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**4<sup>TH</sup> EDITION**

# STORAGE AND HANDLING OF SILANE AND SILANE MIXTURES



## PREFACE:

As part of a program of harmonization of industry standards, the Compressed Gas Association (CGA) has published CGA G-13, *Storage and Handling of Silane and Silane Mixtures*, jointly produced by members of the International Harmonization Council.

This publication is intended as an international harmonized standard for the worldwide use and application of all members of the Asia Industrial Gases Association (AIGA), Compressed Gas Association (CGA), European Industrial Gases Association (EIGA), and Japan Industrial and Medical Gases Association (JIMGA). Each association's technical content is identical, except for regional regulatory requirements and minor changes in formatting and spelling.

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NOTE—Appendices A, B, and C (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, video display manufacturers, producers of solar cells, and allied technologies. Systems once imagined to be rare are now commonplace and are in use worldwide. Hazards of this material are noteworthy due to the ability of this material to self-ignite with visible flame upon release or in other cases to be released with either no ignition or delayed ignition. This material has been the subject of technical study by users and suppliers [1].<sup>1</sup> 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, 3, 4]. 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 lessen 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 these 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.

It is intended that this standard applies to storage and use of silane containers with the exception of small containers with 0.5 scf (14 L) or less of silane content.

## 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. 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 this standard apply to pure silane and silane mixtures with a silane content greater than 1.4% by volume [5]. A concentration of 1.4% has been chosen as it represents the lower flammability limit (LFL) for this material in air under conditions of normal temperature and pressure. Silane containers include tube trailers, International Organization for Standardization (ISO) modules, cylinder packs with manifolded cylinders, and individual cylinders. Silane mixes containing other hazardous components (e.g., toxics) may have additional requirements beyond this standard. These other requirements shall also be taken into consideration and may exceed requirements in this standard.

#### 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.

The following subjects are outside the scope of this standard:

- Equipment downstream of a gas cabinet with the exception of valve manifold boxes (VMBs) when used;
- Off-site transportation of compressed gases regulated by the U.S. Department of Transportation (DOT), European Agreement concerning the International Carriage of Dangerous Goods by Road (ADR), or other regulatory authorities; and
- Requirements within the jurisdiction of local, state, provincial/territorial, and 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 (AHJ) be guided by this standard in determining requirements.

<sup>1</sup> References are shown by bracketed numbers and are listed in order of appearance in the reference section.

This standard is not intended to replace or fulfill the requirements of a Risk Management Plan (RMP) as mandated under Section 112(r) of the *Clean Air Act*, generally referred to as the Environmental Protection Agency (EPA) RMP rule. A full RMP is comprised of a hazard assessment, a management system, a prevention program, and an emergency response program. Such programs and assessments shall be developed on a case-by-case basis in response to the requirements of the RMP 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 AHJ.

## 3 Definitions

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

### 3.1 Publication terminology

#### 3.1.1 Shall

Indicates that the procedure is mandatory. It is used wherever the criterion for conformance to specific recommendations allows no deviation.

#### 3.1.2 Should

Indicates that a procedure is recommended.

#### 3.1.3 May

Indicates that the procedure is optional.

#### 3.1.4 Will

Is used only to indicate the future, not a degree of requirement.

#### 3.1.5 Can

Indicates a possibility or ability.

### 3.2 Technical definitions

#### 3.2.1 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.

#### 3.2.2 Barrier, shield

Partition constructed of materials to isolate the hazard from contact with personnel.

NOTE—Barriers are designed with structural strength and arranged to resist physical forces.

NOTE—See Appendix A for information on personnel protection.

#### 3.2.3 Burning velocity

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

### 3.2.4 Container

#### 3.2.4.1 Cylinder

Seamless pressure vessel having a nominal water capacity up to 50 L.

##### 3.2.4.1.1 Cylinder packs

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.

For silane service, each cylinder shall be fitted with an individual shutoff valve. The frame system is allowed to be on skids or wheels to permit movement.

##### 3.2.4.1.2 ISO module

Multi-modal assembly of cylinders, tubes, or bundles of cylinders that are interconnected by a manifold and assembled within an ISO frame. An ISO module is sometimes referred to as an MEGC.

NOTE—The ISO module includes service equipment and structural equipment necessary for the transport of gases. The frame of an ISO module and its corner castings are specially designed and dimensioned for use in multi-modal transportation service on container ships, special highway chassis, and container-on-flatcar railroad equipment.

##### 3.2.4.1.3 Multiple-element gas container (MEGC)

Assembly of cylinders, tubes, or bundles of cylinders that are interconnected by a manifold and are assembled within an ISO frame.

NOTE—The MEGC module includes service equipment and structural equipment necessary for the transport of gases.

#### 3.2.4.2 Packages greater than 50 L

Any individual or manifolded collection of seamless pressure vessel(s) having a collective nominal water capacity greater than 50 L.

NOTE—These can include an ISO module, MEGCs, tubes, tube trailers, cylinder packs, nominal 450 L (ton tank), or other packages as defined by regulations or codes.

##### 3.2.4.2.1 Ton tank(s)

Seamless pressure vessel having a nominal water capacity of 450 L.

##### 3.2.4.2.2 Tube trailers

Truck or semitrailer on which a number of tubes have been mounted and manifolded into a common piping system.

##### 3.2.4.2.3 Tubes

Seamless pressure vessel having a nominal water capacity exceeding 150 L but not more than 3000 L.

### 3.2.5 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.

NOTE—A deflagration will have an explosive effect.

### 3.2.6 Detonation

Exothermic reaction characterized by the pressure of a shock wave in material that establishes and maintains the reaction.

NOTE—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.

### 3.2.7 Emergency response containment vessel (ERCV)

Nationally or regionally approved pressure vessel used to contain leaking gas cylinders for transportation.

**3.2.8 Emergency shutoff (ESO)**

Valve that provides source isolation and stops the flow of gas at the source and has the same function as an automated cylinder valve (ACV) or automated shutoff valve (ASV).

**3.2.9 Exhausted enclosure**

Appliance or piece of equipment that consists of a top, a back, and at least two sides providing a means of local exhaust for capturing gases and vapors.

**3.2.10 Explosion control**

Means to either prevent or mitigate the effects of an explosion.

NOTE—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.

**3.2.11 Face seal fitting**

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

**3.2.12 Fire barrier**

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

**3.2.13 Fire partition**

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

**3.2.14 Flame speed**

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

**3.2.15 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.

**3.2.16 Gas cabinet**

Fully enclosed, noncombustible enclosure used to provide an isolated environment for compressed gas cylinders in storage or use.

NOTE—Doors and access ports for exchanging cylinders and accessing pressure regulating controls are allowed to be included.

**3.2.17 Gas filling room**

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

**3.2.18 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.

**3.2.19 Incompatible materials**

Incompatible materials are defined by the following hazard class; toxic/highly toxic, pyrophoric, flammable, oxidizing, corrosive, combustible liquids, and unstable reactive Class 2, Class 3, and/or Class 4.

NOTE—Gases not in these hazard classes such as inert gas are not considered incompatible and separation distances do not apply.

**3.2.20 Instrument nomenclature**

See Figure 1.

|                                                                                     |                                           |
|-------------------------------------------------------------------------------------|-------------------------------------------|
|    | burst disk                                |
|    | process heater                            |
|    | auto valve with constant purge            |
|    | auto valve                                |
|    | control valve self-contained (regulator)  |
|    | manual valve                              |
|    | excess flow valve (or excess flow switch) |
|    | check valve                               |
|    | auto valve 3-port (dark leg on/off)       |
|    | filter                                    |
|   | pressure gauge or transducer              |
|  | pressure safety valve                     |
|  | restricted flow orifice                   |
|  | pigtail                                   |
|  | manual cylinder valve                     |
|  | cylinder valve with automatic shutoff     |
|  | vacuum venturi                            |

**Figure 1—Instrument nomenclature**

### 3.2.21 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.

NOTE—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.

### 3.2.22 Location

#### 3.2.22.1 Indoor

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

### 3.2.22.2 Outdoor

Location that is either:

- Outside the confines of a building; or
- Sheltered from the elements by overhead cover (roof) and is protected from weather exposure by not more than three detached walls so the roof and walls are separated from one another with adequate space between the walls and between the walls and the roof structure, thereby reducing the possibility of confinement or accumulation of silane if there is a leak.

NOTE—The open space can be constructed of chain link fencing or a similar open structure that does not restrict airflow.

### 3.2.23 Nitrogen, facility or house

Supply of nitrogen that is used for utilities and general purposes.

NOTE—It is usually supplied from an on-site air separation plant, liquid nitrogen tank, or other sources. It is piped to use points throughout the facility. Use of nitrogen for utilities and general purpose that is not greater than or equal to 99.998% pure can lead to silane purity and system reliability issues.

### 3.2.24 Operations

#### 3.2.24.1 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 when the operation occurs.

#### 3.2.24.2 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.

#### 3.2.24.3 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.

### 3.2.25 Panel

#### 3.2.25.1 Panel, control

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.

#### 3.2.25.2 Panel, process

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

#### 3.2.25.3 Panel, purge

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.

### 3.2.26 Parts per million (ppm)

Concentration of a gas in ppm as opposed to expressing the concentration in terms of volume or mole percent.

NOTE—One molar ppm or one ppm by volume is equal to 0.0001%.

**3.2.27 Pigtail**

Relatively short and semiflexible section of connecting piping or tubing that is used to connect a compressed gas source to the piping system.

NOTE—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 container, 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.

**3.2.28 Piloted ignition**

Ignition by application of a pilot flame.

NOTE—By comparison, ignition without a pilot energy source is referred to as autoignition, self-ignition, or spontaneous ignition.

**3.2.29 Pressure relief device (PRD)**

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 the AHJ.

NOTE—PRD is synonymous with “safety relief device” as used in transportation regulations.

**3.2.30 Purging**

Replacement of the atmospheric contamination or process gas in a piping system using a nonreactive gas.

NOTE—Purging may also be used for dilution inside enclosures housing mechanical or electrical connections by the introduction of a controlled atmosphere consisting of a nonreactive gas or fresh air as well as to prevent potential ingress of a process gas.

**3.2.31 Rack system**

Unenclosed silane process gas panel and purge gas panel mounted to a support structure used with silane containers.

NOTE—It is designed for unconfined open ventilation, as opposed to the confinement provided in ventilated gas cabinets.

**3.2.32 Remotely located, manually activated shutdown control**

Control system that is designed to start shutdown of the flow of gas and is activated from a point located some distance from the delivery system.

**3.2.33 Silane systems and sources****3.2.33.1 Silane**

Silane and silane in combination or mixed with other gases where the concentration of silane exceeds 1.4% (LFL) by volume.

**3.2.33.2 Silane, bulk source**

Container or interconnected group of containers with a water volume exceeding 8.8 ft<sup>3</sup> (250 L).

**3.2.33.3 Silane delivery system**

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.

NOTE—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 when it is used as a means to supply individual points of use.

NOTE—The delivery system does not include:

- silane containers (cylinders, tubes, etc.);
- gas cabinet enclosure;
- gas disposal equipment; or
- auxiliary equipment related to a silane installation.

#### **3.2.33.4 Silane, nonbulk source**

Container or interconnected group of containers with a water volume not exceeding 8.8 ft<sup>3</sup> (250 L).

#### **3.2.34 Site**

Location on a premise from which distances to exposures are measured.

#### **3.2.35 Storage**

Keeping or retention of material in containers not connected to a delivery system.

#### **3.2.36 Ultra high integrity service (UHS)**

Acronym used for outlet connections designed for ultra high integrity service.

NOTE—CGA 632 is the specific connection used in silane service. See CGA V-1, *Standard for Compressed Gas Cylinder Valve Outlet and Inlet Connections* and ISO 10692-1, *Gas cylinders - gas cylinder valve connections for use in the micro-electronics industry - Part1: outlet connections* [6, 7].

#### **3.2.37 Use**

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

#### **3.2.38 Valve**

##### **3.2.38.1 Valve, automatic**

Valve designed to be operated by pneumatic pressure or other power source other than manual means.

##### **3.2.38.2 Valve, check**

Valve designed to provide for flow in one direction.

NOTE—The internal components of the valve are designed to prevent flow in the reverse direction.

##### **3.2.38.3 Valve manifold box (VMB)**

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.

##### **3.2.38.4 Valve, pressure relief**

Valve designed to open if a predetermined pressure is exceeded.

NOTE—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.

#### **3.2.39 Vapor cloud explosion (VCE)**

Explosion occurring in an unconfined space that results in a damaging pressure wave (overpressure).

NOTE—It is started by the 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 1.4% to 96% volume in air [5]. At concentrations between 1.4% and approximately 4.5%, mixtures can react if an ignition source is provided. When the silane concentration in air is greater than approximately 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. Low grade silane has been reported to have an odor while high purity may not. Odor is not to be relied upon as a means to indicate the absence of silane.

### 4.2 Properties

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

**Table 1—Physical and chemical properties of silane**

| Parameter                                            | Value                                                       |
|------------------------------------------------------|-------------------------------------------------------------|
| Chemical name                                        | Silane                                                      |
| Synonyms                                             | Silicon tetrahydride, silicane, monosilane, silicon hydride |
| Chemical formula                                     | SiH <sub>4</sub>                                            |
| 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 <sup>3</sup> (1.35 kg/m <sup>3</sup> )          |
| Specific gravity (gas) at 1 atm and 70 °F (21.1 °C)  | 1.2 (Air = 1)                                               |
| Specific volume at 1 atm and 70 °F (21.1 °C)         | 12.0 ft <sup>3</sup> /lb (0.75 m <sup>3</sup> /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) [8, 9]                                    |
| Critical pressure                                    | 702.5 psia (4844 kPa, abs) <sup>2</sup> [8, 9]              |
| Critical density                                     | 15.4 lb/ft <sup>3</sup> (0.247 g/cm <sup>3</sup> )          |
| Compressibility                                      | See Appendix B.                                             |
| Heat of combustion                                   | 19 076 Btu/lb (44 370 kJ/kg)                                |
| Flammable limits in air                              | <u>1.4%</u> to 96%                                          |
| Autoignition temperature                             | −58 °F (−50 °C)                                             |

### 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 (VCEs) that can range in character from deflagration to detonation. A critical exit velocity exists below which the prompt ignition of silane release is ensured. Above this critical exit velocity, silane can be released indefinitely into air without any ignition. The critical exit velocity is found to vary with the vent size [11].

<sup>2</sup> psi, bar, and kPa shall indicate gauge pressure unless otherwise noted as (psia; bar, abs; and kPa, abs) for absolute pressure or (psid; bar, dif; and kPa, dif) for differential pressure. All kPa values are rounded off per CGA P-11, *Guideline for Metric Practice in the Compressed Gas Industry* [10].

### 4.3.1 Ignition and combustion

The ignition and combustion characteristics of a 100% silane release have been the subject of major studies [1, 2, 5, 12]. Based on these studies, the LFL of silane in air has been established as 1.4%. Concentrations from 1.4% 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/s (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]. See Appendix C for more information.

### 4.3.2 Combustion reaction

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



The stoichiometric mixture contains 9.51 volume percent silane [12]. Large quantities of amorphous silica are formed during the combustion of silane. For each 1 lb (0.45 kg) of silane completely burned, approximately 1.87 lb (0.85 kg) of amorphous silica is formed.

### 4.3.3 Health hazards

The primary health hazards associated with silane are burns due to silane flame exposure or thermal radiation. The LC<sub>50</sub> (inhalation-rat) for silane is 9600 ppm at 4 hours of exposure [14]. Little information exists on the toxicity of silane because of its pyrophoric nature; however, several countries have established Occupational Exposure Limits (OELs) (see Table 2). Table 2 contains some of the known values, but the user should review their local regulations to determine if other values apply. In addition, the inhalation of oxidized silane presents a potential health hazard. The combustion of silane forms oxides of silicon that can cause irritation to the respiratory tract.

**Table 2—Occupational exposure limits (OELs)**

| Country        | Type | Value                  |
|----------------|------|------------------------|
| Belgium        | TWA  | 5 ppm                  |
| Denmark        | TWA  | 0.5 ppm                |
| France         | TWA  | 5 ppm                  |
| Ireland        | TWA  | 5 ppm                  |
| Spain          | TWA  | 5 ppm                  |
| Switzerland    | TWA  | 0.5 ppm                |
| United Kingdom | TWA  | 0.5 ppm                |
|                | STEL | 1 ppm                  |
| United States  | TWA  | 5 ppm (NIOSH REL) [15] |

In addition to the national values listed in Table 2, the American Conference of Governmental Industrial Hygienists (ACGIH) has established a TLV®–TWA concentration to protect workers from the risk of eye, skin, and upper respiratory tract irritation with exposure to this substance [16].

### 4.3.4 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 (4844 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 comply with applicable transport of dangerous goods regulations. See Tables 3 and 4 for ADR and DOT packaging information.

### 5.2 Container outlet

Container connections shall meet the requirements as defined by industry standards such as CGA V-1, ISO 10692-1, and DIN 477-1, *Gas cylinder valves for cylinder test pressures up to and including 300 bar - Part 1: Valve inlet and outlet connections* [6, 7, 17].

### 5.3 Cap (plug) of container outlet

The main container outlet connection(s) shall be capped or plugged during transportation and storage. The cap (plug) shall be designed to be leak-tight at the service pressure of the container.

**Table 3—ADR packaging information**

|                            |                                                                                                                    |
|----------------------------|--------------------------------------------------------------------------------------------------------------------|
| Hazard class               | 2.1                                                                                                                |
| Label                      | 2.1 FLAMMABLE GAS                                                                                                  |
| United Nations (UN) number | UN 2203                                                                                                            |
| UN Proper Shipping Name    | Silane                                                                                                             |
| Valve outlet connection    | As required by national legislation (See also EIGA Doc 97, <i>Valve outlet connections for gas cylinders</i> [18]) |
| Packaging instruction      | P200                                                                                                               |

**Table 4—DOT packaging information**

|                                |                                                                                                                                                                                                                                                                                                                                          |
|--------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| DOT hazard class               | 2.1                                                                                                                                                                                                                                                                                                                                      |
| DOT label                      | FLAMMABLE GAS                                                                                                                                                                                                                                                                                                                            |
| DOT/United Nations (UN) number | UN 2203                                                                                                                                                                                                                                                                                                                                  |
| Valve outlet connection        | CGA 350, CGA 632 (UHIS), <u>or CGA 510 (low pressure)</u>                                                                                                                                                                                                                                                                                |
| Packaging                      | 49 CFR Parts 100-180 [19]                                                                                                                                                                                                                                                                                                                |
| CGA publications               | V-1 [6]<br>V-7, <i>Standard Method of Determining Cylinder Valve Outlet Connections for Industrial Gas Mixtures</i> [20]<br>S-1.1, <i>Pressure Relief Device Standards—Part 1—Cylinders for Compressed Gases</i> [21]<br>S-7, <i>Standard Method for Selecting Pressure Relief Devices for Compressed Gas Mixtures in Cylinders</i> [22] |

## 6 Outdoor storage and use

### 6.1 Applicability

In addition to these requirements in Section 6, outdoor storage and use of silane shall meet the requirements of Sections 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, and 18, 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 lessen or eliminate these effects.

## **6.2.1 Location**

Silane sources and delivery systems shall be located outdoors. Exceptions to this are nonbulk systems installed in accordance with the requirements of Section 7 and bulk systems installed in accordance with the requirements of Section 18. Although indoor locations are allowed, it is preferred that areas for the storage and use of silane be located outdoors to lessen 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 in accordance with 6.3 to allow for free airflow and reduce the potential for accumulation of silane in the event of a leak. See 3.2.22.1. Objects that are not part of the silane system or its supporting structures or fire barriers but could interfere with free air movement through the silane system, shall be located at a minimum distance from the silane containing equipment of twice the objects height. Objects that do not present a significant obstruction to free airflow do not require a minimum separation distance. Examples include tall narrow objects such as telephone poles. Supporting structures and fire barrier walls shall be designed to allow as much free air movement as possible. See Figure 4 for an example.

#### **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.

For example, assume that an equipment item 10 ft (3 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. Forced air circulation is allowed as a means of mitigation. Mitigation for silane use is accomplished by moving air over container valve connections and nonwelded mechanical connections to prevent silane accumulation in the structure. See 13.1.1.

#### **6.2.1.1.2 Weather protection**

Where controls or containers in storage or use require protection against the elements, an overhead roof or canopy may be provided. If an overhead cover (roof) is used for containers in storage or use with or without a pressure relief device (PRD), the overhead cover shall be designed to reduce the possibility of confinement or accumulation of silane and any impingement that can lead to structural support failure. 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.

#### **6.2.1.2 Height of overhead construction**

When a roof is provided, the lowest point of the roof shall be not less than 4 ft (1.2 m) above the highest point of the container and not less than 12 ft (3.7 m) from the surrounding floor.

#### **6.2.1.3 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<sup>2</sup> (19 m<sup>2</sup>) 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).

#### **6.2.1.4 Hardware**

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

Panic hardware and fire exit hardware consist of a door latching assembly incorporating a device that releases the latch upon the application of a force in the direction of exit travel.

Where a door is required to be equipped with panic hardware or fire exit hardware, such releasing device shall:

- consist of bars or panels, the activating portion of which shall extend across not less than one-half of the width of the door leaf and not less than 30 in (76 cm) nor more than 44 in (112 cm) above the floor; and
- cause the door latch to release when a force not to exceed 15 lb (67 N) is applied.

## **6.2.2 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.

## **6.2.3 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.

## **6.2.4 Fire apparatus access roads**

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

## **6.2.5 Securing of containers**

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

## **6.3 Distances to exposures and separation**

### **6.3.1 Distances between cylinder and cylinder packs and exposures**

Silane cylinders, with an internal volume of 1.8 ft<sup>3</sup> (50 L) or less, in storage or use shall be separated from exposure hazards by distances not less than those indicated in Table 5. Cylinder packs, in storage only, shall also meet the requirements of the separation distances in Table 5. Separation distances are variable since distances providing protection from radiant heat are dependent upon storage volume and whether the cylinder has a PRD or not. The distances are based on exposure to thermal radiation from a silane jet fire. Fire, not explosion, is the plausible event for cylinders in outdoor storage and use. See Appendix C for guidelines to other exposures with silane cylinders in storage and use. Individual containers with 0.5 scf (14 L) or less of silane content are not subject to the separation distances in Table 5.

### **6.3.2 Distances between silane containers with a water volume greater than 50 L, cylinder packs, ISO modules, or trailers, and exposures**

The minimum distances from exposures for silane containers with a water volume greater than 50 L, cylinder packs, ISO modules, or trailers containing silane in use shall be not less than those listed in Table 5. The minimum distances from exposures for containers with a water volume greater than 50 L, ISO modules, or trailers containing silane in storage shall not be less than those listed in Table 7. Tables 6 and 7 shall not apply to piping systems downstream of the restrictive flow orifice (RFO). The container volumes are based on the maximum water content of individual containers whether manifolded or not.

Additional exposures are as follows:

- Silane containers shall not be located within 12 ft (3.6 m) horizontal distance from overhead electrical power lines; and
- In areas where exposure to other electrical hazards is present, suitable protective measures shall be taken.

The distances are based on the potential flame jet from the individual container PRD of the size noted or flame jet from a pigtail release. Overpressure due to latent ignition of released silane from a PRD is an unlikely event

that is not considered as a minimum distance. Overpressure from a pigtail release is an unlikely event that is not considered as a minimum distance in Table 6, as long as the pull away scenario has been mitigated as listed.

“Pull away” is the act of removing the bulk container while the pigtail is still connected to the system. A minimum of three independent levels of protection are required to prevent a pull away to use the distances listed in Table 6. If this mitigation is not met, then the distances shall be based on the greater of Table 6 or overpressure determined by a detailed engineering evaluation as described in Appendix D.

Recommended approaches include:

- Containers with a nominal capacity greater than 50 L shall have a mechanical device to prevent connection of the tractor/fork lift to the container or prevent the movement of these containers;
- Brake interlock system that locks the brakes when the pigtail is connected (e.g., a device that allows the brakes to function only when the device physically covers the pigtail connection);
- Pneumatic valve on the container or on the pigtail that is close coupled to the container connection with a pneumatic actuator that will automatically close the valve in the event the container is moved with the pigtail connected or an excess flow valve that will stop flow in the event the flow exceeds a set value;
- Lock on the trailer air connection, electrical connection, or fifth wheel with the key controlled by the operator responsible for the pigtail connection;
- Automated mechanical system with a physical barrier, to prevent removal of the bulk container, that is disengaged only when the pigtail is disconnected and placed in its home position (i.e., a pigtail home position that actuates a valve to open/close a gate/flag in front of the container, when the pigtail is placed in the home); and
- Administrative control to prevent the removal of the container until the pigtail is disconnected. This includes but is not limited to operating procedures to install signs, wheel chocks, and/or barriers that are not removed until the pigtail is disconnected.

Other approaches may also provide a layer of protection.

### 6.3.3 Proximity to external fire exposures and hazardous materials

Silane storage and use areas shall be located so spills or leaks from outdoor, aboveground fluid storage vessels or systems 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.

Where required by the AHJ or established risk targets, distances between outdoor silane installations and large external fire sources such as bulk flammable liquids, outdoor storage of combustible materials, or combustible buildings shall be determined by engineering analysis.

### 6.3.4 Separation from incompatible materials in compressed gas containers

Silane containers in storage or use shall be separated from incompatible materials in gas containers, cylinders, or tanks by the use of distance or a fire-resistant barrier. Incompatible materials are defined by the following hazard class: toxic/highly toxic, flammable, oxidizing, corrosive, and unstable reactive Class 2, Class 3, and/or Class 4. There is no separation required for gases that are not in these hazard classes. The distances shown in Table 5, 6, and 7 shall be permitted to be reduced to 0 ft (0 m) where compressed gas containers are separated by a barrier of noncombustible construction that has a fire-resistant rating of at least 0.5 hours. The fire-resistant barrier shall extend 18 in (46 cm) above the top and beyond the footprint of the containers.

### **6.3.5 Protective barrier walls**

The distances in Tables 5, 6, and 7 are allowed to be reduced to 5 ft (1.5 m) when fire partitions or fire barrier walls, having a minimum fire-resistant rating of 2 hr as defined by the local AHJ, interrupt the line-of-sight between the container and the exposure. For silane tube trailers or ISO modules, a PRD flame jet will extend above the container. To mitigate against a tube trailer or ISO module PRD flame jet release, the partition shall have a fire-resistant rating of 0.5 hours; however, the height of the partition is dependent on the height of the exposure and shall be engineered using Appendix C as guidance. When provided, the partitions or walls shall be at least 5 ft (1.5 m) from the exposure.

A thermal radiation barrier, or other engineering controls may also be used in lieu of fire partitions or fire barrier walls for PRD releases. See Appendix C for thermal radiation levels and distances. A partition or barrier shall not confine a silane release or direct flames towards the tubes or containers storing the silane. Fire sprinklers shall be supported so that they are not affected by a silane release and resultant flame.

#### **6.3.5.1 Obstructions and arrangement of fire barrier walls**

The configuration of fire partitions or fire 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. In addition, the configuration of equipment or containers attached to or adjacent to fire partitions or fire barrier walls shall allow natural ventilation to prevent the accumulation of vapors.

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

#### **6.3.5.2 Penetrations and openings**

Penetrations and openings in fire partitions or fire barrier walls shall be protected in accordance with the requirements of the local AHJ. The fire-resistant rating of opening protectives provided shall not be less than the required fire-resistant rating of the fire partition or fire barrier wall being penetrated.

**Table 5—Distances to exposure for outdoor cylinders in storage or use up to 50 L**

| Type of exposure                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | Minimum distance to exposures <sup>1), 2), 3), 4), 5), 6)</sup> |                                                                                                      |                                |                                                                                     |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------|------------------------------------------------------------------------------------------------------|--------------------------------|-------------------------------------------------------------------------------------|
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | Without PRD                                                     |                                                                                                      | With PRD                       |                                                                                     |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | Cylinders in use <sup>7)</sup>                                  | Cylinder in storage less than 200 000 ft <sup>3</sup> (5660 m <sup>3</sup> or 7620 kg) <sup>8)</sup> | Cylinders in use <sup>7)</sup> | Cylinder in storage less than 10 000 ft <sup>3</sup> (283 m <sup>3</sup> or 381 kg) |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | ft (m)                                                          | ft (m)                                                                                               | ft (m)                         | ft (m)                                                                              |
| Off-site places of public assembly <sup>9)</sup>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 25 (8)                                                          | 25 (8)                                                                                               | 29 (9)                         | 50 (15)                                                                             |
| Property lines <sup>9)</sup>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | 25 (8)                                                          | 25 (8)                                                                                               | 23 (7)                         | 45 (14)                                                                             |
| Buildings on-site, noncombustible nonrated construction <sup>9)</sup>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | 20 (6)                                                          | 20 (6)                                                                                               | 23 (7)                         | 26 (8)                                                                              |
| 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 materials or other silane nests <sup>10)</sup>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | 20 (6)                                                          | 20 (6)                                                                                               | 20 (6)                         | 20 (6)                                                                              |
| Incompatible materials <sup>10)</sup>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | 20 (6)                                                          | 20 (6)                                                                                               | 23 (7)                         | 26 (8)                                                                              |
| <p>NOTE—Distances to exposures may vary due to local regulatory requirements. Any reduction to the distances given shall be subject to an engineering analysis and/or a risk assessment.</p> <p><sup>1)</sup> The distances are based on permissible exposure to thermal radiation. See Appendix C for thermal radiation data.</p> <p><sup>2)</sup> Cylinders referred to in this table shall be 50 L water volume or smaller. For larger cylinders, use Table 6.</p> <p><sup>3)</sup> Cylinders in storage are listed with the maximum nest size in total ft<sup>3</sup> (m<sup>3</sup>, kg) of silane of all the cylinders in the nest.</p> <p><sup>4)</sup> Cylinder packs in storage shall meet the requirements of this table based on the total contents in the pack. Cylinder packs in use shall meet the requirements of Table 6.</p> <p><sup>5)</sup> When mounting process panels and cylinders against a 4 hr fire wall, adequate ventilation shall be provided.</p> <p><sup>6)</sup> Distances for thermal radiation exposures to silane storage or use, from large external fire sources such as bulk flammable liquids, outdoor storage of combustible materials, or combustible buildings shall be determined by engineering analysis subject to the approval by the AHJ.</p> <p><sup>7)</sup> Cylinders in use (with or without PRD) shall be separated to prevent flame impingement as required by 6.4.2.</p> <p><sup>8)</sup> Silane cylinders without PRDs shall be separated from flammable and silane gas cylinders with PRDs. The maximum amount of silane in a nest, for cylinders without PRDs is 7620 kg of silane (200 000 ft<sup>3</sup> [5660 m<sup>3</sup>]) based on gas density at 1 atm and 68 °F (20 °C).</p> <p><sup>9)</sup> The distances specified are allowed to be reduced to 5 ft (1.5 m) when protective walls are provided in accordance with 6.3.5.</p> <p><sup>10)</sup> The distances specified are allowed to be reduced to 0 ft (0 m) when fire-resistant barriers are provided in accordance with 6.3.4.</p> |                                                                 |                                                                                                      |                                |                                                                                     |

**Table 6—Distance to exposures for outdoor silane tube trailers, ISO modules, ton tank, and cylinder packs in use**

| Type of exposure                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | Minimum distance to exposure <sup>1), 2), 3), 4), 5), 6)</sup> |                                              |                                              |                                                                |                                                                |                                                                |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------|----------------------------------------------|----------------------------------------------|----------------------------------------------------------------|----------------------------------------------------------------|----------------------------------------------------------------|
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | Without PRD or cylinder packs <sup>7), 8)</sup>                | With PRD                                     |                                              |                                                                |                                                                |                                                                |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | Ton tank, ISO module, or tube trailer<br>ft (m)                | Ton tank less than 0.39 in orifice<br>ft (m) | Ton tank less than 0.57 in orifice<br>ft (m) | ISO module or tube trailer less than 0.45 in orifice<br>ft (m) | ISO module or tube trailer less than 0.64 in orifice<br>ft (m) | ISO module or tube trailer less than 0.85 in orifice<br>ft (m) |
| Off-site places of public assembly <sup>9)</sup>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | 55 (17)                                                        | 108 (33)                                     | 130 (40)                                     | 125 (38)                                                       | 162 (49)                                                       | 165 (50)                                                       |
| Property lines <sup>9)</sup>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | 55 (17)                                                        | 90 (27)                                      | 115 (35)                                     | 80 (24)                                                        | 105 (32)                                                       | 108 (33)                                                       |
| Buildings on-site, noncombustible nonrated construction <sup>9)</sup>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 40 (12)                                                        | 80 (24)                                      | 108 (33)                                     | 50 (15)                                                        | 52 (16)                                                        | 60 (18)                                                        |
| 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)                                                        | 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)                                                          | 0 (0)                                                          | 0 (0)                                                          |
| Compatible materials or other silane nests <sup>10)</sup>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | 40 (12)                                                        | 75 (23)                                      | 103 (31)                                     | 20 (6)                                                         | 20 (6)                                                         | 20 (6)                                                         |
| Incompatible materials <sup>10)</sup>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 40 (12)                                                        | 80 (24)                                      | 110 (34)                                     | 52 (16)                                                        | 56 (17)                                                        | 65 (20)                                                        |
| <p>NOTE—Distances to exposures may vary due to local regulatory requirements. Any reduction to the distances given shall be subject to an engineering analysis and/or a risk assessment.</p> <p><sup>1)</sup> Columns list either different sizes of the PRD orifice or without PRD. Tube trailers and ISO modules both using high pressure tubes (greater than 1800 psi [12 410 kPa]).</p> <p><sup>2)</sup> Cylinders greater than 50 L water volume shall meet the requirements of ton tank distances. For cylinders less than 50 L, see Table 5.</p> <p><sup>3)</sup> The distances for containers with PRDs are based on the potential flame jet from the individual container PRD of the size noted. Distances for containers without PRDs or cylinder packs in use are based on a flame jet from a pigtail release with a 0.125 in (3.175 mm) RFO. Cylinder packs can be with or without PRD. For a detailed description of the basis for distances, see Appendix C.</p> <p><sup>4)</sup> Distances for exposures other than listed in this table shall be determined by engineering analysis subject to the approval by the AHJ. See Appendix C. If it is desired to use distances based on overpressure, see Appendix D.</p> <p><sup>5)</sup> When mounting process panels and cylinders against a 4 hr fire wall, adequate ventilation shall be provided.</p> <p><sup>6)</sup> Distances for thermal radiation exposures to silane storage or use, from large external fire sources such as bulk flammable liquids, outdoor storage of combustible materials, or combustible buildings shall be determined by engineering analysis subject to the approval by the AHJ.</p> <p><sup>7)</sup> If the pigtail pull away is not mitigated as described in 6.3.2, then distance to exposures in column labeled without PRD or cylinder packs shall be determined by the greater of thermal radiation exposures in Table 6 or overpressure distances for pigtail releases based on an engineering evaluation as described in Appendix D.</p> <p><sup>8)</sup> Cylinder packs in use shall meet the requirements of the column labeled without PRD or cylinder packs. Cylinder packs in storage shall meet the requirements of Table 7.</p> <p><sup>9)</sup> The distances specified are allowed to be reduced to 5 ft (1.5 m) when protective walls are provided in accordance with 6.3.5.</p> <p><sup>10)</sup> The distances specified are allowed to be reduced to 0 ft (0 m) when fire-resistant barriers are provided in accordance with 6.3.4. <u>Note that a setback distance from a fire-resistant barrier can be required for emergency egress.</u></p> |                                                                |                                              |                                              |                                                                |                                                                |                                                                |

**Table 7—Distance to exposures for outdoor silane tube trailers, ISO modules, and ton tanks in storage**

| Type of exposure                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | Minimum distance to exposure <sup>1), 2), 3), 4), 5), 6), 7)</sup> |                                              |                                              |                                                                |                                                                |                                                                |
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|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | Without PRD                                                        | With PRD                                     |                                              |                                                                |                                                                |                                                                |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | Ton tank, ISO module, or tube trailer<br>ft (m)                    | Ton tank less than 0.39 in orifice<br>ft (m) | Ton tank less than 0.57 in orifice<br>ft (m) | ISO module or tube trailer less than 0.45 in orifice<br>ft (m) | ISO module or tube trailer less than 0.64 in orifice<br>ft (m) | ISO module or tube trailer less than 0.85 in orifice<br>ft (m) |
| Places of public assembly <sup>8)</sup>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 25 (8)                                                             | 75 (23)                                      | 95 (29)                                      | 125 (38)                                                       | 162 (49)                                                       | 165 (50)                                                       |
| Property lines <sup>8)</sup>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | 25 (8)                                                             | 70 (21)                                      | 90 (27)                                      | 80 (24)                                                        | 105 (32)                                                       | 108 (33)                                                       |
| Buildings on-site, noncombustible nonrated construction <sup>8)</sup>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 25 (8)                                                             | 65 (20)                                      | 85 (26)                                      | 50 (15)                                                        | 52 (16)                                                        | 60 (18)                                                        |
| 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)                                                        | 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)                                                          | 0 (0)                                                          | 0 (0)                                                          |
| Compatible materials or other silane nests <sup>9)</sup>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | 20 (6)                                                             | 62 (19)                                      | 85 (26)                                      | 20 (6)                                                         | 20 (6)                                                         | 20 (6)                                                         |
| Incompatible materials <sup>9)</sup>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | 20 (6)                                                             | 65 (20)                                      | 85 (26)                                      | 52 (16)                                                        | 56 (17)                                                        | 65 (20)                                                        |
| <p>NOTE—Distances to exposures may vary due to local regulatory requirements. Any reduction to the distances given shall be subject to an engineering analysis and/or a risk assessment.</p> <p><sup>1)</sup> Columns list either different size of the PRD orifice or without PRD. Tube trailers and ISO modules, both using high pressure tubes (greater than 1800 psi [12 410 kPa]).</p> <p><sup>2)</sup> Cylinders greater than 50 L water volume shall meet the requirements of the ton tank distances. For cylinders less than 50 L, use Table 5.</p> <p><sup>3)</sup> The distances for containers with PRDs are based on the potential flame jet from the individual container PRD of the size noted. The distances for no PRD are based on National Fire Protection Association's NFPA 55, <i>Compressed Gases and Cryogenic Fluids Code</i>, Chapter 7 [23]. For a detailed description of the basis for distances, see Appendix C.</p> <p><sup>4)</sup> Distances for exposures other than listed in this table shall be determined by engineering analysis subject to the approval by the AHJ. See Appendix C. If it is desired to use distances based on overpressure, see Appendix D.</p> <p><sup>5)</sup> Distances for thermal radiation exposures to silane storage from large external fire sources such as bulk flammable liquids, outdoor storage of combustible materials, or combustible buildings shall be determined by engineering analysis subject to the approval by the AHJ.</p> <p><sup>6)</sup> Cylinder packs in use shall meet the requirements of Table 6 column labeled without PRD or cylinder packs. Cylinder packs in storage shall meet the requirements of Table 5.</p> <p><sup>7)</sup> The maximum nested ton tank, with or without PRD, is 7620 kg of silane (200 000 ft<sup>3</sup> or 5660 m<sup>3</sup>). There are no nest size limitations for tube trailers or ISO Modules. No protective walls are required between tube trailers or ISO modules.</p> <p><sup>8)</sup> The distances specified are allowed to be reduced to 5 ft (1.5 m) when protective walls are provided in accordance with 6.3.5.</p> <p><sup>9)</sup> The distances specified are allowed to be reduced to 0 ft (0 m) when fire-resistant barriers are provided in accordance with 6.3.4.</p> |                                                                    |                                              |                                              |                                                                |                                                                |                                                                |

## 6.4 Silane delivery systems

### 6.4.1 Shutdown and source isolation

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

#### 6.4.1.1 Remotely located, manually activated shutdown

At least one remotely located, manually activated shutdown control (ESO) shall be provided per 10.2.3. 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 (cylinder or pigtail ESO) and isolate the source from the delivery system. Additional remotely located, manually activated shutdown controls (ESO) shall be located at each exit from the secured area.

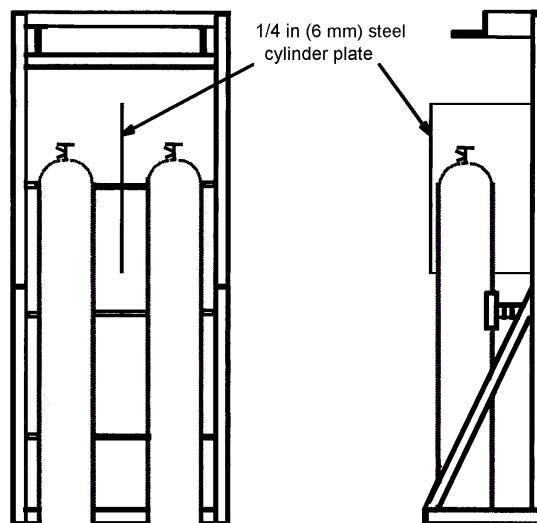
#### 6.4.1.2 Automatic shutdown

An automatic shutdown system shall be provided to automatically shut off the gas flow when gas or flame are detected by gas monitors or flame detectors in accordance with the requirements in Section 11.

NOTE—Silane source containers with pneumatically actuated valves are highly recommended as they provide the highest safety, also protecting against the consequence of leaks at container connection.

### 6.4.2 Arrangement of cylinder systems

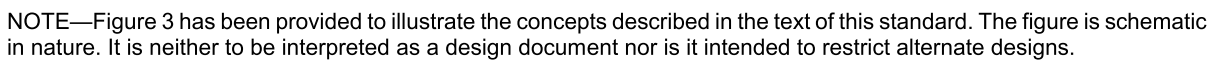
Individual cylinders containing silane shall be secured and separated from other silane cylinders to prevent flame impingement from a silane release to an adjacent cylinder or valve area. Separation shall be by 1/4 in (6 mm) thick steel plates with the plate extended a minimum of 18 in (460 mm) below 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. Exceptions to this are cylinder bundles and 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. 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. Figure 2 has been provided to illustrate the concepts described in the text of this 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



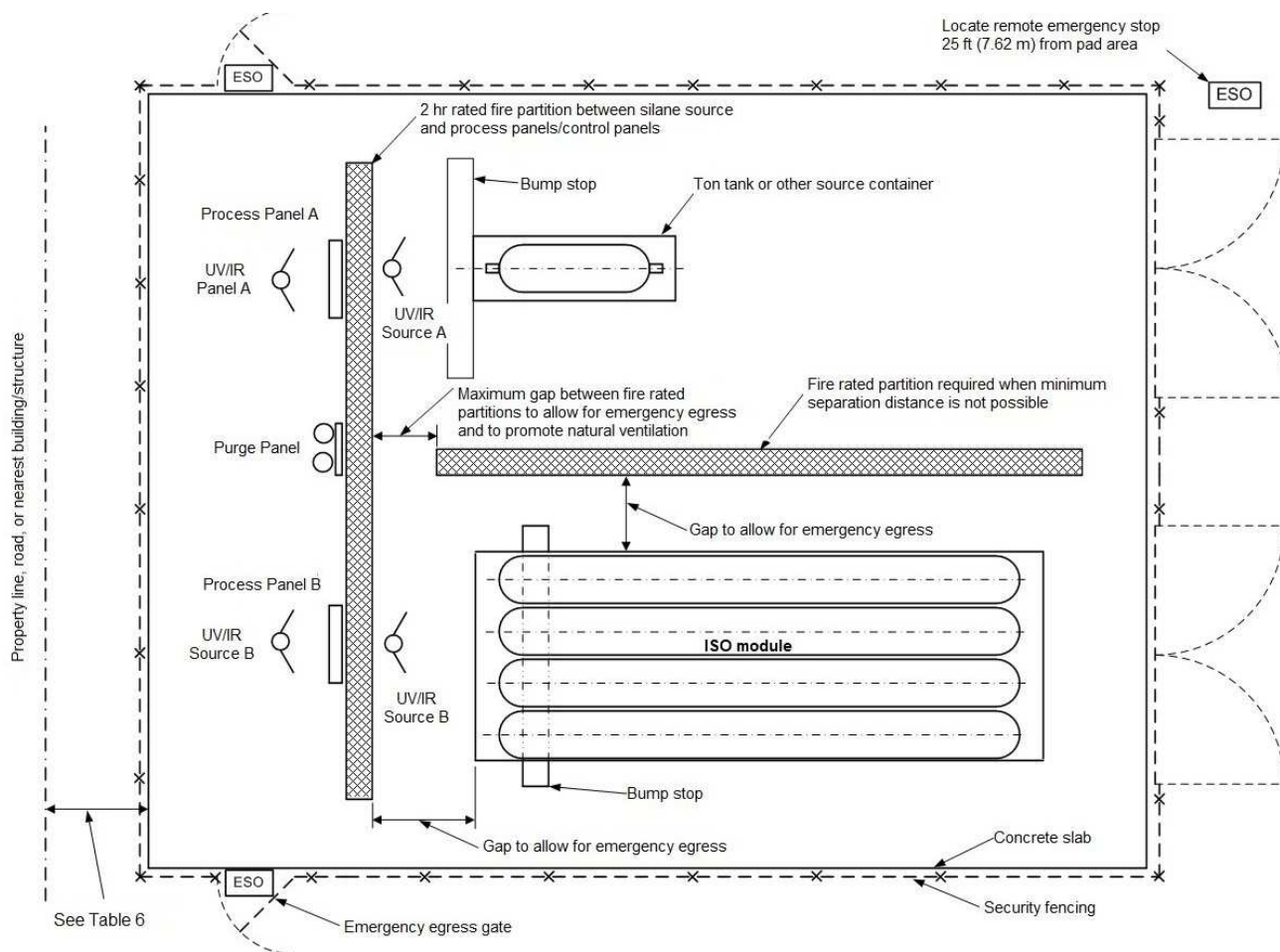


### 6.4.3 Arrangement of bulk source systems

#### 6.4.3.1 Operator controls

#### 6.4.3.2 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 this 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 4—Typical bulk source container layout**

#### 6.4.3.2.1 Separation between control panels and bulk sources

There shall be a 2 hr 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 panels or process gas panels.

#### 6.4.3.2.2 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 to protect the operator from potential silane leaks during operation of the panel. Control panels (operator interface panel) may be closer if firewalls or other protective systems are used to protect the operator.

## 7 Indoor storage and use

### 7.1 Applicability

In addition to these requirements in Section 7, indoor storage and use of silane shall meet the requirements of Sections 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, and 18 as applicable. An exception to this is individual containers with a silane content not greater than 0.50 scf (14 L).