health hazards

The primary health hazards associated with silane are burns due to silane flame exposure or thermal radiation. The LC_{50} (inhalation-rat) for silane is 9600 ppm at 4 hour of exposure [8]. Little information exists on the toxicity of silane because of its pyrophoric nature; however, the American Conference of Governmental Industrial Hygienists (ACGIH) has established a TLV-TWA concentration of 5 ppm to protect workers from the risk of eye, skin, and upper respiratory tract irritation with exposure to this substance [9]. In addition, the inhalation of oxidized silane presents a potential health hazard. The combustion of silane forms oxides of silicon that is able to cause irritation to the respiratory tract.

4.5 Gaseous/liquid phase of silane

The critical temperature of silane is 25.8 °F (–3.4 °C) and the critical pressure is 702.5 psia (4840 kPa, abs). Silane is able to exist in liquid form depending upon temperature and pressure conditions. Engineering analysis and controls are required in systems where liquefaction is to be avoided, for example, equipment operability under liquid fill conditions.

5 Packaging information

5.1 General

Containers used to contain silane offered for transportation shall the relevant governing regulations. As an example, in the US, transport regulations for silane are governed by the US DOT Information from the US DOT is shown in the following Table 2.

Table 2—DOT packaging information

DOT hazard class	2.1
DOT label	Flammable gas
DOT/United Nations (UN) number	UN 2203
Valve outlet connection	CGA 350 or CGA 632 (UHIS)
Packaging	49 CFR Parts 100-180 [5]
CGA publications	V-1, *Standard for Compressed Gas Cylinder Valve Outlet and Inlet Connections* [6] V-7, *Standard Method of Determining Cylinder Valve Outlet Connections for Industrial Gas Mixtures* [10] S-1.1, *Pressure Relief Device Standards–Part 1–Cylinders for Compressed Gases* [11] S-1.2, *Pressure Relief Device Standards–Part 2–Cargo and Portable Tanks for Compressed Gases* [12] S-7, *Method for Selecting Pressure Relief Devices for Compressed Gas Mixtures in Cylinders* [13]

6 Outdoor storage and use

6.1 Applicability

In addition to the requirements of Section 6, outdoor storage and use of silane shall be in accordance with the requirements of Sections 8 through 17 as applicable.

6.2 General

The release of silane represents a hazard due to the potential for fire or explosion. If released into a confined space, the effects of either immediate or latent ignition or autoignition of silane have the potential to be severe as the atmosphere immediately surrounding the burning material is heated and expands. The expansion of the atmosphere and the potential shock wave propagating through the ignited material can cause injuries to personnel and damage buildings and equipment in proximity to the source. Outdoor areas are used as a means to minimize or eliminate these effects.

6.2.1 Location

Silane sources and systems shall be located outdoors. An exception to this is nonbulk systems installed in accordance with the requirements of Section 7. Although indoor locations are allowed, it is preferred that areas for the storage and use of silane be located outdoors to minimize risk to users and facilities in the event of a fire or explosion. By locating silane installations in an unconfined space, the surrounding environment is able to absorb unlimited amounts of heat, and the surrounding environment is free to infinitely expand allowing overpressures to quickly attenuate.

6.2.1.1 Openness

A system shall be sited so it is open to the surrounding environment (see the definition of outdoor in 3.20.1). A system is open to the environment when objects that encroach on the silane sources are located at a distance from the source not less than twice the height of the encroaching object).

6.2.1.1.1 Mitigation

Silane sources and systems that are not in conformance with the requirements of 6.2.1.1 shall be provided with mitigation measures to address encroachment. When mitigation measures are applied, the maximum encroachment is allowed to be reduced to a distance not less than the height of the encroaching object. This limitation results in the angle between the height of the encroaching object and the base of the silane containers being not greater than 45 degrees. Overpressures and thermal effects shall also be included when locations are specified. See Appendices C and D.

For example, assume that an equipment item 10 ft (3.0 m) high is located off to one side of silane cylinders that are located under a roofed structure. Applying the rule, the equipment shall be located at a distance not less than 20 ft (6.1 m) from the roofed structure. If a distance of 20 ft (6.1 m) is not able to be achieved, mitigation shall be applied before further encroachment is allowed. Forced air circulation is allowed to be used as a means of mitigation. Mitigation is accomplished by moving air over cylinder valves and valve connections at a rate not less than 150 ft/min (0.8 m/s). See 13.1.1.

6.2.1.1.2 Weather protection

Where controls or unconnected cylinders in storage require protection against the elements, an overhead roof or canopy shall be provided. An exception to this is that roofs shall not be provided to shelter silane bulk sources.

6.2.1.2 Height of overhead construction

When a roof is provided, the lowest point of the roof shall be not less than 12 ft (3.7 m) high as measured from the surrounding floor. For lighter than air gas mixtures, a slanted roof with a vent at the apex is allowed to be used for venting of fugitive gases.

6.2.2 Egress

Outdoor storage and use areas shall have no less than two exits. An exception to this is that one exit is allowed for outdoor storage and use areas less than 200 ft^2 (19 m^2) when a dedicated means of egress between cylinders or silane equipment is maintained. The maximum distance to an exit shall not be greater than 75 ft (23 m).

6.2.2.1 Hardware

Means of egress gates or doors in fenced areas shall not be provided with a latch or lock unless it is panic hardware.

6.2.3 Security

Storage or use areas shall be secured against unauthorized entry. Barriers against entry shall allow for the free circulation of air throughout the area of storage or use.

6.2.4 Vehicular traffic

Storage or use systems shall be located so there is access to transport vehicles to allow for loading and exchange operations to be conducted. Storage and use areas shall be protected from damage by vehicular traffic.

6.2.5 Fire apparatus access roads

Fire apparatus access roads shall be provided in accordance with local regulations.

6.2.6 Separation from incompatible materials

Silane in storage or use shall be separated from incompatible materials by the use of distance or fire-resistive partitions.

6.2.6.1 Separation by distance or barrier protection

Silane storage or use shall be separated from incompatible materials by a minimum separation distance of 20 ft (6.1 m) or by a 2 hour fire barrier wall extending 18 in (46 cm) above and beyond the footprint of the containers.

6.2.6.2 Arrangement of fire barrier walls

When used to separate incompatible materials, fire barrier walls shall be arranged so as not to preclude the flow of air through areas where silane sources are in use.

Walls used to separate unconnected containers in storage shall not be considered encroachment as described in 6.2.1.1.

6.2.6.3 Proximity to physical hazard fluids

Silane storage and use areas shall be located so spills or leaks from outdoor, aboveground fluid storage vessels or systems used to contain fluids with physical hazards will not present an exposure hazard to the storage or use area. Dikes, diversion curbs, grading, or alternate means may be used to divert liquids and runoff away from the silane area of storage or use.

6.2.7 Securing of containers

Cylinders and mobile supply units shall be secured to resist movement.

6.2.8 Other requirements

In addition to the previously stated provisions, outdoor delivery systems shall be in accordance with the following. Refer to the applicable section for details:

- system configuration (cylinder sources) See Section 8
- system configuration (bulk sources) See Section 9
- piping and components See Section 10
- gas monitoring See Section 11.1

– flame or heat detection — See Section 11.2
– fire protection — See Section 12
– ventilation — See Section 13
– venting and treatment — See Section 14
– purge gas systems — See Section 15
– electrical — See Section 16
– supervisory control systems — See Section 17

6.3 Distances to exposures

6.3.1 Distances between cylinder sources and exposures

Silane source cylinders in storage or use shall be separated from exposure hazards by distances not less than those indicated in Table 3. Separation distances are variable since distances providing protection from radiant heat are dependent upon storage volume. The distances are based on permissible exposure to thermal radiation. Fire, not explosion, is the plausible event for cylinders in storage. See Appendix C for guidelines to other exposures with silane cylinders in storage. An exception to this is individual containers with a silane content not to exceed 0.50 ft^3 (14 L).

6.3.2 Protective walls

6.3.2.1 Encroachment

The distances in Table 3 are allowed to be reduced to 5 ft (1.5 m) when fire-resistive partitions or fire barrier walls having a minimum fire resistance rating of 2 hour as defined by national or regional building and/or fire codes interrupt the line-of-sight between the container and the exposure. When provided, the partitions or walls shall be at least 5 ft (1.5 m) from the exposure.

6.3.2.2 Penetrations and openings

Penetrations and openings in fire-resistive partitions or walls shall be protected in accordance with the requirements of national or regional building and/or fire codes. The fire-resistive rating of opening protectives provided shall be not less than the required fire-resistance rating of the fire-resistive partition or wall being penetrated.

6.3.2.3 Obstructions

The configuration of the fire partitions or barrier walls shall allow natural ventilation to prevent the accumulation of vapors. An exception to this is outdoor storage consisting of unconnected cylinders with closed valves.

6.3.3 Distances between ISO modules or trailers and exposures

The minimum distances from exposures for ISO modules or trailers containing silane in storage or use shall be not less than those listed in Table 4. Table 4 shall not apply to piping systems downstream of the restrictive flow orifice (RFO).

Additional exposures are as follows:

– In installations where electrical power lines are present or in areas where exposure to electricity is conceivable, silane delivery vehicles used for loading and unloading shall be at least 25 ft (8 m) horizontal distance from overhead electrical wires; and

– The area above silane bulk sources shall be unobstructed.

The distances are based on the potential for overpressure due to latent ignition of released silane from individual containers of the size noted. Overpressures are determined in part by potential release from the pressure relief device used for containers of the size noted. The container volumes shown are based on the maximum water content of individual containers whether manifolded or not.

Table 3—Minimum distance from cylinder sources in storage or use to outdoor exposures

Type of exposure	Minimum distance to exposures for different storage volumes or nests 1) 2) 3)							
	Cylinders 4) ≤ 600 ft³ (17 m³)		Cylinders 5) 601 ft³ to 2500 ft³ (71 m³)		Cylinders 5) 2501 ft³ to 10 000 ft³ (283 m³)		450 L cylinders 6) ≤ 10 000 ft³ (283 m³)	
	ft	(m)	ft	(m)	ft	(m)	ft	(m)
Places of public assembly, property line that is able to be built upon.	20	(6)	30	(9)	50	(15)	60	(18)
Public street and sidewalk	20	(6)	30	(9)	50	(15)	60	(18)
Buildings of nonrated construction 7)	15	(5)	25	(8)	25	(8)	40	(12)
Buildings of nonrated construction 8)	20	(6)	25	(8)	25	(8)	40	(12)
Buildings with 2 hr fire rating and no openings within 25 ft (8 m)	5	(1.5)	5	(1.5)	5	(1.5)	5	(1.5)
Buildings with 4 hr fire rating and no openings within 25 ft (8 m)	0	(0)	0	(0)	0	(0)	0	(0)
Compatible compressed gas cylinder storage or other silane nests 7)	9	(3)	9	(3)	12	(4)	30	(9)
Compatible compressed gas cylinder storage or other silane nests 8)	20	(6)	20	(6)	20	(6)	40	(12)
Incompatible compressed gas cylinders and materials	20	(6)	20	(6)	20	(6)	40	(12)
Flammable and/or combustible liquid storage above ground 7)								
(a) 0 gal to 1000 gal (3785 L)	10	(3)	10	(3)	25	(8)	25	(8)
(b) In excess of 1000 gal (3785 L)	25	(8)	25	(8)	50	(15)	50	(15)
Flammable and/or combustible liquid storage above ground 8)								
(a) 0 gal to 1000 gal (3785 L)	20	(6)	20	(6)	25	(8)	25	(8)
(b) In excess of 1000 gal (3785 L)	25	(8)	25	(8)	50	(15)	50	(15)

1) The distances are based on permissible exposure to thermal radiation. See Appendix C for thermal radiation data.

2) The distances specified are allowed to be reduced to 5 ft (1.5 m) when protective walls are provided in accordance with 6.3.2 or reduced to zero feet (metre) when in accordance with 6.2.6.2.

3) Volume shown in liters refers to the water volume of the cylinder.

4) For cylinders with an internal volume of 1.8 ft³ (50 L) or less in storage or for those in use when separated to prevent flame impingement as required by 6.4.4.

5) For cylinders with an internal volume of 1.8 ft³ (50 L) or less in storage only.

6) For cylinders with an internal volume greater than 1.8 ft³ (50 L) and not exceeding 16 ft³ (450 L) in storage or use.

7) Silane packaged in steel cylinders or fiber overwrapped aluminum cylinders or silane stored in proximity to compatible gases packaged in steel or aluminum fiber overwrapped cylinders.

8) Silane packaged in aluminum cylinders or silane stored in proximity to compatible gases packaged in aluminum cylinders.

Table 4—Distance to exposures for outdoor silane trailers, ISO modules, and containers >450L in storage or use

Type of exposure	Minimum distance to exposure [1) 2) 3) 4) 5) 6)]		
	>450 L[5)] cylinder to include tube trailer or ISO module[1)]		
	<600 psig (4140 kPa) ft (m)	**>600 psig to 1000 psig (6900 kPa)** ft (m)	**>1000 psig to 1600 psig (11 030 kPa)** ft (m)
Places of public assembly	175 (53)	275 (84)	450 (137)
Property lines	110 (34)	180 (55)	300 (91)
Buildings on site [7)]	110 (34)	180 (55)	300 (91)

1) Maximum silane pressure in the container.

2) The distances are based on the potential for overpressure due to latent ignition of released silane from individual containers of the size noted. Overpressures are determined in part by potential releases from the pressure relief device used for containers of the size noted. The container volumes shown are based on the maximum water content of individual containers whether manifolded or not.

3) Distances to buildings are allowed to be reduced depending on the ability of the building to resist overpressure. See Appendix D.

4) Distances for pressures or volumes outside of those shown in the table shall be determined by engineering analysis subject to the approval by the authority having jurisdiction.

5) Volumes expressed in liters refer to the water content of containers specified.

6) Tube trailers or ISO modules equipped with PRDs with a venting orifice of ≤ 1.0 in (25 mm) in diameter.

7) Where greater encroachment is required for buildings on site refer to Appendix D for guidance.

6.4 Silane delivery systems

6.4.1 General

Outdoor locations are advised for silane delivery systems to prevent the potential accumulation of silane in the event of a release. Although outdoor locations are advised, the use of outdoor systems is not always achievable due to site or environmental considerations such as when the other constituents of silane mixtures are toxic.

6.4.2 System operation

A means of detecting a potential fire at the source connection or process gas panel shall be provided in accordance with the requirements of 11.2.1. The means provided shall be designed to minimize personnel exposure when silane flow is initiated after a change of source containers occurs.

6.4.3 Shutdown and source isolation

A means for shutting down the silane delivery system shall be provided in accordance with the requirements of 6.4.3.

6.4.3.1 Remotely located, manually activated shutdown

At least one remotely located, manually activated shutdown control shall be provided. The shutdown control shall be located not less than 15 ft (4.6 m) from the source of supply and the process gas panel control system. Activation of the shutdown control shall immediately stop the flow of gas at the source and isolate the source from the delivery system. Additional remotely located, manually activated shutdown controls shall be located at each exit from the secured area.

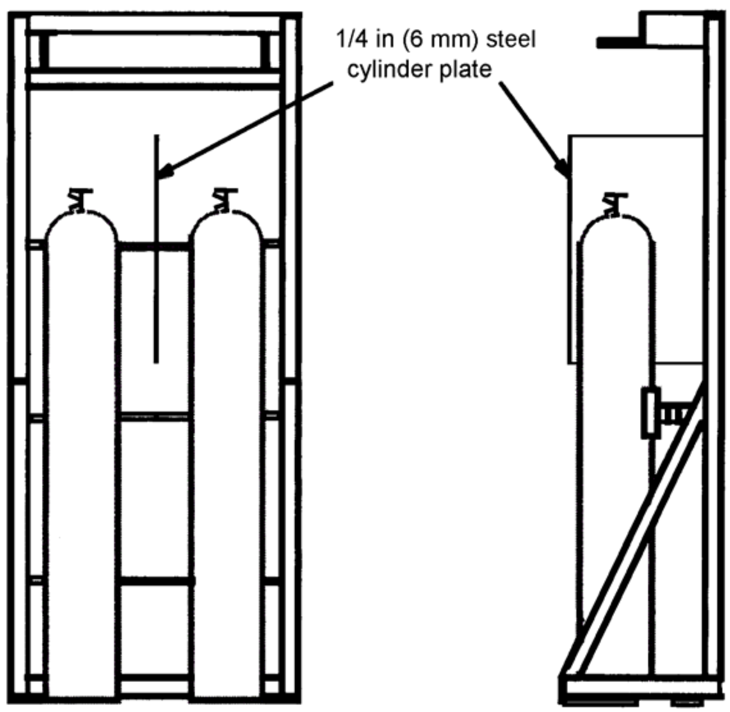
6.4.3.2 Automatic shutdown

An automatic shutdown system shall be provided to automatically shut off the gas flow when fire is detected in accordance with the requirements in 11.2.

6.4.4 Arrangement of cylinder systems

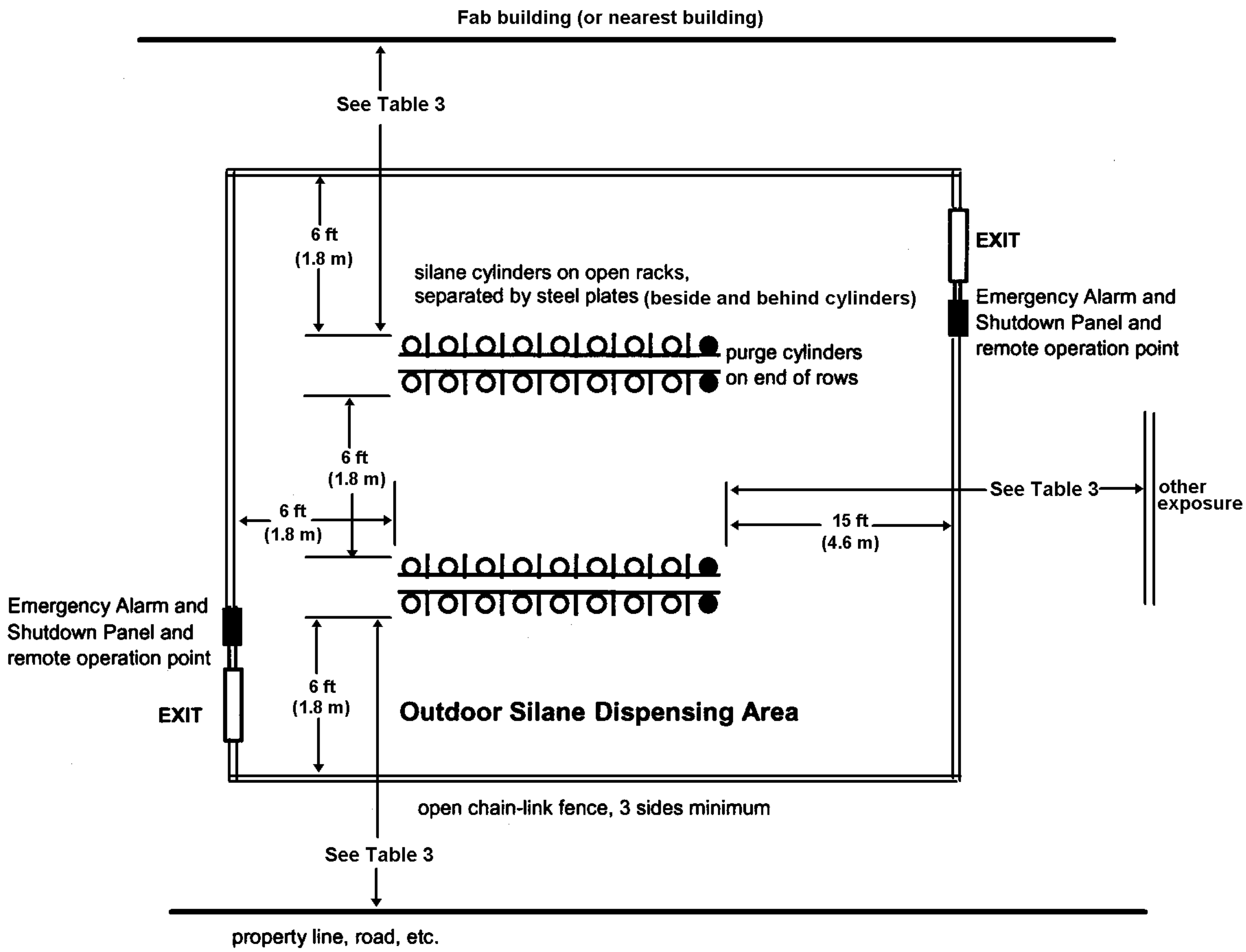
Individual cylinders containing silane shall be secured in open steel racks and separated from other silane cylinders to prevent flame impingement from a silane release to an adjacent cylinder or valve area. Separation shall be by 1/4 in (6 mm) thick steel plates with the plate extended a minimum of 18 in (460 mm) below the centerline of a cylinder valve and a minimum of 6 in (150 mm) above the centerline of the cylinder valve or other means providing equivalent protection. An exception to this is individual cylinders in attended transfer operations that are in the process of being filled shall not be required to be separated by barriers to prevent flame impingement.

Figure 2 shows an example of an open steel rack with steel plate separators designed to prevent flame impingement on adjacent cylinders if failure at a cylinder valve occurs. Figure 3 shows a typical outdoor area used for unattended operations.



NOTE—The plate is designed to prevent flame impingement from the valve source to the adjacent cylinder. The plate shall be extended below the centerline of the valve a minimum of 18 in (460 mm). Figure 2 has been provided to illustrate the concepts described in the text of the standard. The figure is schematic in nature. It is neither to be interpreted as a design document nor is it intended to restrict alternate designs.

Figure 2—Support structure protection against flame impingement



NOTE—Figure 3 has been provided to illustrate the concepts described in the text of the standard. The figure is schematic in nature. It is neither to be interpreted as a design document nor is it intended to restrict alternate designs. For instrument nomenclature, see Figure 1. Figure 3 applies only to steel cylinder or aluminum cylinder protected with aluminum overwrap. For unprotected aluminum cylinders, see Table 3.

Figure 3—Typical end user outdoor cylinder layout

6.4.5 Arrangement of bulk source systems

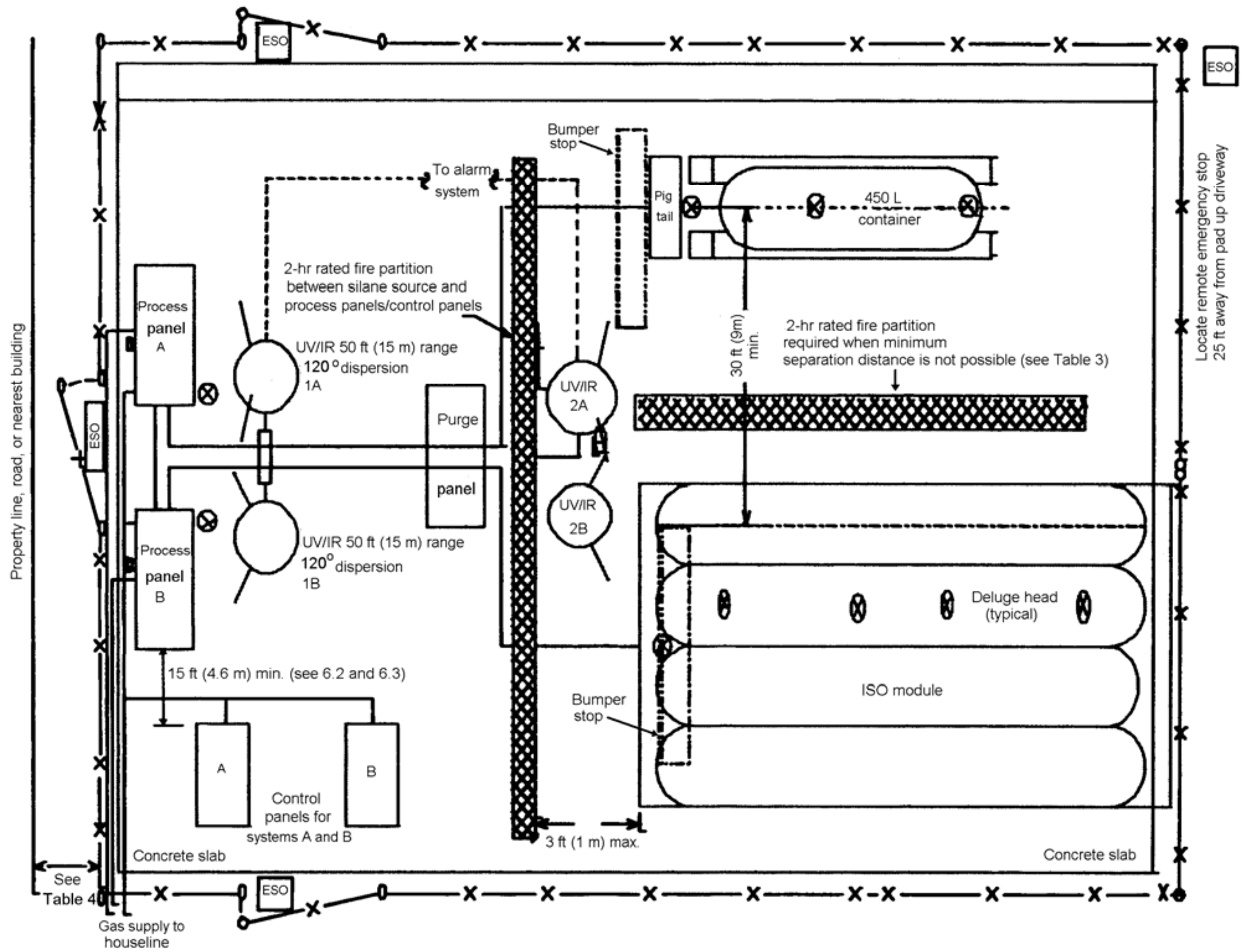
A silane bulk source system includes a bulk container of silane discharging through a pressure control and piping system. Bulk source delivery systems shall be in accordance with the requirements of 6.4.5 and Section 9.

6.4.5.1 Operator controls

The silane bulk gas supply control system shall consist of one or more control panels and one or more process gas panels.

6.4.5.2 Panel location

A typical bulk source container layout is shown in Figure 4.



NOTE—Figure 4 has been provided to illustrate the concepts described in the text of the standard. The figure is schematic in nature. It is neither to be interpreted as a design document nor is it intended to restrict alternate designs. For instrument nomenclature, see Figure 1.

Figure 4—Typical bulk source container layout (unattended operations)

6.4.5.2.1 Separation between control panels and bulk sources

There shall be a 2 hour fire partition provided between the silane bulk source containers and the control panels or process gas panels. Alternatively, a 30 ft (9 m) separation shall be provided between the supply containers and the control or process gas panels.

6.4.5.2.2 Separation between control panels and process gas panels

Control panels shall be located not less than 15 ft (4.6 m) from process gas panels.

6.4.5.2.3 Field of view between control panels and process gas panels

Control panels shall be mounted in a location that allows an unobstructed view of the process gas panels (potential leak points).

7 Indoor storage and use

7.1 Applicability

In addition to the requirements of Section 7, indoor storage and use of silane shall be in accordance with the requirements of Sections 8 through 17 as applicable. An exception to this is individual containers with a silane content not greater than 0.50 scf (14 L).

7.2 Indoor storage

Indoor storage of silane shall be in accordance with the requirements of 7.2 and 7.4 through 7.10 as applicable. Buildings, rooms, or areas used for silane storage shall be constructed in accordance with the requirements of national codes and regulations.

7.2.1 Bulk sources

Silane bulk sources shall not be located indoors.

7.2.2 Location

Silane shall not be stored in locations below ground level.

7.3 Indoor use

Indoor use of silane shall be in accordance with the requirements of 7.3 and 7.4 through 7.10 as applicable.

7.3.1 Bulk sources and systems

Silane bulk sources shall not be located indoors.

7.3.2 Nonbulk sources and systems

Nonbulk silane sources and delivery systems are allowed indoors. Buildings, rooms, or areas used for the installation of silane delivery systems shall be constructed in accordance with 7.3.2.2 and the requirements of national codes and regulations. The guidelines for indoor cylinder systems are analogous to those for outdoor cylinder systems. The difference is that indoor installations have additional requirements for forced fresh air ventilation across mechanical connections to prevent accumulation of silane in the event of a release and controls to limit potential damage in the event of fire or explosion.

7.3.2.1 Location

Silane delivery systems shall not be installed below ground level.

7.3.2.2 Barricade construction

7.3.2.2.1 Unattended operations

Rooms or areas used to contain silane sources used in unattended operations shall be constructed to meet the requirements for barricade construction designed to address the potential for a detonation of released material. Ordinary construction methods and the use of explosion venting or relief systems are not allowed as a means to offset the effects of a detonation.

7.3.2.2.2 Attended operations

Rooms or areas used for attended transfer operations shall not be required to meet the requirements for barricade construction when such areas are in conformance with the requirements of 7.3.2.2.3 or 7.3.2.2.4 as applicable.

7.3.2.2.3 Filling in exhausted enclosures

Cylinders shall be filled in exhausted enclosures in accordance with the requirements of 7.3.2.2.3 or shall be filled in a gas filling room in accordance with the requirements of 7.3.2.2.4. Filling operations conducted in exhausted enclosures shall comply with all of the following:

- Explosion control shall be provided in accordance with 7.5;
- Cylinders being filled shall be located within an exhausted enclosure that is ventilated in accordance with the requirements of 13.2; and
- Gas monitoring shall be provided in accordance with 11.1.2. The gas monitoring system shall initiate a local alarm to alert operators at concentrations of 5 ppm (TLV-TWA) or less [7]. Activation of the monitoring system shall automatically isolate the source of gas supply from the filling manifold.

7.3.2.2.4 Filling in gas filling rooms outside of exhausted enclosures

Cylinders shall be filled in gas filling rooms in accordance with the requirements of 7.3.2.2.4 or shall be filled in an exhausted enclosure in accordance with the requirements of 7.3.2.2.3. Filling operations in gas filling rooms shall comply with all of the following:

- Explosion control shall be provided in accordance with 7.5;
- Cylinders being filled shall be considered to be in unenclosed indoor installations. Ventilation shall be provided in accordance with the requirements of 13.2; and
- Gas monitoring shall be provided in accordance with 11.1.2. The gas monitoring system shall initiate a local alarm to alert operators at concentrations of 5 ppm (TLV-TWA) or less [7]. Activation of the monitoring system shall automatically isolate the source of gas supply from the filling manifold.

7.4 Egress

There shall be a minimum of two exits from storage and use areas. An exception to this is one exit is allowed when areas are less than 200 ft^2 (19 m^2). unless national regulations indicate otherwise and the equipment is arranged so the exit access is clear.

7.4.1 Travel distance to exits

The maximum travel distance to an exit shall not exceed 75 ft (23 m).

7.5 Explosion control

A means of explosion control shall be provided when the quantity of silane in individual containers exceeds 0.50 scf (14 L). Explosion control shall be designed and constructed in accordance with the requirements of national building and/or fire codes.

7.6 Electrical requirements

For requirements see 16.3.

7.7 Ventilation

For requirements see 13.2.

7.8 Quantity limits

7.8.1 Buildings containing mixed uses

The maximum quantity of silane and other pyrophoric gases stored or used inside buildings containing other occupancies or uses (mixed uses) as defined by national building codes shall not exceed detached building threshold limits as established by national codes. Quantities of silane and other pyrophoric gases exceeding this amount shall either be located in a detached building or outdoors.

7.8.2 Detached buildings

The maximum quantity of silane in detached buildings shall not be limited when the use of the building is confined solely to the storage or use of hazardous materials and the building, storage or use conditions comply with applicable national codes.

7.9 Separation from incompatible materials

Regardless of whether a detached building or mixed-use building is used, silane shall be separated from incompatible materials in storage and use as required by national or regional codes and regulations. Separation shall be provided by distance, gas cabinets or similar appliances, or noncombustible partitions.

7.10 Gas cabinets

Gas cabinets or equivalent ventilated enclosures shall be provided for silane sources or systems in use where the pressure of the gas supply exceeds 30 psig (207 kPa) or where silane is mixed with a toxic or highly toxic component. When gas cabinets are used, refer to 8.2.2.

An exception to this is cylinders in rooms meeting the requirements of 7.3.2 and the requirements of 13.2 for unenclosed indoor installations.

7.11 Other requirements

The additional control measures required by 7.11 shall be provided when silane storage or delivery systems are located indoors.

7.11.1 Engineering controls

Detailed information on the required controls is provided in the referenced sections:

- system configuration — See Section 8
- piping and components — See Section 10
- gas monitoring — See Section 11.1
- flame or heat detection — See Section 11.2
- fire protection — See Section 12
- ventilation — See Section 13
- venting and treatment — See Section 14
- inert purge gas systems — See Section 15
- electrical — See Section 16
- supervisory control systems — See Section 17

7.11.2 Shutdown and source isolation

A means for shutting down the silane delivery system shall be provided.

At least one remotely located, manually activated emergency shutdown system is required. The shutdown system shall be capable of being activated from a point immediately outside of and adjacent to each exit door from the room or area in which silane delivery systems are located. Activation of the shutdown system shall immediately stop the flow of gas at the source and isolate the source from the delivery system. Activation of the shutdown control shall sound a local alarm.

8 System configuration—cylinder sources

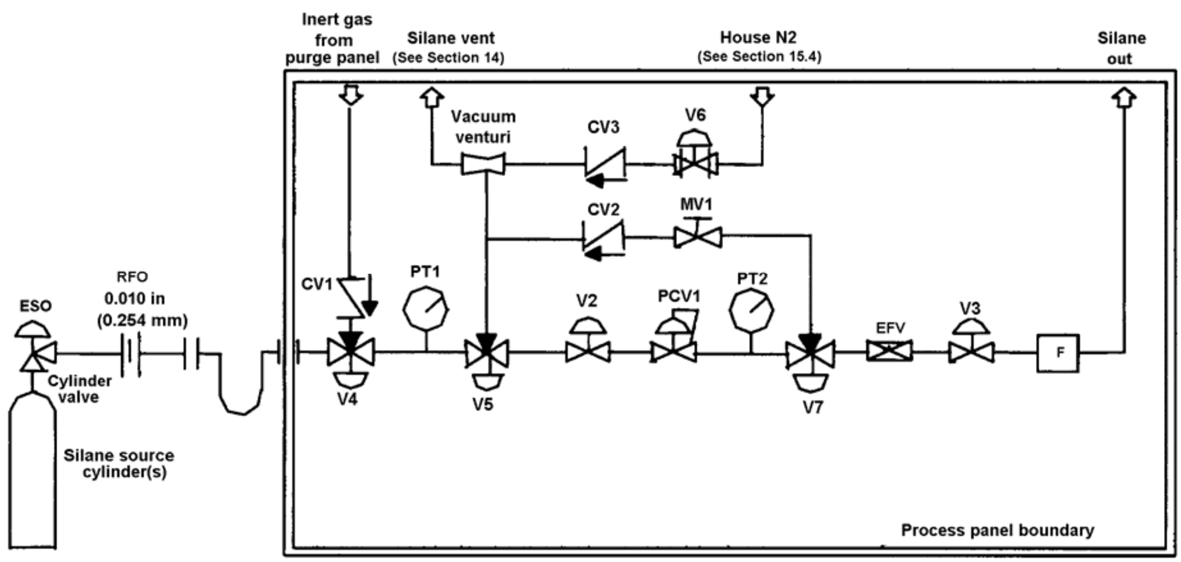
8.1 Outdoor installations

8.1.1 Use equipment

Equipment used for outdoor cylinder installations consists of individual source and purge gas supply cylinders, a process gas panel, a purge gas panel, and a support structure. For information on locating cylinders, support structures, and typical layout, see 6.1 and 6.3 and Figures 2 and 3.

8.1.2 Process gas panel

Process gas panels shall be used to regulate the downstream pressure of gas from the silane source cylinder(s) to a VMB or point of use. General requirements for process gas panel piping systems, RFO, emergency shutoff system (ESO) valves, and components are specified in Section 10. See Figure 5.



NOTE—The ESO valve is allowed to be located on the cylinder or on the pigtail close coupled to the cylinder. Figure 5 has been provided to illustrate the concepts described in the text of the standard. The figure is schematic in nature. It is neither to be interpreted as a design document nor is it intended to restrict alternate designs. For instrument nomenclature, see Figure 1.

Figure 5—Typical silane process gas panel

8.1.2.1 Materials of construction

Process gas panel components shall be constructed of materials compatible with silane and assembled with components and fittings designed to minimize leakage.

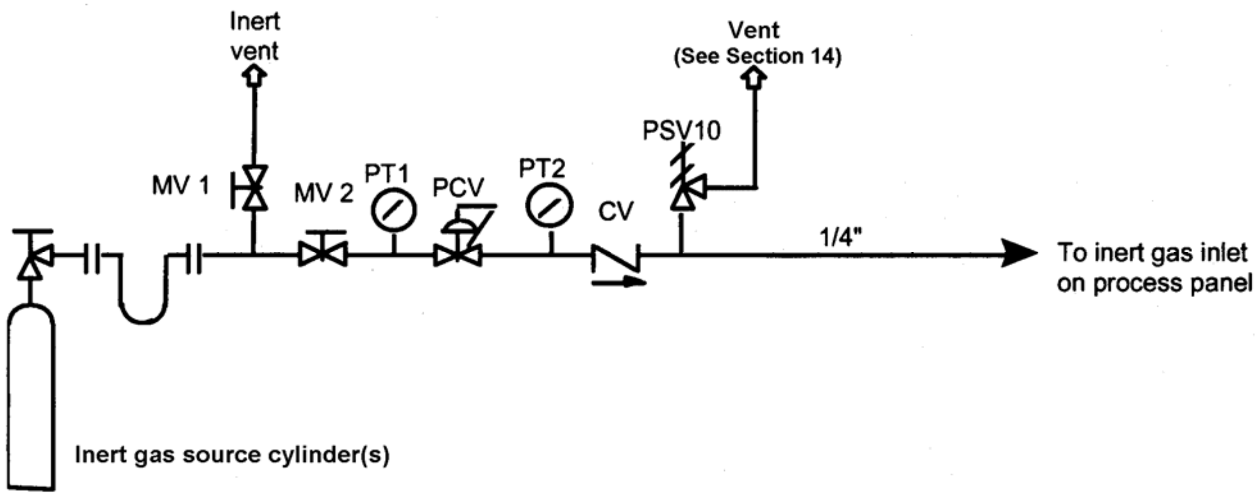
8.1.2.2 Excess flow control

Process gas panels shall be provided with excess flow control in accordance with the requirements of 10.2.5.

8.1.3 Purge gas panel

Purge gas panels shall be provided as a means to control the supply of inert purge gas to process gas panels serving each silane delivery system. Purge gas panels shall be designed to prevent the backflow of process gas and potential cross-contamination of the purge gas source. Individual purge gas panels serving process gas panels used to control silane gas shall be solely for use on silane delivery systems.

Silane systems shall be purged with an inert gas by means that ensures complete purging of silane from the piping and control system before the source system is either opened to the process or to the atmosphere at times when silane sources are changed or for purposes of maintenance. See Figure 6.



NOTE—Figure 6 has been provided to illustrate the concepts described in the text of the standard. The figure is schematic in nature. It is neither to be interpreted as a design document nor is it intended to restrict alternate designs. For instrument nomenclature, see Figure 1.

Figure 6—Typical silane purge gas panel

8.2 Indoor installations

8.2.1 Use equipment

Equipment used for unattended operations conducted with indoor cylinder installations consists of individual source and purge gas supply cylinders, a process gas panel, a purge gas panel, and gas cabinet or rack system. VMBs are customarily used in indoor installations where distribution to multiple use points is required. See 8.2.4.

8.2.2 Gas cabinet systems

A gas cabinet system is comprised of the cabinet or enclosure, the controller (when automated controls are provided), and process gas panel(s). A gas cabinet is a protective device used to house compressed gas cylinder(s) and to ensure that a potential gas release is confined to the area where released and directed away from operators and plant personnel. Gas cabinets are connected to an exhaust system that is used to capture and remove leaked gas and transport it to a point of discharge away from personnel, air intakes, or building openings.

Gas cabinets are fully enclosed appliances designed to house the cylinder(s) they contain. They are uniformly exhausted to maximize operator protection during use and to ensure operator protection while making and breaking connections during cylinder changes. Once a gas cylinder has been secured into an enclosure, limited access is used (usually a large lockable window) to allow operators to view and operate the process gas panels contained inside the cabinet. The purge gas panel(s) is typically housed within the cabinet as well. The control panels used to operate the process gas panel(s), when such panels are automated, are typically installed outside the cabinet. The controller is commonly used to enable automated purge procedures to ensure efficiency and consistency in purge operations. The process gas panel is typically designed to eliminate dead ends in the piping system, to minimize gas stream contamination, and to ensure the optimum purge efficiency.

8.2.2.1 Limitations

Where gas cabinets are used, only single-cylinder cabinets are recommended to minimize the exposure potential in the event of fire. Where there is more than one source cylinder in a gas cabinet, each cylinder shall be separated by a 1/4 in (6 mm) steel plate as described in 6.4.4.

8.2.2.2 Labeling

Gas cabinets shall be labeled with the name of the process tool or equipment they serve, as well as with the name of the gases contained such as SILANE or SILANE MIXTURE and the type of purge gas used. Additional labeling indicating HAZARDOUS—KEEP FIRE AWAY shall be placed on the cabinet as a warning to prevent potential fire exposure and as a means to alert emergency response personnel to the presence of compressed gas cylinders.

8.2.3 Process gas and purge gas panel

Process gas panels and purge gas panels for indoor use shall be in accordance with the requirements of 8.1.

8.2.4 Valve manifold box

8.2.4.1 Description

Gases in closed piping systems shall be allowed to be distributed through a VMB to one or more points of use. Distribution to multiple use points serves to reduce the quantity of source cylinders on site as well as the number of individual gas pipelines containing silane located throughout the user facility. VMBs are allowed to be controlled automatically using pneumatically operated valves. Operations such as emergency gas shutoff at the point of use and purging at the point of use are allowed to be accomplished with automated VMB systems without venting the primary delivery line from the gas source thereby minimizing the potential for contamination as well as the consumption of silane.

8.2.4.2 VMB manifold branch purging

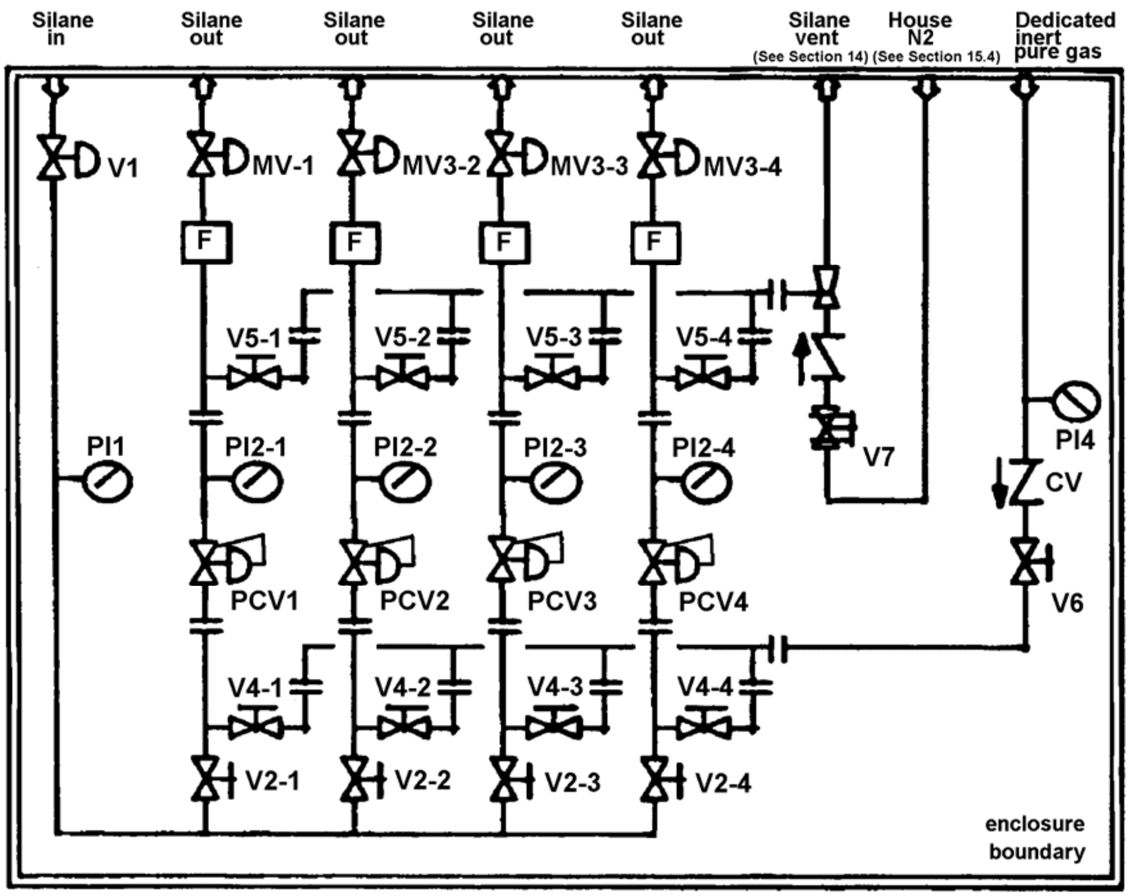
VMB manifold branches shall be purged with an inert gas by means that ensure complete purging of the piping and control system before the system is used to deliver silane to the process or before the system is allowed to be opened to atmosphere for maintenance purposes. See Figure 7 for recommended locations of VMB manifold branch purging points.

8.2.4.3 Gas monitoring

Gas monitoring shall be provided at the VMB in accordance with the requirements of 11.1.2. Activation of the gas monitoring system shall shut down the source of gas at the VMB being monitored in accordance with the requirements of 11.1.5.

8.2.4.4 Flame detection

Flame detection shall be provided at the VMB in accordance with the requirements of 11.2.2.3. Activation of the flame detection system shall shut down the source of the gas supply at the VMB being monitored in accordance with the requirements of 11.2.3.



NOTE—Figure 7 has been provided to illustrate the concepts described in the text of the standard. The figure is schematic in nature. It is neither to be interpreted as a design document nor is it intended to restrict alternate designs. For instrument nomenclature, see Figure 1.

Figure 7—VMB flow schematic

9 System configuration—bulk sources

9.1 Use equipment

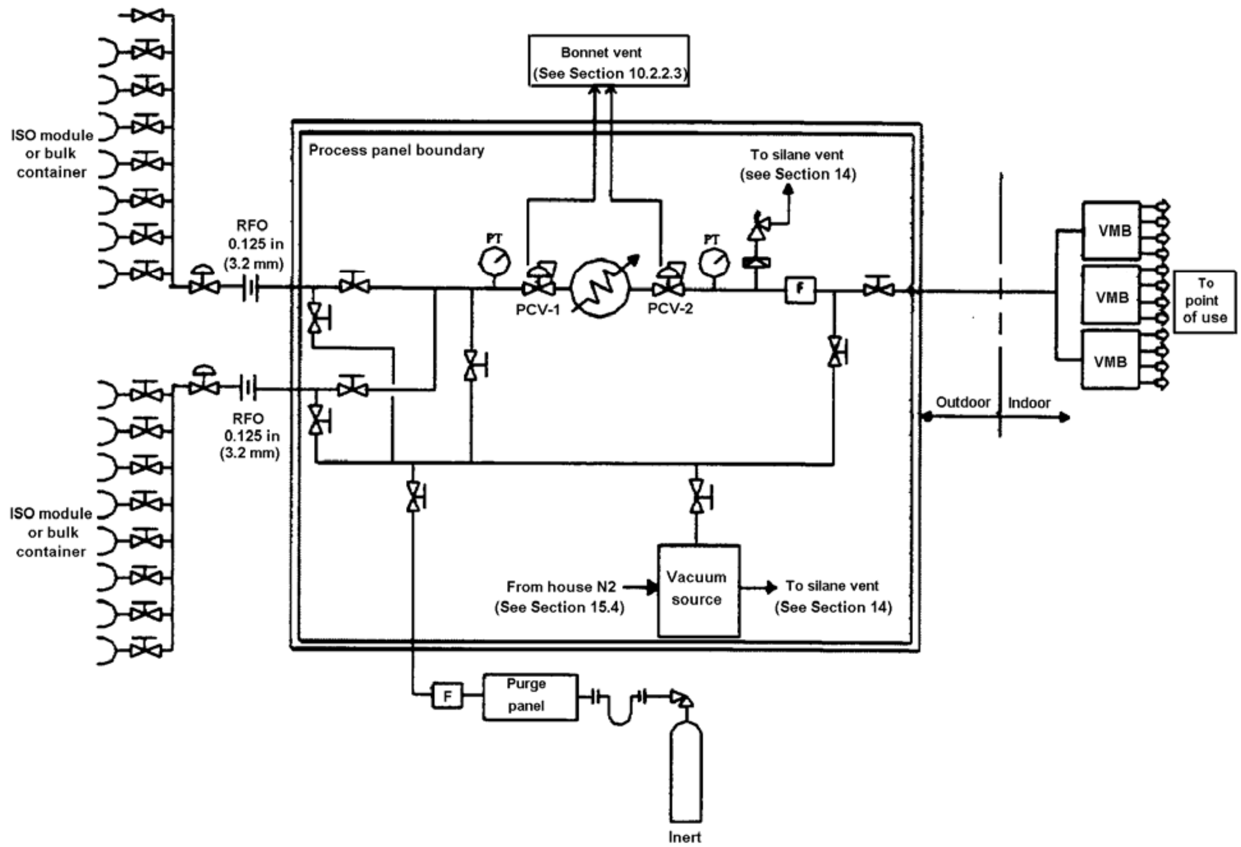
Equipment used for silane bulk source installations consists of a silane bulk source and its attendant control systems**.** A silane bulk source consists of an ISO module, tube trailer, cylinder packs, or individual containers having an aggregate water volume greater than 8.8 ft^3 (250 L). The attendant control systems include a process gas panel, purge gas panel, and control panel. Bulk silane source systems distribute silane to use points located indoors. Distribution within the building where the material is used is customarily performed using of VMBs. A typical process flow diagram is shown in Figure 8. Equipment used for bulk source systems shall be in accordance with the requirements of 6.4.5.

9.2 Outdoor installations

The location of outdoor delivery systems shall be in accordance with the requirements of Section 6.

9.3 Bulk containers

Silane bulk source containers shall comply with 9.2 and relevant national regulations.



NOTE—The vacuum source is either a vacuum pump system or a vacuum venturi system. Figure 8 has been provided to illustrate the concepts described in the text of the standard. The figure is schematic in nature. It is neither to be interpreted as a design document nor is it intended to restrict alternate designs. For instrument nomenclature, see Figure 1.

Figure 8—Typical bulk system process flow diagram

9.3.1 Tube trailers and ISO modules

An ISO module consists of a number of cylindrical tubes that have been mounted onto a frame suitable for over-the-road and ocean transport. The typical tube is 2 ft (0.6 m) in diameter and ranges from 20 ft to 40 ft (6.1 m to 12.2 m) in length. The delivery end of the module is typically equipped with a piping manifold that interconnects each of the tubes in the system. Each tube contained within tube trailers or ISO modules shall have an isolation valve capable of isolating the silane supply from the piping manifold.

9.3.2 450-liter cylinders

A 450-liter cylinder is an individual cylinder with an internal water volume of approximately 16 ft^3 (450 L). The cylinder shall be mounted horizontally and fastened to a skid so a forklift truck or suitable power mover is able to move it. The typical 450-liter cylinder has a valve on one end.

9.3.3 Cylinder packs

Cylinder packs have multiple silane cylinders assembled on a cart or skid**.** Some carts are equipped with wheels and a frame so they are able to be moved manually or with a forklift truck. The larger carts do not have wheels and depend on a forklift for movement. The typical internal water volume of the individual cylinders ranges from 1.52 ft^3 to 1.76 ft^3 (43 L to 50 L).

9.3.3.1 Securing of cylinders

Individual cylinders shall be firmly supported within the cart and frame assembly.

9.3.3.2 Isolation valves

Each cylinder shall be equipped with an isolation valve capable of isolating the cylinder from the piping manifold. The isolation valves shall be connected to a piping manifold that interconnects each cylinder to a common outlet valve and connection.

9.3.3.3 Protection from flame impingement

Cylinders shall be separated from each other by 1/4 in (6 mm) thick steel plates or other means designed to prevent flame impingement from a silane release to an adjacent cylinder or valve.

9.4 Pressure relief devices

Individual tubes or cylinders shall be equipped with pressure relief devices per relevant national regulations and industry standard. When multiple cylinders or tubes are grouped into a framework or other fixed system, the discharge from pressure relief devices shall be directed away from adjacent containers within the group.

9.4.1 Bulk source process gas panel

The silane bulk source process gas panel is used to regulate the pressure from silane bulk source storage systems downstream to the VMB(s) that is (are) customarily installed inside the building where the material is used. The process gas panel is typically an independent module mounted on a skid or independent frame. It consists of an arrangement of isolation valves, pressure regulation controls, filtration equipment, excess flow control, and other shutoff controls. A process heater is allowed to be used to prevent two phase flow where there are high flow demands and a Joule-Thompson cooling effect is probable. See Figure 8.

9.4.2 Location

The silane bulk source process gas panel shall be located outdoors.

9.5 Valve manifold box

VMBs are used in bulk distribution applications where there are multiple use points to be served by a single source. The typical VMBs used for bulk sources are of the same design as those described for use with indoor installations. See 8.2.4.

9.5.1 Location

VMBs used in conjunction with bulk source systems are allowed to be located indoors.

10 Piping and components

10.1 Piping system design

Piping systems shall be designed, constructed, examined, inspected, and tested in accordance with established and recognized standards like ASME B31.3, *Process Piping* [14].

10.1.1 Construction

Piping systems used for silane service shall be of metal construction.

10.1.2 Piping connections

Connections in the piping system shall be in accordance with established and recognized standards like ASME B31.3 [14]. Welded connections are the required method of assembly where connections in the piping system are needed. Exceptions are as follows:

– Face-seal fittings are allowed where connections are used for maintenance. Gaskets used with face-seal fittings shall be constructed of metal. The number of unwelded mechanical fittings shall be kept to a minimum and shall be secured in such a manner as to prevent leaks resulting from rotational or vibratory forces especially between the cylinder valve and the connecting pigtail; and

– Threaded connections used on cylinder valves inserted into source cylinders.

10.1.3 Secondary containment

Secondary containment of piping systems shall not be required for piping used to convey silane or silane mixtures that are neither toxic nor highly toxic. When secondary containment or coaxial piping or tubing is provided, the secondary containment shall be of metal construction that is rated to contain the maximum pressure expected based on system design under failure of the primary piping or tubing system.

When secondary containment is provided, the use of air as a means to purge the annular space between the primary and secondary containment piping or tubing shall not be allowed due to the potential for an air/silane reaction and the resultant fire, explosion, and/or the subsequent plugging of the annular space.

10.1.4 Manifolding with gases other than silane

10.1.4.1 Manifolding at the source of supply

Silane shall not be piped into manifolds used to convey other process gases upstream of the point of use.

10.1.4.2 Manifolding at the point of use

Controls downstream of the first point of control within users' facilities are outside of the scope of this standard. See 2.1.2. Safeguards internal to the process equipment are used to prevent the material from coming into contact with reactive gases until the right conditions are achieved. The use of a manifold to handle multiple gases at point-of-use process equipment shall be the responsibility of the equipment manufacturer and/or the owner.

10.1.4.3 Manifolding of vent gases

Silane and vent gases containing silane and an inert gas, e.g., nitrogen, from silane delivery systems or VMBs shall not be piped into manifolds used to convey other process gases.

10.1.5 Leak testing

Before initial operation and after the applicable examinations required by established and recognized standards like ASME B31.3, piping systems shall be leak tested to ensure tightness [14]. Piping systems that have been modified and/or repaired shall be tested as required for new installations.

10.1.5.1 Test pressure

Test pressures shall be determined to enable the system to be assessed for leaks under the conditions of use expected but not less than that specified by established and recognized standards like ASME B31.3 [14].

10.1.5.2 Portions of the system subject to testing

Pressure testing of newly constructed systems shall include the entire piping system beginning from the source valves at the point of supply. Portions of the system are allowed to be tested independently; however, the entire system is subject to pressure tests as required by established and recognized standards like the ASME code. Testing of the source connection is required after each cylinder or container change.

10.1.5.3 Test fluid

The test gas used for pneumatic testing, if not air, shall be nonflammable and nontoxic. Inert gases are customarily used in conducting pneumatic pressure tests. Regardless of the test gas that is used to supply pneumatic pressure, residual air or other oxidizing gases shall be removed from the piping system after the test is complete and before charging the system with silane.

10.1.6 Identification

Piping systems shall be marked, labeled, and identified in accordance with established and recognized standards like ASME A13.1, *Scheme for the Identification of Piping Systems* as follows [15]:

- Markings used for piping systems shall consist of the content's name and include a direction of flow arrow;
- Markings or labels shall be provided:
  - at each valve
  - at wall, floor, or ceiling penetrations
  - at each change of direction; and
- At a minimum of every 20 ft (6.1 m) or fraction thereof throughout the piping run.

10.2 Components

10.2.1 Valves

Packed valves shall not be used since silane has a potential to autoignite when exposed to the atmosphere. Bellows sealed valves and diaphragm sealed valves are allowed to be used in lieu of packless design. The selection of valves or components with bonnet seals shall be of the type where the seal nuts or fittings are not able to be loosened or removed from the component without tools. Valves shall be designed so that rotation of the manual valve handle against its stop does not loosen the seal nut. Automatic actuated valves shall be of fail-safe or fail-closed design to protect against the accidental flow of gas in the event of energy loss to the valve actuator.

10.2.2 Backflow prevention

A means of protection shall be provided to prevent backflow and back diffusion of silane into portions of the piping system that are designed to convey gases other than silane.

10.2.2.1 Check valves

Check valves shall not be used as the sole means of control to prevent backflow. When used, check valves shall be used to provide a means of redundant protection. Check valves shall be spring-opposed, positive shutoff type.

10.2.2.2 Regulators

Regulators shall be equipped with a metal diaphragm.

10.2.2.3 Bonnet relief vents

Regulator bonnets shall be equipped with bonnet relief vents provided with an attached vent line or positioned to allow silane to escape to a protected location in the event of a diaphragm leak or rupture. A means to detect a ruptured regulator diaphragm shall also be provided. When bonnet relief vent lines are provided, they shall be sized not to restrict the flow from the bonnet relief vent. See Section 14.

10.2.3 ESO system

Silane delivery systems shall be provided with ESO systems that are able to be activated at each point of use and at the source. ESO valves shall be located to be clearly visible and accessible. See Sections 6.4.3 and 7.11.2.

10.2.3.1 Shutoff at source

A manual or automatic fail-safe ESO valve shall be installed on supply piping at the cylinder or bulk source.

10.2.3.2 Shutoff at point of use

Shutoff systems provided to shut off the flow of gas at a designated VMB are allowed to be used as a means of ESO for systems where distribution to multiple use points is involved.

10.2.3.3 Marking

ESO valves and shutoff controls shall be identified by means of a sign.

10.2.4 Restrictive flow orifice

10.2.4.1 Nonbulk sources

Silane source cylinder outlet valves shall be equipped with an RFO. The inside diameter of the RFO used on individual cylinders shall not exceed 0.010 in (0.254 mm). Exceptions follow:

– source cylinders in the process of being filled or serviced to remove residual product; and

– cylinders in storage at the filling or distributor location equipped with a solid plug that forms a metal-to-metal gas-tight seal at the valve outlet.

10.2.4.2 Bulk sources

An RFO shall be placed in each outlet valve or in the outlet valve of the delivery manifold serving bulk source systems. The inside diameter of the RFO used on outlet valves for individual cylinders of unmanifolded bulk sources shall not exceed 0.125 in (3.175 mm) in diameter. For bulk source systems connected to a manifold, the outlet valve from the manifold shall be limited-by-design with an effective orifice not exceeding 0.125 in (3.175 mm) in diameter. An exception is bulk sources equipped to service attended transfer operations.

10.2.5 Excess flow control

Means shall be provided to shut off the flow of silane due to a rupture of the piping system. Excess flow valves, control devices, or the use of pressure and/or flow control systems are allowed. The use of a flow switch that activates an automatic shutoff valve or an automatic positive shutoff device is allowed.

10.2.5.1 Location of shutoff device

The shutoff device shall be located as close to the silane source as practicable.

10.2.5.2 Venting of gas

Systems that incorporate the venting of gas in the system design shall be designed to vent the gas in a controlled manner. See Section 14.

10.2.5.3 System controls

The excess flow control device or system shall be capable of being manually reset once corrective action to the excess flow condition has been taken.

10.2.6 Overpressure protection

An overpressure relief device shall be used to protect silane delivery systems where the design pressure of the delivery system is less than the supply source pressure and where, due to the gas capacity of the source, the system design pressure is able to be exceeded. Sources of pressure to be considered shall include but not be limited to ambient influences, pressure oscillations and surges, improper operation of equipment, and failure of control devices.

10.2.7 Static seals

In addition to chemical compatibility, gaskets, O-rings, and seals used in pressure-retaining components shall be suitable for the operating pressure and temperature of the system. When selecting polymeric materials, consideration shall be given to the rate at which these materials mechanically extrude or thermally behave over time. Since these properties directly affect the ability of a seal to repeatedly perform positive containment during pressure or thermal cycling, the selection of thin seals (1/32 in [<0.795 mm] or less) in these services is required. There shall be no thickness restriction for metallic gaskets, seals, or metallic O-rings provided that the component is suitable for the operating pressure and temperature of the system, and that it is constructed from metals having comparable thermal expansion characteristics compared to the housing, flange, or valve body that it seals.

10.3 Support of piping systems

10.3.1 Method of piping support

Piping used to convey silane shall be supported in accordance with the requirements of national codes by supports designed in accordance with established and recognized standards like ASME B31.3 [14]. Typical means for piping system support includes the use of a supporting structure such as a cable tray, pipe trestle, or rack system.

10.3.1.1 Minimum installation height

When piping is to be located in overhead support systems in a space that is occupied by operating personnel, it shall be located at a height not less than 7 ft (2.1 m). Where vehicle access is required, the height shall permit clearance of vehicular traffic.

10.3.1.2 Piping containing other materials

Other process gas and/or chemical piping is allowed to be installed in the same trestle or racking system used to support the silane piping system.

10.3.2 Alternate method of piping support

Silane piping installed through trenches or tunnels that are closed or sealed shall be contained within coaxial piping or tubing systems in accordance with the requirements of 10.1.3. Protection from impact hazards shall be provided through use of structural guards or bollards where the tubing enters or exits the tunnel or trench.

11 Gas and flame detection

11.1 Gas monitoring

11.1.1 Outdoor locations

Gas monitoring is not required for outdoor storage or use installations.

11.1.2 Indoor locations

Indoor silane delivery systems shall be monitored for gas leaks using a gas monitoring system.

11.1.3 Location of monitors

11.1.3.1 Exhaust ducts serving enclosures and cabinets

When gas monitoring is provided, sampling points shall be placed in the exhaust ventilation ducts serving enclosures used to protect mechanical connections. Sampling points placed inside of exhaust ducts serving enclosures or cabinets shall be located at a point not less than five duct diameters downstream of the point where the exhaust duct is connected to the enclosure or cabinet.

11.1.3.2 Areas without enclosures

When area gas monitoring systems are used, sampling points shall be within the room or area where silane delivery systems or sources are located.

11.1.4 Sensing requirements

11.1.4.1 Monitoring within exhausted zones

When gas monitoring is provided within exhausted zones, the gas monitoring system shall initiate a warning at concentrations of 0.34% (25% of the LFL) or less.

11.1.4.2 Monitoring outside of exhausted zones

When gas monitoring is provided outside of exhausted zones, the gas monitoring systems shall initiate a warning at concentrations of 5 ppm (TLV-TWA) or less [7].

11.1.5 Shutdown requirements

11.1.5.1 Monitors in ducts serving enclosures

Activation of the gas monitoring system shall shut off the flow of gas at the source or within the enclosure being monitored when a concentration of greater than 0.34% (or 25% of the LFL) is detected.

11.1.5.2 Monitors used for area monitoring

Activation of area monitors shall not require automatic shutdown of the system.

11.1.6 Alarms

Activation of the gas monitoring system shall initiate a local alarm and transmit a signal to a constantly attended location so responsible parties will act on the alarm condition.

11.2 Flame detection

11.2.1 Outdoor systems

When silane delivery systems are located outdoors, an optical flame detection system approved for silane service shall be located to detect fire in potential silane leak zones, e.g., cylinder support rack, cylinder packs, ISO modules, and process and purge gas panels. Detectors used outdoors shall be approved for outdoor service and tested for immunity to sunlight, arc welding, artificial area lighting, or stray sources of ultraviolet or infrared light that are able to inadvertently trip a detector.

11.2.2 Indoor systems

An optical flame detection system shall be provided in rooms or areas where silane delivery systems are used. The flame detection system shall be approved for silane service. The flame detection system shall be located in accordance with 11.2.2.1 through 11.2.2.3 as appropriate. Optical flame detectors used indoors shall be tested for immunity to arc welding, artificial area lighting, or stray sources that are able to inadvertently trip a detector.

Alternatively, a temperature switch placed directly above individual gas cylinders is allowed to be used in lieu of the optical flame detection system.

11.2.2.1 Outside of gas cabinets

Optical flame detection systems shall be provided to detect a fire at potential leak points on the delivery system. Coverage shall be provided to address container connections, process gas and purge gas panels, and other potential leak points where unwelded fittings or connections are used.

11.2.2.2 Inside gas cabinets

An optical flame detection system shall be provided inside of gas cabinets to detect a fire within the cabinet.

11.2.2.3 Inside VMBs

An optical flame detection system shall be provided inside of VMBs to detect a fire within the VMB.

11.2.3 Shutdown requirements

Automatic shutdown of the silane delivery system is required whenever flame detection occurs. Whenever a shutdown action occurs as the result of optical flame detection, an alarm shall be transmitted to a constantly attended location on the premises so responsible parties will act on the alarm condition.

12 Fire protection system

12.1 General

Do not attempt to extinguish a silane flame. Shutting off the source of the gas is the preferred method of control. If shutdown is not practicable, let the fire burn until the container is either determined to be empty or the flame decreases to a point where shutoff is able to be achieved without endangering personnel. The container and associated equipment involved in a silane fire shall be cooled and the silane source isolated. Halogenated hydrocarbon fire extinguishers such as Halon™ or similar systems shall not be used on silane fires. Silane will react with Halon chemicals. The reaction has the potential to be violent. Fire extinguishing agents designed to deplete oxygen such as carbon dioxide shall not be used.

12.2 Outdoor systems

12.2.1 Deluge system

A manually activated deluge water spray fire protection system shall be provided to protect bulk silane delivery systems. In the event of fire, silane bulk sources shall be cooled if the source cannot be shut off since the continued leaking of silane is able to result in an explosion if the container ruptures.

12.2.1.1 Manual activation

Automatic deluge systems are allowed as an option to manual activation; however, automatic systems shall not be required.

12.2.1.2 System installation—seismic considerations

Systems shall be designed and installed in accordance with national codes. The system shall be designed to resist seismic forces.

12.2.1.3 Design density

The deluge system shall provide a minimum density of 0.30 gallons per minute per square foot (gpm/ft^2) (12 liters per minute per square meter [lpm/m^2]) for a minimum of a 2-hour duration over the external container surface areas including the silane cylinders, bulk containers, and process gas panels. The water spray shall be directed toward the walls of the containers for cooling as well as the valves and piping connections that represent a potential location for a leak to propagate.

12.2.1.4 Materials of construction

Sprinkler system piping shall be of metal construction. Joints used in the piping system shall be threaded or welded fittings. Clamped fittings with elastomeric seals shall not be used in portions of the system that are installed within 50 ft (15 m) of the silane bulk source.

12.2.1.5 Automatic shutdown

Activation of the water deluge system shall shut off the flow of gas at the bulk source.

12.2.2 Protection of structures

When the outdoor installation is located beneath a roof or canopy constructed as weather protection under the requirements of 6.2.1.1.2, an automatic fire extinguishing system shall be provided. The system design shall be not less than Extra Hazard Group 2 with a minimum design area of 2500 ft^2 (232 m^2). For more information, see NFPA 13, *Installation of Sprinkler Systems* [16] or equivalent national fire codes.**12.2.3 Fire hydrants**

A fire hydrant shall be located not greater than 150 ft (46 m) from a silane supply container.

12.3 Indoor systems

12.3.1 Gas cabinet sprinkler systems

Gas cabinets shall be provided with an automatic sprinkler equipped with a quick response sprinkler head positioned to keep the source cylinder cool but not to extinguish a fire in the cabinet. Water extinguishing systems shall be provided. Alternate fire extinguishing systems shall not be used.

12.3.2 Area sprinkler systems

Indoor rooms or areas where silane is stored or used shall be protected by an automatic sprinkler system. The design of the sprinkler system in storage rooms shall not be less than Extra Hazard Group 1 with a minimum design area of 2500 ft^2 (232 m^2). See NFPA 13 [16 or equivalent national fire codes].

13 Ventilation systems

13.1 Outdoor systems

13.1.1 Air flow requirements

Natural ventilation is allowed for outdoor storage and use installations providing the space is unconfined. See 3.20.1. An exception to this is when confined as described by 6.2.1.1.1, mechanical ventilation shall be provided in accordance with the requirements of 13.2.2.

13.1.2 Spacing between equipment

System design shall allow for the unrestricted natural flow of air between equipment to prevent accumulation of gas in the event of a silane release. See 6.2.1.1.

13.2 Indoor systems

A continuous mechanical exhaust ventilation system shall be provided in locations where cylinders are stored or connected for use.

13.2.1 Ventilation rate

Where silane is stored or used in a room without being placed in a gas cabinet or an exhausted enclosure, the room itself shall be exhausted at not less than 1 cubic foot per minute per square foot (300 lpm/m^2) of floor area or six changes per hour, whichever is greater.

A supply of outside air shall be used to replace the air removed by the mechanical exhaust system. The pressure in the room shall be maintained negative to the surrounding space.

13.2.2 System air flow requirement for unenclosed indoor installations

Containers connected for use located outside of gas cabinets or exhausted enclosures shall be provided with a mechanical ventilation system designed to dilute potential leakage from mechanical connections. The ventilation system shall direct a source of air across unwelded mechanical connections at a velocity of not less than 150 ft/min (0.8 meter/s). Recirculated air shall not be used as the source of forced, induced, or captured air to be directed across mechanical connections. System design shall promote ventilated airflow so the allotted spacing between equipment will not cause a restriction in the airflow in the event of a silane release.

13.2.3 System air flow requirement for ventilated enclosures, exhausted enclosures, and gas cabinets

Exhaust ventilation shall be used to prevent accumulation of silane resulting from a leak and to limit silane leak concentrations not more than 25% of the LFL(LEL). The LFL for silane under atmospheric conditions has been established as 1.37% by volume. The use of 25% of LFL results in a maximum concentration of 0.34% thereby providing a safety factor of four to one (4:1).

13.2.3.1 Determining minimum volumetric air flow

The minimum volumetric flow rate of ventilation air shall be in accordance with 13.2.3.1.

13.2.3.1.1 Standard silane volumetric flow rate, unattended operations

The standard silane volumetric flow rate for unattended operations shall be determined by the maximum flow rate of silane that can be discharged from the piping system into the enclosure. The flow rate is determined by the size of the RFO in the discharge line or cylinder valve at the maximum silane source pressure. For concentrations of silane less than a nominal 100%, the standard silane volumetric flow shall be determined based on the mole or volume fraction of silane present in the supply source. The minimum volumetric flow rate of air ventilation across unwelded fittings and connections at the silane source cylinder or the piping system shall not be less than the maximum silane volumetric flow rate multiplied by 300. For gas cabinets, the maximum silane volumetric flow rate is determined by the maximum flow through an RFO with a maximum source pressure on the inlet and 1 atmosphere on the outlet. This assumes a rupture of the connecting tubing or piping between the cylinder valve and the first point of pressure control within the delivery system. For a VMB or other enclosure, the maximum silane flow into the enclosure must be determined. The use of an RFO in the piping feeding the enclosure can be used to restrict the maximum flow into the enclosure.

Where mixtures of silane and other pyrophoric gases are present, the standard silane volumetric flow rate shall be determined by assuming that the combination of silane and other pyrophoric components is all silane. For typical flows see Table 5.

13.2.3.1.2 Minimum volumetric air flow rate for cabinets and enclosures, unattended operations

Table 5 illustrates the minimum volumetric flow rate of air as a function of RFO size and source pressure for four specific orifices typical of those used in conjunction with gas cabinets and VMBs. Regardless of the orifice used, the minimum volumetric flow rate of dilution air shall not be less than the standard silane volumetric flow rate multiplied by 300.

13.2.3.1.3 Standard silane volumetric flow rate, attended transfer operations

The standard silane volumetric flow rate used for attended transfer operations shall be determined by assuming discharge from a valve or fitting under the maximum silane source pressure through an opening with an RFO equivalent diameter of 0.006 in (0.15 mm). The RFO equivalent diameter shall be used to determine a theoretical leak recognizing that cylinders in the process of being filled or processed are not equipped with an RFO. For typical flows see Table 6.

Table 5—Minimum ventilation volumetric flow rate for gas cabinets and VMBs, unattended operations

Source pressure (psig)	Typical gas cabinet RFO 0.006 in diameter (0.15 mm diameter)		Typical gas cabinet RFO 0.010 in diameter (0.25 mm diameter)		Typical VMB RFO 0.014 in diameter (0.36 mm diameter)		Typical VMB RFO 0.020 in diameter (0.51 mm diameter)	
	Silane flow (scfm)	Ventilation flow (scfm)	Silane flow (scfm)	Ventilation flow (scfm)	Silane flow (scfm)	Ventilation flow (scfm)	Silane flow (scfm)	Ventilation flow (scfm)
50	0.025	8	0.069	21	0.136	41	0.288	86
100	0.045	14	0.124	37	0.243	73	0.497	149
200	0.085	26	0.237	71	0.465	140	0.949	285
400	0.173	52	0.480	144				
600	0.275	83	0.755	227				
800	0.395	119	1.08	324				
1000	0.555	167	1.51	453				
1200	0.724	217	1.97	591				
1500	0.913	274	2.50	750				
1650	0.987	296	2.70	810				

NOTES

1 Silane source temperature is 75 °F (24 °C).

2 RFO downstream pressure is 0 psig.

3 RFO discharge coefficient is 0.8.

4 To convert standard cubic feet per minute (scfm) to standard liters per minute (slpm), multiply by 28.32.

5 To convert psig to kPa, multiply by 6.895.

Table 6—Minimum ventilation volumetric flow rate for exhausted enclosures, attended operations

Source pressure (psig)	RFO equivalent 0.006 in diameter (0.15 mm diameter)	
	Silane flow (scfm)	Ventilation flow (scfm)
50	0.025	8
100	0.045	14
200	0.085	26
400	0.173	52
600	0.275	83
800	0.406	122

1000	0.568	170
1200	0.711	213
1500	0.852	256
1650	0.917	275

13.2.3.1.4 Minimum volumetric flow rate for exhausted enclosures, attended transfer operations

Table 6 illustrates the minimum volumetric flow rate of air as a function of an RFO equivalent diameter and source pressure. The minimum volumetric flow rate of dilution air shall not be less than the standard silane volumetric flow rate multiplied by 300.

13.2.3.2 Ventilation system design (pocketing)

Ventilation within enclosures shall be designed to eliminate dead zones and pocketing at potential leak sites.

13.2.4 Ventilation monitoring

Exhaust from gas cabinets, VMBs, exhausted enclosures, or room ventilation exhaust ducts shall be monitored to detect a failure in the ventilation system.

13.2.4.1 Loss of ventilation alarm

A failure in the ventilation system shall activate an alarm. Activation of the alarm shall initiate a local alarm and transmit a signal to a remotely located constantly attended location.

13.2.4.2 Isolation of gas supply

Loss of the ventilation system in gas filling rooms shall automatically cause the source of silane supply to be isolated from filling manifolds.

14 Venting and treatment

14.1 General

Requirements for venting and treatment of silane shall be limited to silane that is vented from process gas panels, VMBs, piping or equipment within the scope of this standard. See 2.1.2.

14.2 Disposal options

The majority of hazards associated with the use of a pyrophoric gas are fires or explosions. These hazards shall be analyzed when selecting a method of treatment for silane that will be released into the atmosphere during emergencies or when systems are purged. A number of methods of treatment are able to be used to reduce the risk of fire or explosion and still meet environmental protection requirements. Dilution with an inert gas followed by open-air disposal is one of the simplest methods when silane is not mixed with a toxic gas. This method is allowed to be used to dispose of small quantities of silane required at times when systems are purged of residual material. For example, the material left in a connecting pigtail that is purged before changing a cylinder can be vented without endangering personnel when well diluted. When dilution is not used, thermal oxidation or radio frequency (RF) plasma treatment, wet scrubbing with caustic soda, or other reactive media are allowable options.

14.3 Treatment system requirements

Treatment systems shall be designed for the use intended. They shall be designed to react with any silane or dilute it to allowable levels so it can be discharged without endangering facilities or personnel. The treatment system shall have the capacity to treat the flow of silane and any components of its mixtures expected under both operational and upset conditions. The potential presence of incompatible gases mixing in the treatment system shall be analyzed to ensure that the design will prevent an unanticipated chemical reaction that will result in an uncontrolled fire, explosion, or the release of a toxic gas. Inert gases shall be allowed to be used as a means to shield the silane from atmospheric oxygen.

14.4 Direct venting into exhaust ducts

Silane shall not be introduced into exhaust ventilation systems in concentrations that produce a fire or explosion within the exhaust system. A fire or explosion can occur due to autoignition of the silane itself, from the ignition of other flammables, or from a chemical reaction with incompatible materials within the exhaust system. When the ignition effects of silane in air is the only concern, the maximum permissible concentration allowed to be released into the duct system shall not be greater than 25% of the LFL or 0.34%. When exhaust systems have the potential to contain other gases or vapors, treatment systems to remove the other gases or vapors shall be provided so the discharge from the exhaust system meets the requirements of national regulations. See 4.3.1.

14.5 Dedicated process vent

Vent lines used for silane to be discharged from process gas panels shall be dedicated to lines that are used exclusively for silane service. Purging of silane vent lines is required to eliminate atmospheric oxygen from migrating into the silane vent system.

14.5.1 Continuous purge

Vent lines shall be purged continuously with an inert gas to prevent atmospheric oxygen from entering in the vent line with the vent line discharge directed to a treatment system. See 14.2. The minimum velocity of purge gas in the vent line system shall be 1 ft/s (0.3 m/s).

14.5.2 Restrictions in vent lines

Vent lines shall be designed for minimum pressure drop by minimizing the use of restrictions including elbows and similar fittings or reductions in the size of vent. When multiport vent line manifolds, silencers, or scrubbers are used, their contribution to vent line backpressure shall be analyzed. Isolation valves shall not be installed downstream of the purge line connection in the vent line.

14.5.3 Vent gas supply

The use of an inert gas such as nitrogen from nondedicated house gas supply systems is allowed providing the vent line system is continuously vented to atmosphere or otherwise arranged to preclude either the backflow of air or the development of backpressure at the point where the vent line is discharged. A purge gas flow with a minimum velocity of 1 ft/s (0.3 m/s) is required.

15 Purge gas system

15.1 Purging of the delivery system

Portions of the silane delivery system that will contain silane shall be purged with an inert or other gas to displace entrained air or other gases that will react under the conditions of use anticipated before the introduction of silane. The use of vacuum as the sole means to remove residual gases that may be entrained within the delivery system shall not be allowed. Vacuum systems shall be used in conjunction with a purge gas to rid the system of undesired atmospheres. Purging of the system shall be by manual or automatic means.

15.2 Dedicated purge source

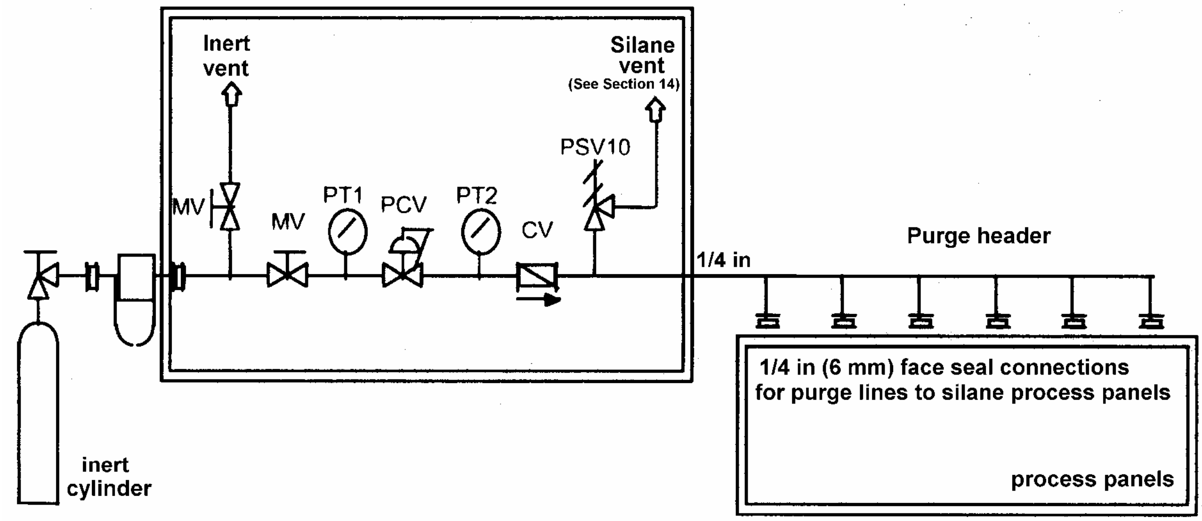
Purge gas used for the purging of silane delivery system piping and components shall be supplied from a dedicated inert gas supply source. A purge gas manifold shall be provided when one inert purge gas cylinder or supply is used as the common purge gas source for multiple silane systems.

15.2.1 Limitations on source of purge gas

House gas supplies shall not be used for purging silane delivery systems due to the risk of back flow into the house gas supply. An exception is made for vent lines from process gas panels when in accordance with the requirements of 14.5.

15.2.2 Protection of the purge gas source

The purge gas source shall be provided with controls to prevent silane from entering the purge gas supply. See Figure 9.



NOTE—The purge gas panel is allowed to be connected to one or more process gas panels with the purge header. Figure 9 has been provided to illustrate the concepts described in the text of the standard. The figure is schematic in nature. It is neither to be interpreted as a design document nor is it intended to restrict alternate designs. For instrument nomenclature, see Figure 1.

Figure 9—Inert purge gas flow schematic

15.3 Controls

The inert gas purge system shall be equipped with a dedicated inert gas supply or source, a pressure regulator, an overpressure relief device, a check valve, and a low purge gas pressure alarm system.

15.3.1 Backflow prevention

Backflow prevention shall be provided on purge gas supply lines to ensure that a potential backflow of silane does not contaminate the dedicated purge gas source. The check valve (CV) and pressure relief valve (PSV10) shown in Figure 9 are used as safeguards to prevent a silane backflow if that silane is fed back into the purge gas system. The PSV10 serves as a redundant feature to protect the CV from overpressure. Electronic interlocks and engineering controls are allowed to be used to prevent backflow. One example is to automatically isolate the purge process if the purge gas pressure is at or below the silane source pressure.

15.3.2 Low pressure alarm

A low pressure alarm system shall be provided to indicate low pressure on the purge gas source of supply. Indication of a low pressure condition shall activate an audio and/or visual local alarm. Low pressure shall be determined by the system designer and is dependent in part with performance of the system. The primary purpose of purge gas source is to purge atmospheric gases from the system and low pressure is determined to be a pressure less than that required for operation of the system. When purge gas is used for purposes of leak checking the system, the minimum purge gas pressure shall not be less than the highest pressure that the component being leak checked will be exposed to under operating conditions.

15.3.3 Pneumatic line source

An inert gas or supply of clean compressed air is required for the operation of pneumatic valves used to operate the purge gas system. Although interruption of the inert gas or compressed air supply ordinarily poses no threat to contamination of the silane system, overpressurization of valve operators is of concern. The pneumatic supply pressure shall be pressure regulated and overpressure protection shall be provided to protect the system component with the lowest working pressure in the system served.

15.4 Vacuum generator purge gas source

When vacuum generators or vacuum venturis are used to produce the vacuum needed for evacuation/purge cycles in silane systems, nitrogen or other inert gas shall be used to provide the motive force necessary to generate the vacuum. Vacuum venturis require high volumetric flow rates (~100 lpm) supplied at modest pressures (~100 psig [690 kPa]) to generate the vacuum needed for clearing systems of silane. See Figure 5.

15.4.1 Source of purge gas used for vacuum venturi systems

The use of facility or house nitrogen shall be allowed as a means to operate vacuum venturi systems connected to the silane venting system. See 14.5.

15.4.2 Backflow prevention at venturi supply

When inert house gas supplies are used to operate vacuum venturi systems, the house gas supply system shall be protected against backflow with a check valve and a pressure relief device located at the connection where the inert gas source is introduced to the vacuum venturi. See Figure 5.

16 Electrical requirements

16.1 General

Electrical systems and components shall comply with the equivalent national standard that meets the requirements of the United States *National Electrical Code*® (NEC) [17]. In case of use of the NEC code, regardless of the provisions in NEC Section 500-2 that allow the use of unclassified electrical equipment where pyrophoric materials are used, electrical equipment shall be classified in accordance with the requirements of Tables 7 and 8.

Table 7—Indoor electrical requirements for silane systems containing silane in concentrations exceeding 1.37% by volume

Indoor installations	Classification	Conduit seals	Purging of control enclosure	Uninterruptible power supply (UPS)
Where electrical enclosure interfaces with a gas cabinet.	Unclassified	Per NEC 501-5(b). Conduits used to join a control box to a gas cabinet shall be sealed.	Purging of the electrical control panel cabinet is required. Purging is allowed to be by means of an inert gas or fresh air supply.	A UPS system shall be provided for required controls that are electrically powered, i.e., gas monitoring system, fire detection system, etc. Mechanical systems shall be provided with an emergency power system in lieu of UPS.
Within gas cabinets.	Class I, Division 2	Per NEC 501-5(b). Conduits used to join a control box to a gas cabinet shall be sealed.		

Indoor installations	Classification	Conduit seals	Purging of control enclosure	Uninterruptible power supply (UPS)
Where electrical enclosures are located within 5 ft (1.5 m) of unwelded silane pipe fittings.	Class I, Division 2 within 5 ft (1.5 m) of enclosure	Conduit seals are required on the electrical enclosure side of the conduit.	Air intakes for the fresh air supply shall be located to prevent migration of unreacted silane into the controller.	The required controls shall remain powered through a power failure or a controller shutdown.
Where other hazardous gases are in the vicinity.	As required for other gases in accordance with NEC Section 500-2.	Conduit seals are required on the electrical enclosure side of the conduit. If gases in the area require classification then conduit seals shall be per requirement of NEC classification.	Additional purging if required per electrical classification.	

Table 8—Outdoor electrical requirements–silane systems containing silane in concentrations exceeding 1.37% by volume

Outdoor installations	Classification	Conduit seals	Purging of control enclosure	Uninterruptible power supply (UPS)
General	Classified Class I, Division 2 within 5 ft (1.5 m) of points of connection, otherwise unclassified.	Conduit seals are allowed to be used; however, they do not always function as intended since silane is capable of dispersing into the surrounding area.	Purging of the electrical control panel cabinet is required when panels are located within 5 ft (1.5m) of points of connection to the gas distribution system. Purged enclosures shall be in accordance with the requirements of NFPA 496, *Standard for Purged and Pressurized Enclosures for Electrical Equipment* [18].	A UPS system shall be provided for required controls that are electrically powered, i.e., fire detection systems, etc. These devices shall remain powered through a power failure or a controller shutdown. Mechanical systems shall be provided with an emergency power system in lieu of UPS.
Where other hazardous gases are in the vicinity.	Other gases in the area are able to require classification per NEC Section 500-2. If other gases in the area require classification then the area shall be classified.	If gases in the area require electrical classification then conduit seals shall be as required by the NEC.		

16.2 Indoor electrical systems

Electrical equipment in indoor areas where silane systems are located shall be in accordance with the requirements of Table 7.

16.3 Outdoor electrical systems

Electrical equipment in outdoor areas where silane systems are located shall be in accordance with the requirements of Table 8. Bulk sources shall be grounded to earth before and during connection to the silane delivery system.

17 Fundamental supervisory control requirements

17.1 Indoor requirements

Supervisory control systems for silane delivery systems used indoors shall be in accordance with Table 9.

17.2 Outdoor requirements

Supervisory control systems for silane delivery systems used outdoors shall be in accordance with Table 10.

Table 9—Indoor requirements for supervisory control
Silane systems containing silane in concentrations exceeding 1.37% by volume

Indoor installations	Exhaust monitoring	Gas monitoring (See 11.1)	Flame detection (See 11.2)	Emergency shutoff (See 10.2.3)
Gas cabinet	Alarm on loss of exhaust. Source shutdown on loss of exhaust NOT required.	Gas monitor required inside gas cabinet. Source shutdown on activation of gas monitor.	An optical flame detection system or temperature switch required in gas cabinet. Source shutdown on fire detection.	Emergency shutdown controls shall be provided outside each exit.
Silane piping systems with unwelded connections in other than coaxial piping systems		Area monitors required in room.	An optical flame detection system is required. Temperature switch not recommended. Source shutdown on fire detection.	
VMB		Gas monitor required inside VMB. Manifold branch shutdown on activation of gas monitor.	An optical flame detection system or temperature switch required in VMB. Manifold branch shutdown on fire detection.	

Table 10—Outdoor requirements for supervisory control
Silane systems containing silane in concentrations exceeding 1.37% by volume

Outdoor installations	Exhaust monitoring	Gas monitoring (See 11.1)	Flame detection (See 11.2)	Emergency shutoff (See 10.2.3)
General	Forced ventilation is NOT required.	Gas monitoring is NOT required.	Fire detection is required. Source shutdown on fire detection.	ESO controls shall be provided at each exit. Shutoff controls shall be located not less than 15 ft (4.6 m) from the supply system.

18 References

Unless otherwise specified, the latest edition shall apply.

[1] *Ignition Characteristics of Releases of 100% Silane,* Technology Transfer #96013067A-ENG, SEMATECH Technology Transfer, Austin, TX, March 7, 1996. www.sematech.org

[2] *Large Scale Silane Release Tests,* Arthur D. Little, Inc., Cambridge, MA., Reference 58339 under contract to the Compressed Gas Association, Chantilly, VA, February, 1998. Available from CGA, 4221 Walney Rd., 5th Floor, Chantilly, VA 20151. www.cganet.com

[3] Britton, L.G., "Combustion Hazard of Silane and Its Chlorides," paper 12b, AIChE Spring National Meeting, 1989, American Institute of Chemical Engineers, Three Park Ave., New York, NY 10016. www.aiche.org (available from Linda Hall Library, 5109 Cherry St., Kansas City, MO 64110. www.lindahall.org)

[4] CGA P-11, *Metric Practice Guide for the Compressed Gas Industry*, Compressed Gas Association, Inc., 4221 Walney Rd., 5th Floor, Chantilly, VA 20151. www.cganet.com

[5] *Code of Federal Regulations*, Title 49 (Transportation) Parts 100-180, Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402. www.gpoaccess.gov

[6] CGA V-1, *Standard for Compressed Gas Cylinder Valve Outlet and Inlet Connections,* Compressed Gas Association, Inc., 4221 Walney Rd., 5th Floor, Chantilly, VA 20151. www.cganet.com

[7] *Documentation of the Threshold Limit Values and Biological Exposure Indices,* American Conference of Governmental Industrial Hygienists, 1330 Kemper Meadow Dr., Cincinnati, OH 45240. www.acgih.org

[8] E.H. Vernot, J.D. MacEwen, C.C. Haun and E.R. Kinkead, "Acute toxicity and skin corrosion data for some organic and inorganic compounds and aqueous solutions," *Toxicology and Applied Pharmacology*, Volume 42, Issue 2, November 1977, Pages 417-423. www.sciencedirect.com

[9] *Documentation of the Threshold Limit Values for Chemical Substances*, American Conference of Governmental Industrial Hygienists, 1330 Kemper Meadow Dr., Cincinnati, OH 45240. www.acgih.org

[10] CGA V-7, *Standard Method of Determining Cylinder Valve Outlet Connections for Industrial Gas Mixtures*, Compressed Gas Association, Inc., 4221 Walney Rd., 5th Floor, Chantilly, VA 20151. www.cganet.com

[11] CGA S-1.1, *Pressure Relief Device Standards–Part 1–Cylinders for Compressed Gases*, Compressed Gas Association, Inc., 4221 Walney Rd., 5th Floor, Chantilly, VA 20151. www.cganet.com

[12] CGA S-1.2, *Pressure Relief Device Standards–Part 2–Cargo and Portable Tanks for Compressed Gases*, Compressed Gas Association, Inc., 4221 Walney Rd., 5th Floor, Chantilly, VA 20151. www.cganet.com

[13] CGA S-7, *Method for Selecting Pressure Relief Devices for Compressed Gas Mixtures in Cylinders,* Compressed Gas Association, Inc., 4221 Walney Rd., 5th Floor, Chantilly, VA 20151. www.cganet.com

[14] ASME B31.3, *Process Piping*, ASME International, Three Park Ave., New York, NY 10016. www.asme.org

[15] ASME A13.1, S*cheme for the Identification of Piping Systems*, ASME International, Three Park Ave., New York, NY 10016. www.asme.org

[16] NFPA 13, *Installation of Sprinkler Systems,* National Fire Protection Association, 1 Batterymarch Park, Quincy, MA 02269. www.nfpa.org

[17] NFPA 70, *National Electrical Code*®, National Fire Protection Association, 1 Batterymarch Park, Quincy, MA 02269. www.nfpa.org

[18] NFPA 496, *Standard for Purged and Pressurized Enclosures for Electrical Equipment,* National Fire Protection Association, 1 Batterymarch Park, Quincy, MA 02269. www.nfpa.org

[19] API RP 521, *Guide for Pressure-relieving and Depressuring Systems,* American Petroleum Institute, 1220 L St., NW, Washington, DC 20005. www.api.org

[20] *Techniques for Assessing Industrial Hazards – A Manual*, The World Bank, 1818 H Street, NW, Washington, DC 20433. www.worldbank.org

[21] *Combustion Hazards of Silane and Its Chlorides*, L.G. Britton, Plant/Operations Progress, Vol. 9, No. 1, January 1990.

[22] CGA S-1.3, *Pressure Relief Device Standards–Part 3–Stationary Storage Containers For Compressed Gases,* 4221 Walney Rd., 5th Floor, Chantilly, VA 20151. www.cganet.com

19 Additional references

CGA V-5, *Diameter Index Safety System (Noninterchangeable Low Pressure Connections for Medical Gas Applications),* Compressed Gas Association, Inc., 4221 Walney Rd., 5th Floor, Chantilly, VA 20151. www.cganet.com

AICHE G-42, *Guidelines for Chemical Process Quantitative Risk Analysis,* Center for Chemical Process Safety, American Institute of Chemical Engineers, 3 Park Ave., New York, NY 10016. www.aiche.org

AICHE G-9, *Guidelines for Evaluating the Characteristics of Vapor Cloud Explosions*, *Flash Fires, and BLEVEs,* Center for Chemical Process Safety, American Institute of Chemical Engineers, 3 Park Ave., New York, NY 10016. www.aiche.org

NFPA 318, Standard for the Protection of Semiconductor Fabrication Facilities, National Fire Protection Association, 1 Batterymarch Park, Quincy, MA 02269. www.nfpa.org

Property Loss Prevention Data Sheet 7-7/17-12, *Semiconductor Fabrication Facilities,* FM Global, 1301 Atwood Ave., P.O. Box 7500, Johnston, RI 02919. www.fmglobal.com

Property Loss Prevention Data Sheet 7-42, *Guidelines for Evaluating the Effects of Vapor Cloud Explosions Using a TNT Equivalency Method*, FM Global, 1301 Atwood Ave., P.O. Box 7500, Johnston, RI 02919. www.fmglobal.com

HUD-1060-CPD, *Siting of HUD-Assisted Projects Near Hazardous Facilities: Acceptable Separation Distances from Explosive and Flammable Hazards*, U.S. Department of Housing and Urban Development, 451 7th St. SW, Washington, DC 20410. www.hud.gov

SEMI S18-1102, *Environmental, Health, and Safety Guideline for Silane Family Gases Handling*, Semiconductor Equipment and Materials International (SEMI®), 3081 Zanker Road, San Jose, CA 95134. www.semi.org

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Appendix A—Personnel protection
(Informative)

A1 Personal protective equipment

Whenever an operator is separated from a silane system by less than two barriers, personal protective equipment (PPE) is required. Examples of two barriers are the container vessel and piping as a primary barrier, and a gas cabinet, fenced off area, or separation distance as a secondary barrier. If silane is in a mixture with a toxic gas, guidelines for the toxic gas shall be followed and additional PPE will be required.

A1.1 PPE for routine system operation

Minimum PPE requirements for operations that involve opening and closing of valves or any work within a 15 ft (4.6 m) vicinity of a silane storage or use system include the following:

- hard hat;
- safety glasses;
- leather gloves;
- fire resistant clothing/coveralls; and
- safety shoes.

A1.2 PPE for opening of process lines

Minimum PPE requirements for operations that involve opening of process lines and equipment in a silane system (e.g., cylinder change out, breaking fittings on a process line for maintenance, etc.) include the same equipment as in A.1.1 plus the following:

- fire resistant hood;
- face shield;
- hearing protection (e.g., ear plugs or ear muffs); and
- provision of a nitrogen shield across the outside of the fitting or a helium purge through the fitting (purge ports) to shield the fitting from exposure to atmosphere.

A1.3 PPE for emergency operations

PPE for emergency response includes:

- NFPA-approved firefighter turnout gear;
- firefighting gloves;
- fire helmet with face shield;
- fire resistant hood; and
- self-contained breathing apparatus (SCBA).

Minimum of two people, shall respond to emergency situations that include firefighting, silane source isolation, or personnel rescue. Any persons responding to an emergency shall be trained in emergency response, proper use of emergency response PPE, and other emergency response equipment.

A2 Training

Persons responsible for the operation of the silane system or storage shall be knowledgeable of the physical and chemical nature of silane and the mitigating actions necessary in the event of fire, explosion, or leakage before being qualified to operate the system. They shall be trained in the operation of the system and associated controls, alarms, and indications. Responsible persons shall be designated and trained to be liaison personnel for the fire department. These persons shall aid the fire department in preplanning emergency responses and identification of the locations where silane is located. They shall have access to the material safety data sheet (MSDS) and knowledge in the site emergency response procedures. Operator competence shall be retested annually or when job assignments are changed.

A3 Emergency procedures

Whenever a leak is discovered downstream of the silane source, the best emergency procedure is to shut off the supply of silane at the source or to isolate the leak as close to the source as practicable. When source isolation is the desired emergency procedure but direct access to the source primary control valve is not possible, shutoff shall be accomplished with a remotely operated valve. When a leak is discovered at the connection of the cylinder valve to the silane source or anywhere on the source valve itself, the source cylinder or container shall be cooled until the release has subsided after which a containment vessel or exhausted enclosure shall be provided. The cylinder or container will be placed inside the enclosure using trained personnel and approved procedures. Once sealed and secured, the enclosure is able to be removed from site. Leaking or defective cylinders or containers shall be returned to the supplier for proper disposal or repair.

A4 Operations and maintenance

Trained personnel who have demonstrated understanding and competence in the operations they will perform shall perform all operations and maintenance of silane systems. Training shall be specific for the systems involved and include the use of written procedures that describe the operations to be conducted. Competence in system operation shall be demonstrated by the use of written tests as well as associated hands-on work.

A4.1 Operational instructions

There shall be printed operating instructions maintained at the operating location. Operating procedures shall be written and approved by knowledgeable personnel or persons knowledgeable of the hazards of silane, the function and use of equipment, and controls as well as with the facility in which the system is installed.

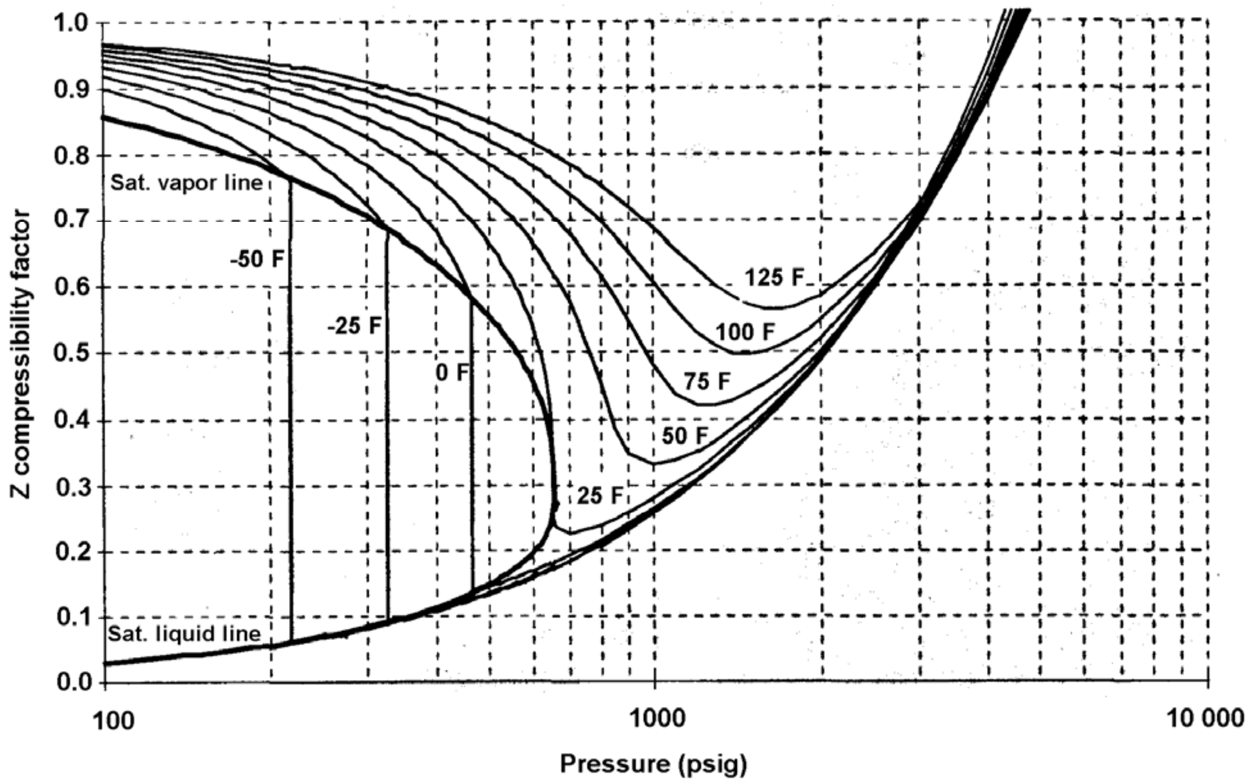
A4.2 Maintenance

Silane supply systems shall be inspected regularly for signs of leakage. A maintenance program shall be set up for the inspection, calibration, or replacement of wearing components such as valves, regulator, pressure transducers/gauges/switches, and flow switches. Defective components shall be replaced immediately. Maintenance procedures shall be written and approved by persons knowledgeable concerning the hazards of silane, the function and use of equipment and controls, and the facility in which the system is installed. Detection and alarm systems shall be maintained in operating condition. Weeds and long dry grass shall be cut and maintained within 15 ft (4.6 m) of outdoor supply systems.

A5 MSDS

Persons working with or around silane shall be knowledgeable with and understand the contents of the supplier’s MSDS.

Appendix B—Silane compressibility
(Informative)



Appendix C—Thermal radiation (Normative)

Thermal radiation kW/m²	Exposure	Minimum distance to exposure ft (m)							
		Cylinders [1] ≤ 600 ft³ (17 m³)		Cylinders 601 to 2500 ft³ (71 m³)		Cylinders 2501 to 10 000 ft³ (283 m³)		450 L cylinder [2] ≤ 10 000 ft³ (283 m³)	
		ft	(m)	ft	(m)	ft	(m)	ft	(m)
1.6	Location where personnel with protective clothing are allowed to be continuously exposed [19].	16	(5)	30	(9)	50	(15)	60	(18)
4.7	Heat intensity where emergency actions lasting up to three minutes is required [19].	12	(4)	20	(6)	30	(9)	50	(15)
6.3	Heat intensity in areas where emergency actions lasting up to 1 minute is required [19].	10	(3)	16	(5)	25	(8)	45	(14)
9.5	Heat intensity at any location where people have access – exposure limited to up to ten seconds, used for escape only [19].	8	(2.4)	15	(5)	23	(7)	40	(12)
15.8	Heat intensity on structures and in areas where operators are performing duties. Shelter from radiant heat is provided [19].	8	(2.4)	12	(4)	20	(6)	40	(12)
37.5	Damage to process equipment [20].	8	(2.4)	10	(3)	12	(4)	40	(12)

NOTE—The data in this thermal radiation table is based on a model with the following assumptions:

- Three nested volumes 600 ft³ (17 m³), 2500 ft³ (71 m³), and 10 000 ft³ (283 m³) for 44 L-size cylinders and one nest size of 10 000 ft³ for 450 L-size cylinders were evaluated.
- Silane released through the rupture disk and exits through two 1-in (25 mm) holes in the cylinder cap. The jets exiting the cylinder cap were assumed to be horizontal.
- The average release rate of a cylinder at 165° F (74 °C) was used in the radiation calculations since the relieving cylinders are expected to be at different stages of venting. Approximate release time for one cylinder is 2 min. The accuracy of the silane radiation calculations was verified by comparison with experimental radiation data [21].
- A low wind speed was selected to provide the maximum radiation.
- Calculations were made for cylinders at 1000 psig (6900 kPa), 1500 psig (10 340 kPa), and 1650 psig (11 380 kPa), and the worst case was listed in the table.
- 50% of the cylinders in the nested volume were assumed to be relieving at one time. The relieving cylinders were those closest to the receptor. The radiation was corrected for the location of cylinders, which were tightly packed.

1) The definition for “cylinders” as it applies to this table is compressed gas cylinders with an internal volume of 1.8 ft³ (50 L) or less.

2) The definition for “450 L cylinder” as it applies to this table is compressed gas cylinders with an internal volume of 16 ft³ (450 L) or less.

Appendix D—Overpressure
(Normative)

Over-pressure Psi (kPa)	Minimum distance to exposure ft (m)													
	PRD with ≤ 0.375 in (10mm) orifice				PRD with > 0.375 in (10mm) to ≤ 0.5 in (13 mm) orifice				PRD with > 0.5 in (13mm) to ≤ 1 in (25 mm) orifice					
	1000 psig (6900 kPa)		1600 psig (11 030 kPa)		1000 psig (6900 kPa)		1600 psig (11 030 kPa)		600 psig (4140 kPa)		1000 psig (6900 kPa)		1600 psig (11 030 kPa)	
	ft	(m)	ft	(m)	ft	(m)	ft	(m)	ft	(m)	ft	(m)	ft	(m)
0.5 (3)	105	(32)	175	(53)	140	(43)	225	(69)	175	(53)	275	(84)	450	(137)
1 (7)	65	(20)	110	(34)	80	(24)	145	(44)	110	(34)	180	(55)	300	(91)
2 (14)	40	(12)	65	(20)	50	(15)	90	(27)	65	(20)	100	(30)	165	(50)
3 (21)	30	(9)	50	(15)	40	(12)	70	(21)	50	(15)	80	(24)	140	(43)
4 (28)	25	(8)	45	(14)	35	(11)	55	(17)	45	(14)	65	(20)	115	(35)
5 (34)	23	(7)	35	(11)	30	(9)	50	(15)	35	(11)	60	(18)	100	(30)
6 (41)	20	(6)	30	(9)	25	(8)	40	(12)	30	(9)	50	(15)	80	(24)

NOTES

1 The data in this overpressure table is based on a model and validated by large scale testing as described in *Large Scale Silane Release Tests* [2]. This table can be used as a guideline for design and layout of equipment, structures, and exposures. There are a number of references that are able to be used to evaluate the effect of overpressure caused by a vapor cloud explosion. See Section 18. The following assumptions were made:

- Silane release is through the PRD on the container with the pressure in the container as indicated in the table;
- The PRD shall be in compliance with CGA S-1.1 and CGA S-1.3 [11, 22]
- The silane release produces a vapor cloud explosion (does not spontaneously ignite upon release).
- The model that generated the data in this table used a yield factor of 1 for the purposes of calculating overpressure. A yield of 1 is conservative relative to the actual test data.

2 The most common orifice size found in PRDs in current use on tube trailers and ISO modules is 0.87 in (22 mm) diameter. The size of the orifice shall be determined in accordance with the requirements of pressure relief device standards [11].

3 This table shall not apply to high pressure piping. Engineering evaluation shall be provided to predict releases from piping systems and the resultant potential overpressure or thermal radiation. The rate of release shall be determined by intrinsic factors including but not limited to system pressure, valve orifice size friction loss, and tubing volume.

The following graphs have been created from the data presented in Appendix D.