CODE OF PRACTICE
SILANE

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PREFACE:

As part of a programme of harmonisation 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 Harmonisation Council.

This publication is intended as an international harmonised 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.

PLEASE NOTE:

NOTE—Technical changes from the previous edition are underlined.

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].[1] Studies conducted by the Compressed Gas Association (CGA) of the release of both large and small scale quantities of silane have produced new technical data [2, 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

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

recommended that the authority having jurisdiction (AHJ) be guided by this standard in determining requirements.

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.

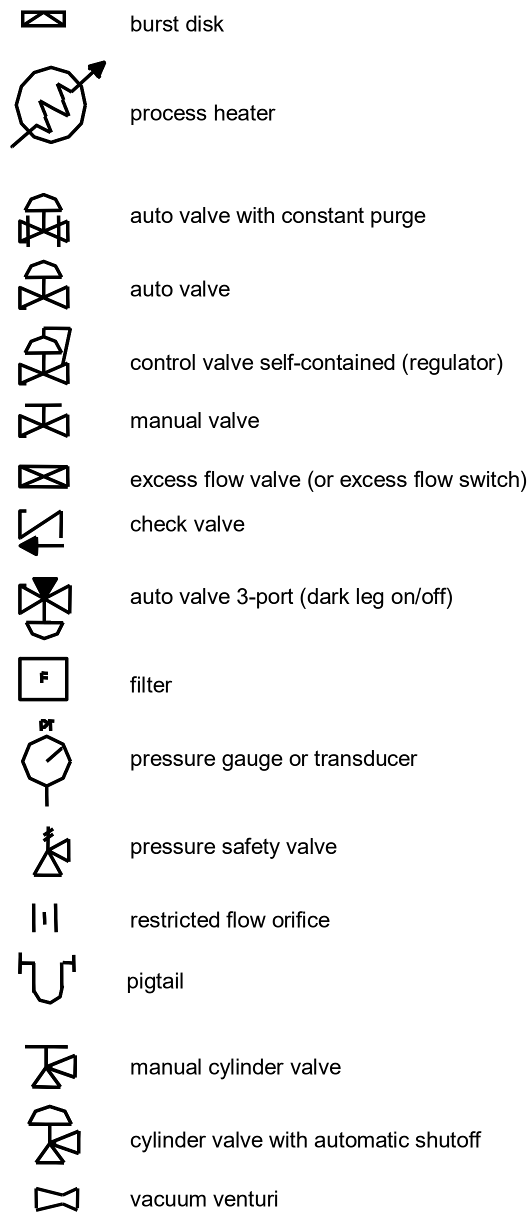


Figure 1—Instrument nomenclature

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^3 (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^3 (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 (UHIS)

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_4
Chemical Abstracts Service (CAS) registration number	7803-62-5
Appearance	Colorless gas
Boiling point	–169 °F (–112 °C)
Melting point	–300.5 °F (–184.7 °C)
Gas density at 1 atm and 68 °F (20 °C)	0.084 lb/ft^3 (1.35 kg/m^3)
Specific gravity (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^3/lb (0.75 m^3/kg)
Vapor pressure at 68 °F (20 °C)	Gas
Molecular weight	32.12
Solubility in water	Negligible. Slowly decomposes.
Critical temperature	25.8 °F (–3.4 °C) [8, 9]
Critical pressure	702.5 psia (4844 kPa, abs)[2] [8, 9]
Critical density	15.4 lb/ft^3 (0.247 g/cm^3)
Compressibility	See Appendix B.
Heat of combustion	19 076 Btu/lb (44 370 kJ/kg)
Flammable limits in air	1.4% 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].

[2] 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:

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

The stoichiometric mixture contains 9.51 volume percent silane [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_{50} (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 STEL	0.5 ppm 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, *Valve outlet connections for gas cylinders* [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), or CGA 510 (low pressure)
Packaging	49 CFR Parts 100-180 [19]
CGA publications	V-1 [6] V-7, *Standard Method of Determining Cylinder Valve Outlet Connections for Industrial Gas Mixtures* [20] S-1.1, *Pressure Relief Device Standards—Part 1—Cylinders for Compressed Gases* [21] S-7, *Standard Method for Selecting Pressure Relief Devices for Compressed Gas Mixtures in Cylinders* [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^2 (19 m^2) when a dedicated means of egress between cylinders or silane equipment is maintained. The maximum distance to an exit shall not be greater than 75 ft (23 m).

6.2.1.4 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^3 (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 1), 2), 3), 4), 5), 6)			
	Without PRD		With PRD	
	Cylinders in use 7) ft (m)	Cylinder in storage less than 200 000 ft^3 (5660 m^3 or 7620 kg) 8) ft (m)	Cylinders in use 7) ft (m)	Cylinder in storage less than 10 000 ft^3 (283 m^3 or 381 kg) ft (m)
Off-site places of public assembly 9)	25 (8)	25 (8)	29 (9)	50 (15)
Property lines 9)	25 (8)	25 (8)	23 (7)	45 (14)
Buildings on-site, noncombustible nonrated construction 9)	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 10)	20 (6)	20 (6)	20 (6)	20 (6)
Incompatible materials 10)	20 (6)	20 (6)	23 (7)	26 (8)

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.

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

2) Cylinders referred to in this table shall be 50 L water volume or smaller. For larger cylinders, use Table 6.

3) Cylinders in storage are listed with the maximum nest size in total ft^3 (m^3, kg) of silane of all the cylinders in the nest.

4) 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.

5) When mounting process panels and cylinders against a 4 hr fire wall, adequate ventilation shall be provided.

6) 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.

7) Cylinders in use (with or without PRD) shall be separated to prevent flame impingement as required by 6.4.2.

8) 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^3 [5660 m^3]) based on gas density at 1 atm and 68 °F (20 °C).

9) 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.

10) 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.

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 1), 2), 3), 4), 5), 6)					
	Without PRD or cylinder packs 7), 8)	With PRD				
	Ton tank, ISO module, or tube trailer ft (m)	Ton tank less than 0.39 in orifice ft (m)	Ton tank less than 0.57 in orifice ft (m)	ISO module or tube trailer less than 0.45 in orifice ft (m)	ISO module or tube trailer less than 0.64 in orifice ft (m)	ISO module or tube trailer less than 0.85 in orifice ft (m)
Off-site places of public assembly 9)	55 (17)	108 (33)	130 (40)	125 (38)	162 (49)	165 (50)
Property lines 9)	55 (17)	90 (27)	115 (35)	80 (24)	105 (32)	108 (33)
Buildings on-site, noncombustible nonrated construction 9)	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 10)	40 (12)	75 (23)	103 (31)	20 (6)	20 (6)	20 (6)
Incompatible materials 10)	40 (12)	80 (24)	110 (34)	52 (16)	56 (17)	65 (20)

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.

1) 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]).

2) Cylinders greater than 50 L water volume shall meet the requirements of ton tank distances. For cylinders less than 50 L, see Table 5.

3) 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.

4) 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.

5) When mounting process panels and cylinders against a 4 hr fire wall, adequate ventilation shall be provided.

6) 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.

7) 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.

8) 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.

9) 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.

10) 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. Note that a setback distance from a fire-resistant barrier can be required for emergency egress.

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

Type of exposure	Minimum distance to exposure 1), 2) ,3), 4), 5), 6), 7)					
	Without PRD	With PRD				
	Ton tank, ISO module, or tube trailer ft (m)	Ton tank less than 0.39 in orifice ft (m)	Ton tank less than 0.57 in orifice ft (m)	ISO module or tube trailer less than 0.45 in orifice ft (m)	ISO module or tube trailer less than 0.64 in orifice ft (m)	ISO module or tube trailer less than 0.85 in orifice ft (m)
Places of public assembly 8)	25 (8)	75 (23)	95 (29)	125 (38)	162 (49)	165 (50)
Property lines 8)	25 (8)	70 (21)	90 (27)	80 (24)	105 (32)	108 (33)
Buildings on-site, noncombustible nonrated construction 8)	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 9)	20 (6)	62 (19)	85 (26)	20 (6)	20 (6)	20 (6)
Incompatible materials 9)	20 (6)	65 (20)	85 (26)	52 (16)	56 (17)	65 (20)

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.

1) 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]).

2) 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.

3) 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, *Compressed Gases and Cryogenic Fluids Code*, Chapter 7 [23]. For a detailed description of the basis for distances, see Appendix C.

4) 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.

5) 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.

6) 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.

7) The maximum nested ton tank, with or without PRD, is 7620 kg of silane (200 000 ft^3 or 5660 m^3). There are no nest size limitations for tube trailers or ISO Modules. No protective walls are required between tube trailers or ISO modules.

8) 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.

9) 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.

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.

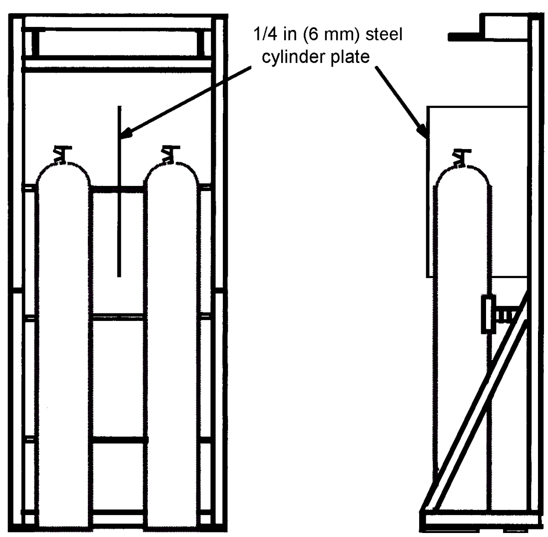
6.4.1.2 Automatic shutdown

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.

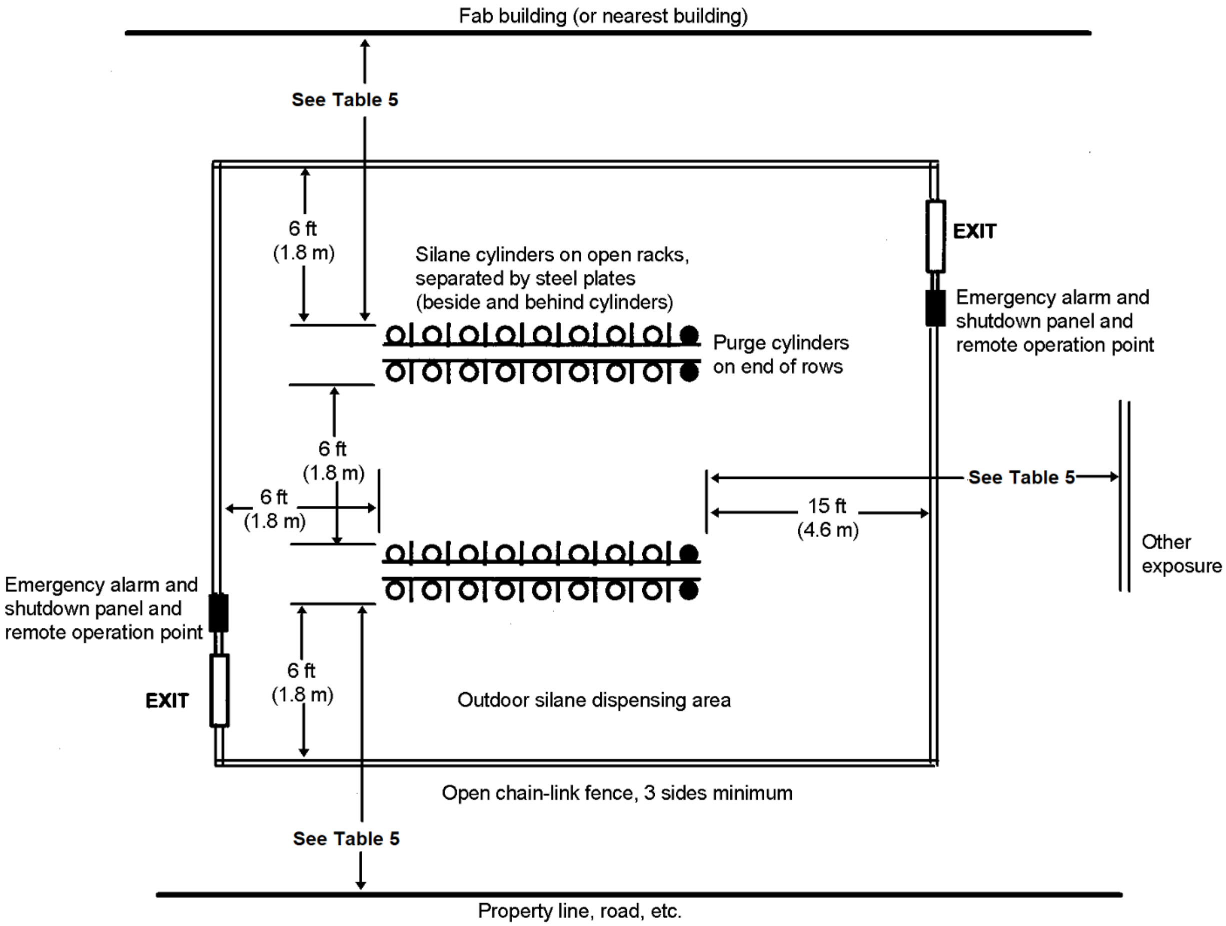
6.4.2 Arrangement of cylinder systems

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



NOTE—Figure 3 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 3—Typical end user outdoor cylinder layout

6.4.3 Arrangement of bulk source systems

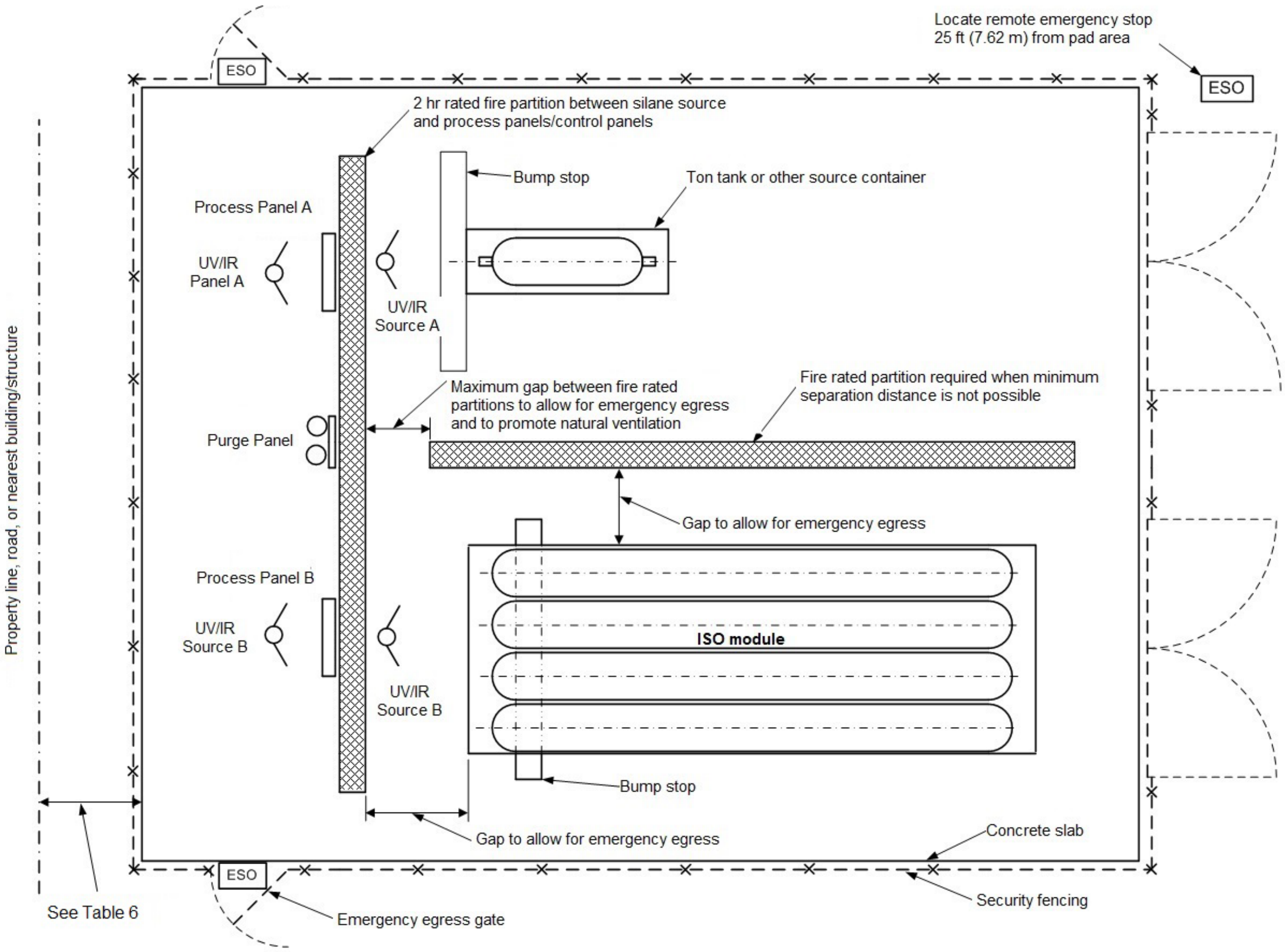
A silane bulk source system includes a bulk container of silane discharging through a pressure control and piping system. Bulk source delivery systems shall be in accordance with the requirements of this section and Section 9.

6.4.3.1 Operator controls

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

6.4.3.2 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, an 18 as applicable. An exception to this is individual containers with a silane content not greater than 0.50 scf (14 L).

7.2 Indoor storage

Buildings, rooms, or areas used for silane storage shall be constructed in accordance with the requirements of the local AHJ. Silane shall not be stored in locations below grade and silane bulk sources shall not be located indoors. For transfilling exceptions, see Section 18.

7.3 Nonbulk sources and systems

Nonbulk silane sources and delivery systems are allowed indoors. The guidelines for indoor cylinder systems are analogous to those for outdoor cylinder systems. The difference is that indoor installations have additional requirements for forced fresh air ventilation across mechanical connections to prevent accumulation of silane in the event of a release and controls to limit potential damage in the event of fire or explosion.

7.4 Barricade construction—unattended operations

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

7.5 Egress

There shall be a minimum of two exits from storage and use areas. An exception to this is one exit is allowed when areas are less than 200 ft^2 (19 m^2) and the equipment is arranged so the exit access is clear. The maximum travel distance to an exit shall not exceed 75 ft (23 m).

7.6 Explosion control

A means of explosion control shall be provided when the quantity of silane in individual containers exceeds 0.50 scf (14 L). Explosion control shall be designed and constructed in accordance with the requirements of the local AHJ.

7.7 Electrical requirements

For requirements, see Section 16.

7.8 Ventilation

For requirements, see Section 13.

7.9 Quantity limits

7.9.1 Buildings containing mixed uses

The maximum quantity of silane stored or used inside buildings containing other occupancies or uses (mixed uses) shall meet the requirements as defined by the local AHJ.

7.9.2 Detached buildings

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

7.10 Separation from incompatible materials

Silane in detached buildings or mixed-use buildings shall be separated from incompatible materials in storage and use as required by the local AHJ.

7.11 Gas cabinets

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

An exception to this is cylinders in rooms meeting the requirements of Section 18 for unenclosed indoor installations.

7.12 Shutdown and source isolation

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

At least one remotely located, manually activated shutdown control (ESO) is required per 10.2.3. The shutdown system shall be capable of being activated from a point immediately outside of and adjacent to each exit door from the room or area in which silane delivery systems are located. Activation of the shutdown system shall immediately stop the flow of gas at the source (cylinder or pigtail ESO) and isolate the source from the delivery system. Activation of the shutdown control shall sound a local alarm.

8 System configuration—cylinder sources

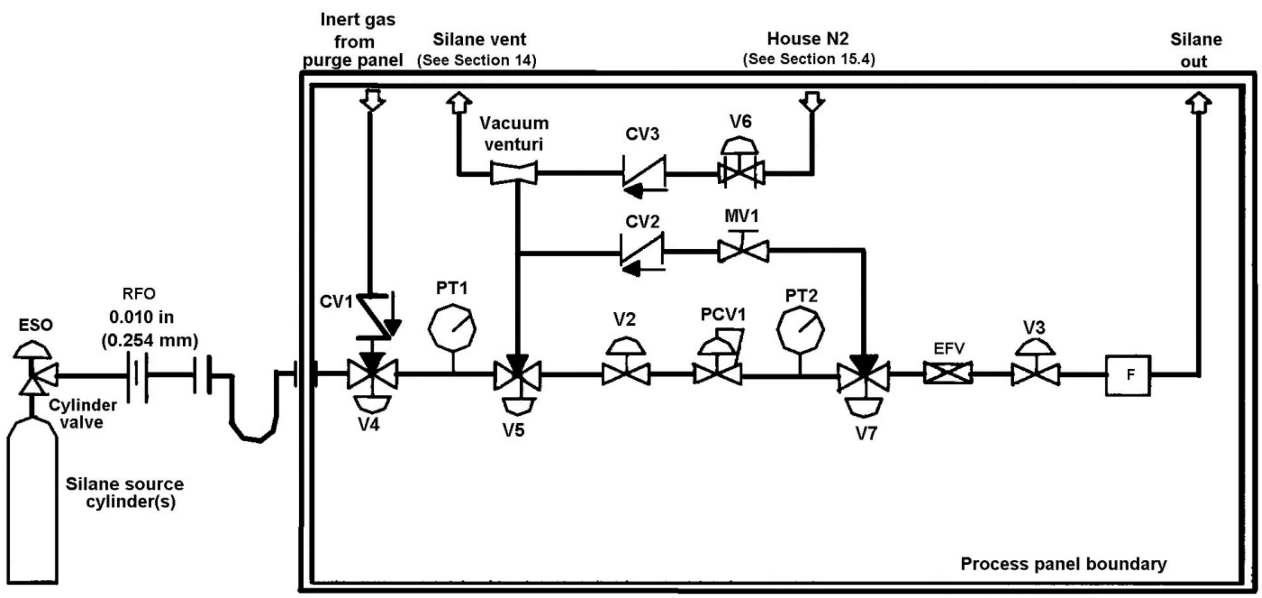
8.1 Outdoor installations

8.1.1 Use equipment

Equipment used for outdoor cylinder installations consists of individual source and purge gas supply cylinders, a process gas panel, a purge gas panel, and a support structure. For information on locating cylinders, support structures, and typical layout, see 6.4 and Figures 2 and 3.

8.1.2 Process gas panel

Process gas panels shall be used to regulate the downstream pressure of gas from the silane source cylinder(s) to a VMB or point of use. General requirements for process gas panel piping systems are specified in Sections 10, 11, 12, 13, 14, 15, 16, 17, and 18. See Figure 5.



NOTE—The ESO valve is allowed to be located on the cylinder or on the pigtail close coupled to the cylinder. Figure 5 has been provided to illustrate the concepts described in the text of 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. For instrument nomenclature, see Figure 1.

Figure 5—Typical silane process gas panel

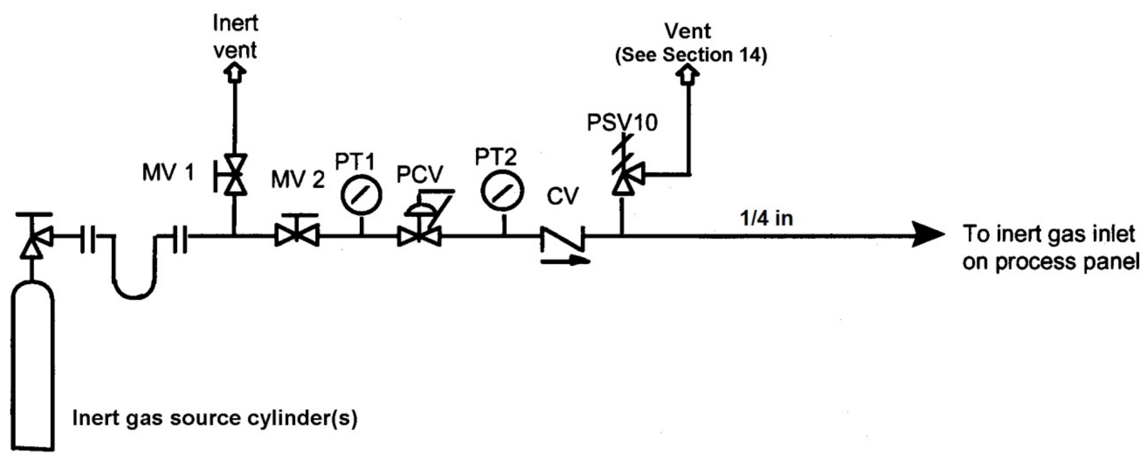
8.1.2.1 Materials of construction

Process gas panel components shall be constructed of materials compatible with silane. Panels shall be designed and assembled to minimize the use of mechanical fittings to lessen the potential for leakage.

8.1.3 Purge gas panel

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

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



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

Figure 6—Typical silane purge gas panel

8.2 Indoor installations

8.2.1 Use equipment

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

8.2.2 Gas cabinet systems

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

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

8.2.2.1 Design safety

Where gas cabinets are used, only single-cylinder cabinets are recommended to lessen the exposure potential in the event of fire. Where there is more than one source cylinder in a gas cabinet, each cylinder shall be separated by a 1/4 in (6 mm) steel plate as described in 6.4.2.

8.2.2.2 Container connection

The disconnection of a silane container in use puts the operator, equipment, and installations at risk of fire or explosion.

Where there is more than one source cylinder in a gas cabinet an adequate means shall be implemented to protect against the risk of disconnecting a container in use. One of the following mitigation barriers shall be used:

- automatic valve connection cover (programmable logic controller [PLC] controlled connection cover);
- manual valve connection cover;
- automatic warning signal (PLC controlled); and
- manual warning signal.

Torque wrenches shall be used for tightening cylinder outlet connections. Excessive or insufficient torque will damage the connection and possibly result in hazardous conditions. Apply the torque recommended by gas suppliers or container-valve vendors. In case of a nonmetallic gasket, a second tightening could be required to ensure proper tightness.

An external leak test at container connection shall be performed each time a silane container is connected to the manifold and before the container valve is opened.

8.2.2.3 Gas monitoring

Gas monitoring shall be provided in the gas cabinet in accordance with the requirements of 11.1.2.

Activation of the gas monitoring system shall shut down the source of gas in accordance with the requirements of 11.1.5.

8.2.2.4 Labeling

Gas cabinets shall be labeled with the name of the process tool or equipment they serve as well as with the name of the gases contained such as SILANE or SILANE MIXTURE and the type of purge gas used. Additional labeling shall be provided as required by the local AHJ.

8.2.3 Process gas and purge gas panel

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

8.2.4 Valve manifold box

8.2.4.1 Description

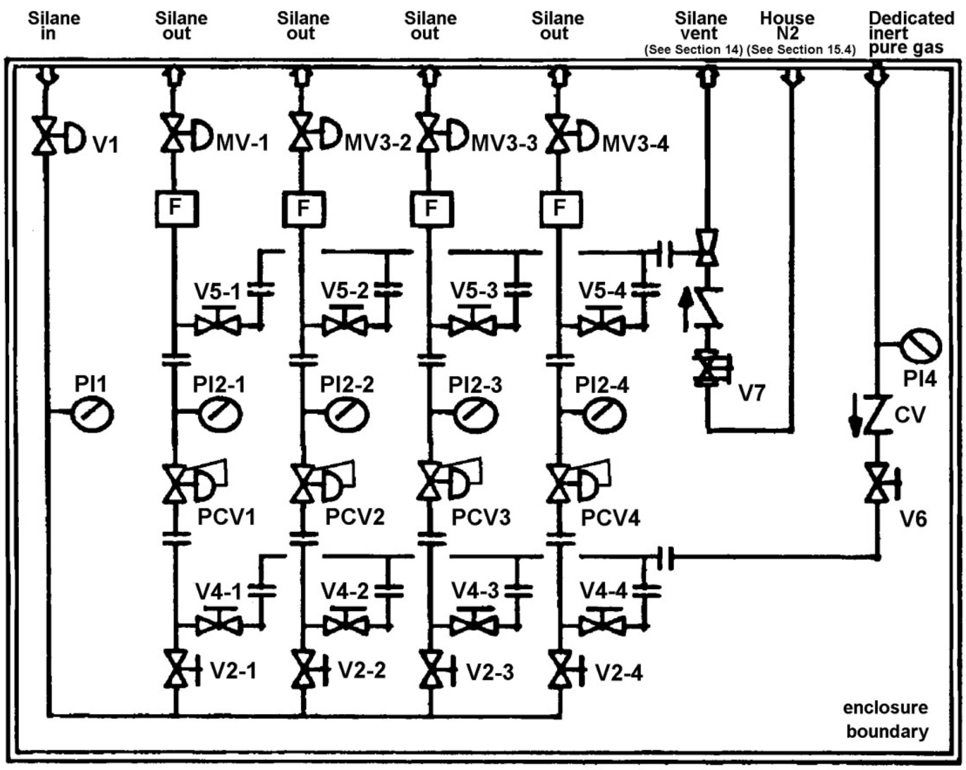
When indoors, a VMB is an enclosed valve and piping panel used to distribute gases to one or more points of use. Distribution to multiple use points serves to reduce the quantity of source cylinders on-site as well as the number of individual gas pipelines containing silane located throughout the user facility. VMBs may be controlled automatically using pneumatically operated valves. Operations such as emergency gas shutoff and purging at the point of use may be accomplished with automated VMB systems without venting the primary delivery line from the gas source thereby minimizing the potential for contamination as well as the consumption of silane.

8.2.4.2 Valve manifold box manifold branch purging

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

8.2.4.3 Gas monitoring

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



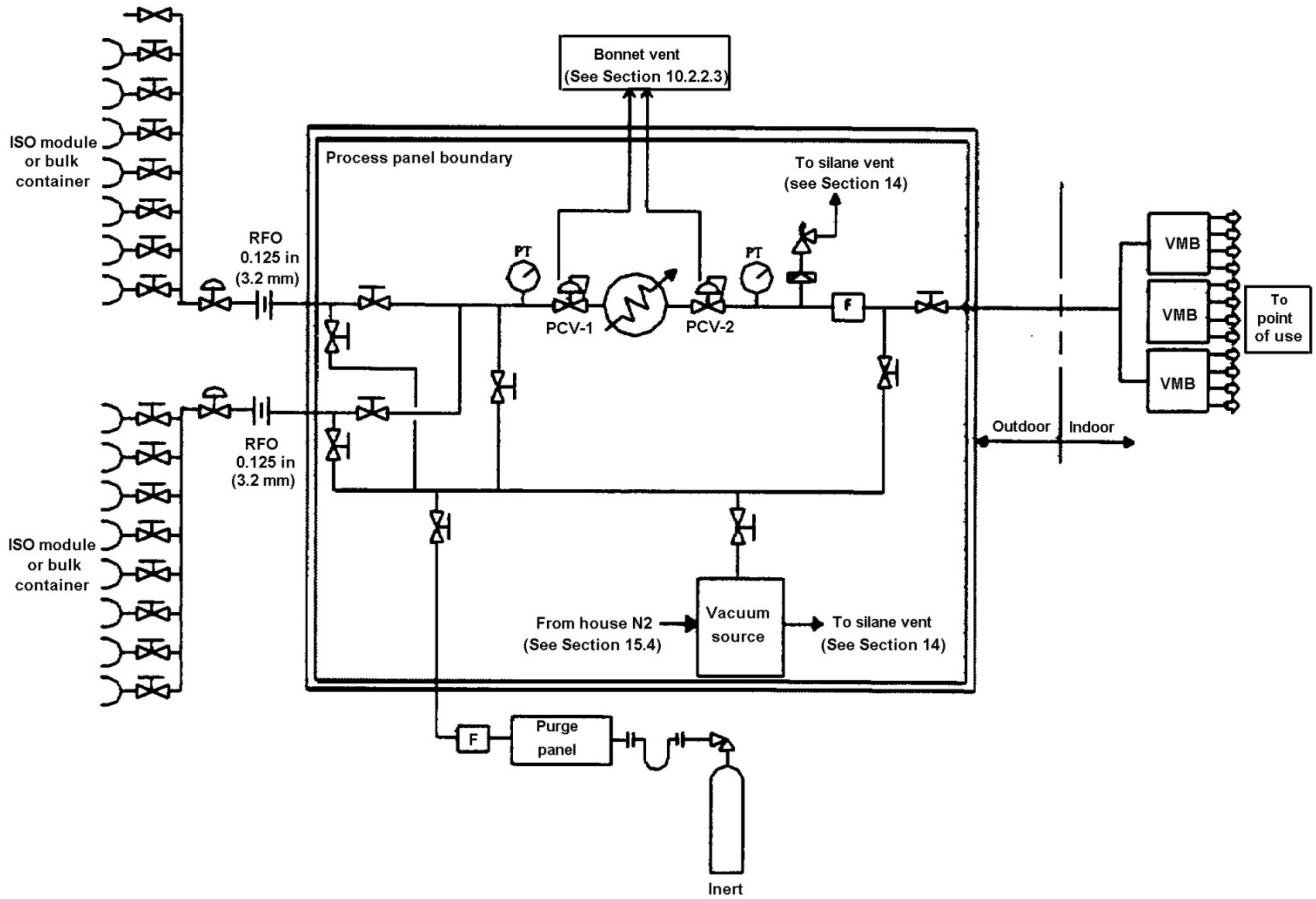
NOTE—Figure 7 has been provided to illustrate the concepts described in the text of this standard. The figure is schematic in nature. It is neither to be interpreted as a design document nor is it intended to restrict alternate designs. For instrument nomenclature, see Figure 1.

Figure 7—Valve manifold box flow schematic

9 System configuration—bulk sources

9.1 Use equipment

Equipment used for silane bulk source installations consists of a silane bulk source and its delivery systems. A silane bulk source consists of an ISO module, tube trailer, cylinder packs, or individual containers having an aggregate water volume greater than 8.8 ft^3 (250 L). The delivery systems include a process gas panel, purge gas panel, and control panel. Bulk silane source systems distribute silane to use points located indoors. Distribution within the building where the material is used is customarily performed using VMBs. A typical process flow diagram is shown in Figure 8. Equipment used for bulk source systems shall be in accordance with the requirements of 6.4.3.



NOTE—The vacuum source is either a vacuum pump system or a vacuum venturi system. Figure 8 has been provided to illustrate the concepts described in the text of 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. For instrument nomenclature, see Figure 1.

Figure 8—Typical bulk system process flow diagram

9.2 Outdoor installations

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

9.3 Bulk containers

Typical silane bulk containers include:

- Tube trailers;
- ISO modules;
- MEGCs;
- Cylinder packs; and
- Ton tank(s).

See 3.2.4.

9.3.1 Manifolded containers—securing of cylinders

Individual containers shall be firmly supported within a cart or frame assembly.

9.3.2 Isolation valves

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

9.4 Bulk source process gas panel

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

High flow silane systems connected to a high pressure source create a significant Joule-Thompson effect resulting in very low temperatures at container connection. As a result, metal gasket face seal and CGA connections can leak because of dissimilar materials' thermal contraction. Therefore, it is not recommended to use nonmetallic gaskets for high flow high pressure connections.

NOTE—Consideration should be given if a nickel gasket can be subject to Joule-Thompson cooling.

Where there is more than one bulk source connected to the process gas panel an adequate means shall be implemented to protect against the risk of disconnecting a container in use. One of the following mitigation barriers shall be used:

- automatic outlet valve connection cover (PLC controlled connection cover);
- manual outlet valve connection cover;
- automatic warning signal (PLC controlled); and
- manual warning signal (e.g., a sign, a tag, a label, etc.).

At each container connection, a high pressure leak test with inert gas or outboard sensitive helium leak check shall be conducted before the source container valve is opened, per manufacturer's instructions.

9.5 Valve manifold boxes

Generally, VMBs used outdoors for bulk sources are of similar design as those described for use with indoor installations. However, for outdoor installations, VMBs may be open and not fully enclosed. If not fully enclosed, flame detection shall be used instead of gas detection. Where fully enclosed, VMBs shall meet the requirements of 8.2.4.

10 Piping and components

10.1 Piping system design

Piping systems shall be designed, constructed, examined, inspected, and tested in accordance with ASME B31.3, *Process Piping* or recognized codes as defined by the local AHJ [24].

10.1.1 Construction

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

10.1.2 Piping connections

Connections in the piping system shall be in accordance with ASME B31.3 or recognized codes as defined by the local AHJ [24]. Welded connections are the required method of assembly where connections in the piping system are needed. Exceptions are as follows:

- Face seal fittings are allowed where connections are used for maintenance. Gaskets used with face seal fittings shall be constructed of metal;
- Pigtail connections are allowed if they are leak checked after a new connection is made and before introduction of silane; and
- Threaded connections used on cylinder valves inserted into source cylinders.

10.1.3 Secondary containment

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

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

10.1.4 Manifolding with gases other than silane

10.1.4.1 Manifolding at the source of supply

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

10.1.4.2 Manifolding at the point of use

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

10.1.4.3 Manifolding of vent gases

Silane and vent gases containing silane and an inert gas (e.g., nitrogen from silane delivery systems or VMBs) shall not be piped into manifolds used to convey other incompatible gases. Safeguards to prevent backflow to other connected compatible vents shall be implemented.

10.1.5 Leak testing

Before initial operation and after the applicable examinations required by ASME B31.3 (or recognized codes as defined by the local AHJ), piping systems shall be leak tested to ensure tightness [24]. Piping systems that have been modified and/or repaired shall be tested as required for new installations.

10.1.5.1 Leak testing pressure

Leak test pressures shall be determined to enable the system to be assessed for leaks under the conditions of use expected but not less than that specified by ASME B31.3 or recognized codes as defined by the local AHJ [24].

10.1.5.2 Portions of the system subject to testing

Leak testing of newly constructed systems shall include the entire piping system beginning from the source valves at the point of supply. Portions of the system are allowed to be tested independently; however, the entire system is subject to pressure tests as required by ASME standards or recognized codes as defined by the local AHJ.

10.1.5.3 Test fluid

The test gas used for pneumatic testing shall be nonflammable and nontoxic. Inert gases are customarily used in conducting pneumatic leak tests. Regardless of the test gas that is used to supply pneumatic pressure, residual air or other oxidizing gases shall be removed from the piping system after the test is complete and before charging the system with silane.

10.1.6 Identification

Piping systems shall be marked, labeled, and identified in accordance with ASME A13.1, *Scheme for the Identification of Piping Systems* (or recognized codes as defined by the local AHJ) as follows [25]:

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

10.2 Components

10.2.1 Valves

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

10.2.2 Backflow prevention

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

10.2.2.1 Check valves

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

10.2.2.2 Regulators

Regulators shall be equipped with a metal diaphragm. Tied diaphragm design is recommended. The Joule-Thompson effect should also be considered when selecting a regulator.

10.2.2.3 Bonnet relief vents

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

10.2.3 Emergency shutoff system

Silane systems shall be provided with ESO systems that are able to be activated at each point of use and at the source. ESO valves shall be located to be clearly visible and accessible. See 6.4.3 and 7.12.

10.2.3.1 Shutoff at source

A manual or automatic fail-safe ESO valve shall be installed on supply piping at the container or the container connection.

10.2.3.2 Shutoff at point of use

An ESO system shall be provided at the VMB. An automatic shutdown shall shut down flow of the gas to either the inlet of the VMB or the outlet to the individual points of use.

10.2.3.3 Marking

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

10.2.4 Restrictive flow orifice

10.2.4.1 Nonbulk sources

The silane source container outlet shall be equipped with an RFO. The inside diameter of the RFO used on individual containers shall not exceed 0.010 in (0.254 mm). Exceptions are as follows:

- source containers in the process of being filled or serviced to remove residual product; and
- containers in storage at the filling or distributor location equipped with a solid plug (cap) that forms a gas-tight seal at the valve outlet.

For the higher flow requirements, an increased orifice size or no RFO may be required. These will necessitate additional engineering safeguards. See 13.2.

10.2.4.2 Bulk sources

An RFO shall be placed:

- in each container outlet, or
- in the outlet of the delivery manifold from the container.
- Exceptions for bulk sources are:
- bulk containers in the process of being filled or serviced to remove residual product; and
- bulk containers in storage at the filling or distributor location equipped with a solid plug (cap) that forms a gas-tight seal at the valve outlet.

The RFO shall not exceed 0.125 in (3.175 mm) in diameter. For bulk source systems connected to a manifold, the outlet from the manifold could be limited by design with an effective orifice not exceeding 0.125 in (3.175 mm) in diameter. For the higher flow requirements, an increased orifice size or no RFO may be required. These will necessitate additional engineering safeguards and analysis of separation distances. See Tables 6, 7, and Appendix C.

10.2.4.3 Restrictive flow orifice purge before cylinder disconnection

Use of an RFO can make it more difficult to adequately purge the space between the valve seat and RFO. Inadequate purging can lead to silicon oxides, which can damage valve seats and/or clog the RFO. Thorough vacuum/pressure/purge cycles are required to adequately remove all silane before disconnection.

10.2.5 Excess flow control

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

10.2.5.1 Location of shutoff device

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

10.2.5.2 Venting of gas

Systems that incorporate the venting of gas in the system design shall be designed to vent the gas in a controlled manner. See Section 13.

10.2.5.3 System controls

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

10.2.6 Overpressure protection

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

10.2.7 Static seals

In addition to chemical compatibility, gaskets, O-rings, and seals used in pressure retaining components shall be suitable for the operating pressure and temperature of the system. When selecting polymeric materials, consideration shall be given to the rate at which these materials mechanically extrude or thermally behave over time. Since these properties directly affect the ability of a seal to repeatedly perform positive containment during pressure or thermal cycling (Joule-Thompson effects), the selection of thin seals in these services is required (1/32 in or less [less than 0.795 mm]). There shall be no thickness restriction for metallic gaskets, seals, or metallic

O-rings if the component is suitable for the operating pressure and temperature of the system and it is constructed from metals having comparable thermal expansion characteristics compared to the housing, flange, or valve body that it seals.

10.2.8 Vacuum generators

The static seals of vacuum generators used for venting piping containing silane at high pressure shall comply with 10.2.7.

10.3 Support of piping systems

10.3.1 Method of piping support

Piping used to convey silane shall be supported in accordance with the requirements of the local AHJ by supports designed in accordance with ASME B31.3 or recognized codes as defined by the local AHJ [24]. Typical means for piping system support includes the use of a supporting structure such as a cable tray, pipe trestle, or rack system.

10.3.1.1 Minimum installation height

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

10.3.1.2 Piping containing other materials

Other welded process gas and/or chemical piping is allowed to be installed in the same trestle or racking system used to support the silane piping system. If the piping contains mechanical connections, vents, or relief devices that could impinge on adjacent piping then appropriate safeguards such as separation distances or shielding shall be implemented.

10.3.2 Alternate method of piping support

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

11 Gas and flame detection

11.1 Gas monitoring

11.1.1 Outdoor locations

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

11.1.2 Indoor locations

Indoor silane delivery systems shall be continuously monitored for gas leaks using a gas monitoring system. Indoor silane storage shall either be monitored for gas leaks using a gas monitoring system or have an optical flame detection system.

11.1.3 Location of monitors

11.1.3.1 Exhaust ducts serving enclosures and cabinets

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

11.1.3.2 Areas without enclosures

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

11.1.4 Sensing requirements

11.1.4.1 Monitoring within exhausted zones

When gas monitoring is provided within exhausted zones, the gas monitoring system shall start a warning at concentrations of 50 ppm or less.

11.1.4.2 Monitoring outside of exhausted zones

When gas monitoring is provided outside of exhausted zones, the gas monitoring systems shall start a warning at concentrations at the exposure limits defined by the local AHJ or less.

11.1.5 Shutdown requirements

11.1.5.1 Monitors in ducts serving enclosures

Activation of the gas monitoring system shall shut off the flow of gas at the source or within the enclosure being monitored when a concentration of greater than 50 ppm is detected.

11.1.5.2 Monitors used for area monitoring

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

11.1.6 Alarms

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

11.2 Flame detection

11.2.1 Outdoor systems

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

11.2.2 Indoor systems

An optical flame detection system shall be provided in rooms or areas where silane delivery systems are used. The flame detection system shall be approved for silane service. The flame detection system shall be located in accordance with 11.2.2.1, 11.2.2.2, and 11.2.3, as appropriate. Optical flame detectors used indoors shall be tested for immunity to arc welding, artificial area lighting, or stray sources of ultraviolet or infared light that can inadvertently trip a detector.

11.2.2.1 Outside of gas cabinets

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

11.2.2.2 Inside gas cabinets

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

11.2.3 Shutdown requirements

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

12 Fire protection system

12.1 General

Do not attempt to extinguish a silane flame. Shutting off the source of the gas is the preferred method of control. If shutdown is not practicable, let the fire burn until the container is either determined to be empty or the flame decreases to a point where shutoff is able to be achieved without endangering personnel. The container and associated equipment involved in a silane fire shall be cooled and the silane source isolated. Fire extinguishing agents designed to deplete oxygen such as carbon dioxide shall not be used.

12.2 Outdoor systems

12.2.1 Deluge system

A manually activated deluge water spray fire protection system shall be provided to protect bulk silane delivery systems. In the event of fire, silane bulk sources shall be cooled if the source cannot be shut off.

12.2.1.1 Manual activation

Manually activated systems shall be able to be activated from a safe distance from the container. Automatic deluge systems are allowed as an option to manual activation; however, automatic systems shall not be required.

12.2.1.2 System installation—seismic considerations

Systems shall be designed and installed in accordance with the local AHJ. The system shall be designed to resist seismic forces.

12.2.1.3 Design density

The deluge system shall provide a minimum density of 0.30 gpm/ft^2 (12 lpm/m^2) for a minimum of a 2 hr duration over the external container surface areas including the silane containers. The water spray shall be directed toward the walls of the silane containers for cooling. An alternative minimum density may be set by the local AHJ.

Alternative technology such as water mist systems, which use considerably less water, may be allowed if:
they can be shown to provide equivalent protection and cooling as the conventional deluge systems; and
they are allowed by local regulations for this application.

12.2.1.4 Materials of construction

For information on materials of construction, see NFPA 13, *Installation of Sprinkler Systems* or other codes as directed by AHJ [26].

12.2.1.5 Automatic shutdown

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

12.2.2 Protection of structures

When the outdoor storage or use is located beneath a roof or canopy that is constructed as weather protection under the requirements of 6.2.1.1.2, an automatic fire extinguishing system shall be provided. The system design shall not be less than Extra Hazard Group 2 with a minimum design area of 2500 ft^2 (232 m^2) or the area of the canopy, whichever is less. See NFPA 13 or other codes from the local AHJ [26].

12.2.3 Fire hydrants

A fire hydrant shall be located no farther than 150 ft (46 m) from a silane supply container.

12.3 Indoor systems

12.3.1 Gas cabinet sprinkler systems

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

12.3.2 Area sprinkler systems

Indoor rooms or areas where silane is stored, filled, or used shall be protected by an automatic sprinkler system. The design of the sprinkler system in storage rooms shall not be less than Extra Hazard Group 1 with a minimum design area of 2500 ft^2 (232 m^2) or the area of the room, whichever is less. See NFPA 13 or other codes from the local AHJ [26].

13 Ventilation systems

13.1 Outdoor systems

13.1.1 Airflow requirements

Natural ventilation is allowed for outdoor storage and use installations providing the space is unconfined. See 3.2.22.2. An exception to this is when confined as described by 6.2.1.1.1, mechanical ventilation shall be provided in accordance with the requirements of 13.2.2.

13.1.2 Spacing between equipment

System design shall allow for the unrestricted natural flow of air between equipment to prevent accumulation of gas in the event of a silane release. This requirement does not apply to silane containers. See 6.2.1.1.

13.2 Indoor systems

A continuous mechanical exhaust ventilation system shall be provided in locations where cylinders are stored or connected for use. Unless provided with firewater sprinklers, noncombustible ventilation ductwork shall be used.

13.2.1 Ventilation rate

Where silane is stored or used in a room without being placed in a gas cabinet or an exhausted enclosure, the room itself shall be exhausted at not less than 1 ft^3/min per ft^2 (300 lpm/m^2) of floor area or 6 changes per hour, whichever is greater.

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

13.2.2 System airflow requirement for unenclosed indoor installations

Containers connected for use located outside of gas cabinets or exhausted enclosures shall be provided with a mechanical ventilation system designed to dilute potential leakage from mechanical connections. The ventilation system shall direct a source of air across unwelded mechanical connections. The ventilation shall prevent dead zones and pocketing where silane can accumulate in the room. Recirculated air shall not be used as the source of forced, induced, or captured air to be directed across mechanical connections. System design shall promote ventilated airflow so the allotted spacing between equipment will not cause a restriction in the airflow in the event of a silane release.

13.2.3 System airflow requirement for ventilated enclosures, exhausted enclosures, and gas cabinets

Exhaust ventilation shall be used to prevent accumulation of silane resulting from a leak and to limit the silane concentration to an average of 0.4%, which is a 250-to-1 volume ratio. Experiments have shown that a 0.4% (average) concentration is capable of causing a partial volume deflagration (PVD) inside the cabinet. The 0.4% limit was estimated to correspond to an overpressure that would vent the explosion by failure of the cabinet latches.

13.2.3.1 Standard silane volumetric flow rate—unattended operations

The standard silane volumetric flow rate for unattended operations shall be determined by the maximum flow rate of silane that can be discharged from the piping system into the enclosure. The flow rate is determined by the size of the RFO in the discharge line or cylinder valve at the maximum silane source pressure. For concentrations of silane less than a nominal 100%, the standard silane volumetric flow shall be determined based on the mole or volume fraction of silane present in the supply source. The minimum volumetric flow rate of air ventilation across unwelded fittings and connections at the silane source cylinder or the piping system shall not be less than the maximum silane volumetric flow rate multiplied by 250. For gas cabinets, the maximum silane volumetric flow rate is determined by the maximum flow through an RFO with a maximum source pressure on the inlet and 1 atm on the outlet. This assumes a rupture of the connecting tubing or piping between the cylinder valve and the first point of pressure control within the delivery system. For a VMB or other enclosure, the maximum silane flow into the enclosure shall be determined. The use of an RFO in the piping feeding the enclosure may be used to restrict the maximum flow into the enclosure.

Where mixtures of silane and other pyrophoric gases are present, the standard silane volumetric flow rate shall be determined by assuming that the combination of silane and other pyrophoric components is all silane. For typical flows, see Table 8.

13.2.3.2 Minimum volumetric airflow rate for cabinets and enclosures, unattended operations

Table 8 illustrates the minimum volumetric flow rate of air as a function of RFO size and source pressure for four specific orifices typical of those used in conjunction with gas cabinets and VMBs. Regardless of the orifice used, the minimum volumetric flow rate of dilution air shall not be less than the standard silane volumetric flow rate multiplied by 250.

Table 8—Minimum ventilation volumetric flow rate for gas cabinets and valve manifold boxes—unattended operations

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

NOTES

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

2 RFO downstream pressure is 0 psi.

3 RFO discharge coefficient is 0.8.

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

5 To convert psi to kPa, multiply by 6.895.

13.2.4 Ventilation system design (pocketing)

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

13.2.5 Ventilation monitoring

Exhaust from gas cabinets, VMBs, exhausted enclosures, or room ventilation exhaust ducts shall be monitored to detect a failure in the ventilation system. A failure in the ventilation system shall activate an alarm. Activation of the alarm shall start a local alarm and transmit a signal to a remotely located constantly attended location.

14 Venting and treatment

14.1 General

Requirements for venting and treatment of silane and silane mixtures shall be limited to gas from the silane delivery system and silane transfill system within the scope of this standard. See 2.1.2.

14.2 Disposal options

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

14.3 Treatment system requirements

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

14.4 Direct venting into exhaust ducts

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

14.5 Dedicated process vent

Vent lines used for silane to be discharged from process gas panels shall be specifically designed for silane and compatible gas service. Whenever different gases share a common vent system, care shall be taken to ensure adequate backflow protection. Purging of silane vent lines is required to eliminate atmospheric oxygen from migrating into the silane vent system.

The vent stack shall be designed to prevent thermal radiation from causing a hazard to buildings and other nearby exposures.

14.5.1 Continuous purge

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

14.5.2 Restrictions in vent lines

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

14.5.3 Vent gas supply

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

15 Purge gas system

15.1 Purging of the delivery system

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

15.2 Dedicated purge source

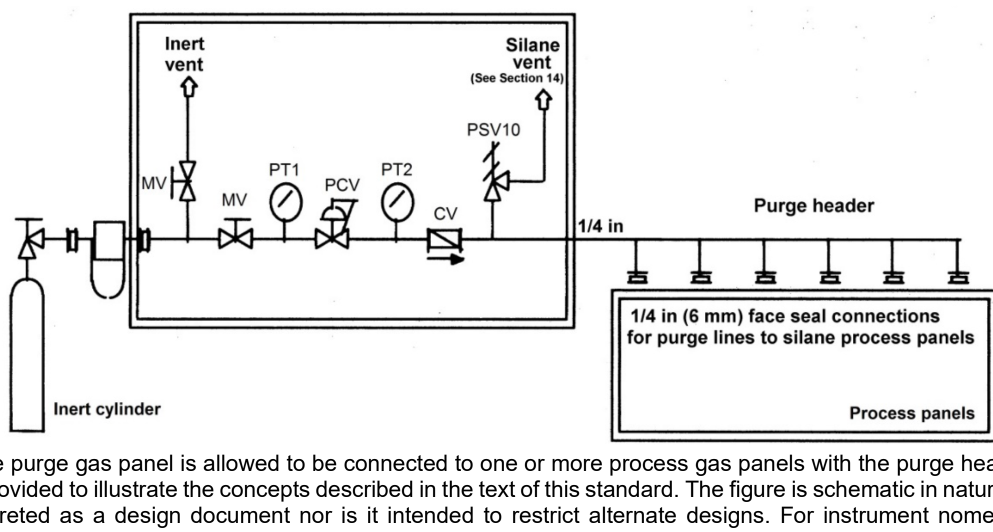
Purge gas used for the purging of silane delivery system piping and components at the source location shall be supplied from a dedicated inert gas supply source. A purge gas manifold shall be provided when one inert purge gas cylinder or supply is used as the common purge gas source for multiple silane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

15.2.1 Limitations on source of purge gas

House gas supplies shall not be used for purging silane delivery systems at the source location due to the risk of backflow into the house gas supply.

15.2.2 Protection of the purge gas source

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



NOTE—The purge gas panel is allowed to be connected to one or more process gas panels with the purge header. Figure 9 has been provided to illustrate the concepts described in the text of 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. For instrument nomenclature, see Figure 1.

Figure 9—Inert purge gas flow schematic

15.3 Controls

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

15.3.1 Backflow prevention

Backflow prevention shall be provided on purge gas supply lines to ensure that the potential backflow of silane does not contaminate the dedicated purge gas source. Where purge panels supply more than one process panel, backflow prevention between process panels shall be provided. See Figure 5. The check valve (CV) and pressure relief valve (PSV10) shown in Figure 9 are used as safeguards to prevent silane backflow into the purge gas system. The PSV10 serves as a redundant feature to protect components from overpressure. Electronic interlocks and engineering controls are allowed to be used to prevent backflow. One example is to automatically isolate the purge process if the purge gas pressure is at or below the silane source pressure.

15.3.2 Low pressure alarm

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

15.4 Vacuum generator purge gas source

When vacuum generators or vacuum venturis are used to produce the vacuum needed for evacuation/purge cycles in silane systems, nitrogen or other inert gas shall be used to provide the motive force necessary to generate the vacuum. Vacuum venturis require high-volumetric flow rates (~3.5 scfm [100 lpm]) supplied at modest pressures (~100 psia [690 kPa, abs]) to generate the vacuum needed for clearing systems of silane. See Figure 5.

15.4.1 Source of purge gas used for vacuum venturi systems

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

15.4.2 Backflow prevention at venturi supply

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

16 Electrical requirements

16.1 General

Electrical systems and components shall comply with recognized local electrical code and the local AHJ.

16.2 Emergency power

When the normal electrical supply system is interrupted, emergency power shall be automatically provided to the following safety systems: exhaust ventilation system, gas detection system, fire alarm system, and emergency alarm system. Uninterruptible power supply (UPS) shall be considered for life safety systems. Emergency power shall be installed in accordance with local electrical codes.

Silane delivery system controls shall fail-safe or shall remain powered through a power loss or a controller shutdown.

16.3 Outdoor electrical systems

Bulk sources shall be grounded to earth before and during connection to the silane delivery system.

17 Fundamental supervisory control requirements

17.1 Indoor requirements

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

Table 9—Indoor requirements for supervisory control—silane systems containing silane in concentrations exceeding 1.4% by volume

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

17.2 Outdoor requirements

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

Table 10—Outdoor requirements for supervisory control—silane systems containing silane in concentrations exceeding 1.4% by volume

Outdoor installations	Exhaust monitoring	Gas monitoring (see 11.1)	Flame detection (see 11.2)	Emergency shutoff (see 10.2.3)
General	If forced ventilation used, alarm on loss of ventilation.	Gas monitoring is *not* required.	Fire detection is required. Source shutdown on fire detection.	ESO controls shall be provided at each exit. Shutoff controls shall be located not less than 15 ft (4.6 m) from the supply system.

18 Container filling

The following requirements and recommendations are to be specifically applied for operations within manufacturing/transfilling plants that are filling and storing silane transportable containers. The source of product may be directly from a manufacturing process or from another supply container. Preparation of mixtures of silane with other gases is excluded from the requirements of Section 18 only.

Filling of bulk silane containers is allowed to take place indoors. When filling, the added safeguards listed within Section 18 shall be applied.

Silane, if below the critical temperature, can be liquefied. See Table 1. Proper safeguards are required to help prevent a container from being overfilled and possible release resulting from hydrostatic overpressure.

18.1 Container filling facilities

18.1.1

All silane storage and filling rooms shall be properly segregated from other hazardous and incompatible materials. Containers shall be stored in properly segregated locations away from filling rooms. See 3.2.17.

Rooms or areas used for transfer operations shall not be required to meet the requirements of barricade construction when such areas are in conformance with the requirements of 18.1.1.1 and 18.1.1.2.

Filling rooms or area design shall also meet the requirements of the local AHJ for pyrophoric materials.

18.1.1.1

Indoor transfill operations (filling) shall be conducted in an exhausted enclosure or gas filling room. Exhausted enclosures are allowed to have access doors. The control velocity at the face of access openings shall not be less than 200 ft/min (61 m/min) average with not less than 150 ft/min (46 m/min) at any single point. Access doors shall be self-closing or interlocked so that they are closed during operation and opening of the cylinder valve.

18.1.1.2

Fire walls shall be designed to meet local requirements.

- Rooms shall be designed with explosion control per 7.6;
- Rooms shall be designed to provide appropriate access for emergency response; and
- Room egress shall be designed to meet the requirements of 7.5.

18.1.2

Forced exhaust ventilation of gas filling rooms shall be provided per local building/fire codes or 6 air changes per hour, whichever is greater. The design of the ventilation shall be optimized to focus airflow to the highest risk areas. Silane fill rooms shall operate at negative pressure versus the surrounding building.

Unless provided with firewater sprinklers, noncombustible ventilation ductwork shall be used.

Ventilation systems shall have monitors to alarm on failure of airflow. See 13.2.5.

Minimum ventilation volumetric flow rate for exhausted enclosures—the standard silane leak volumetric flow rate used for filling in an exhausted enclosure shall be determined by assuming discharge from a valve or fitting under the maximum silane source pressure through an opening with an equivalent diameter of 0.006 in (0.15 mm). This equivalent leak diameter shall be used to determine the potential leak rate. The minimum exhausted volumetric flow rate of dilution air shall not be less than the standard silane leak volumetric flow rate multiplied by 250. See Table 11 for minimum flows.

Table 11—Minimum ventilation volumetric flow rate for exhausted enclosures

Source pressure (psi)	0.006 in (0.15 mm) diameter leak	
	Silane flow (scfm)	Ventilation flow (scfm)
50	0.025	8
100	0.045	14
200	0.085	26
400	0.173	52
600	0.275	83
800	0.395	191
1000	0.555	167
1200	0.724	217
1500	0.913	274
1650	0.987	296

18.1.3

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

18.1.4

Electrical classification of gas filling rooms and exhausted enclosures shall be designed in accordance with local codes and regulations.

18.1.5

Silane bulk containers in use (e.g., tube trailers, ISO modules), either supplying or being filled, shall have water deluge protection or a water monitor installed nearby capable of being aimed at and covering the container. The bulk container deluge shall have manual activation capability and should be automatically activated based on local optical flame detection.

18.1.6

Gas filling rooms or rooms containing enclosures shall meet the requirements as specified in 10.2.3. A remote shutdown location shall have the ability to shutdown the entire filling system.

18.1.7

Emergency venting and process safety devices shall discharge into a dedicated vent stack designed to prevent plugging and meet the requirements as specified in 14.5.2.

18.1.8

All indoor fill processing of silane shall have gas monitoring and warning alarm for silane set no greater than the exposure limits defined by the local AHJ.

Gas detection at a maximum of 10 ppm shall cause an automated system shutdown of the silane filling processes including the supply and containers being filled.

18.1.9

Optical flame detectors shall be used to view all connected silane leak sources (valves, fittings, and connections), both indoors and outdoors. Optical flame detection shall cause an automated system shutdown of the silane filling processes including the supply and containers being filled. See 11.2.3.

18.1.10

When filling bulk containers indoors, heat and/or smoke detectors shall be provided in the silane filling rooms.

18.1.11

For electrical systems and component requirements, see Section 16.

18.1.12

The silane system shall be designed to prevent operator exposure to leaks during filling operations. Safeguards shall include physical barriers and/or written procedures.

18.1.13

Minimum personal protective equipment (PPE) for container change out shall include face shield, leather gauntlet gloves, flame-resistant coveralls, safety shoes, and safety glasses.

18.1.14

A two-person rule should be considered for silane container change-out operations.

18.2 Filling system

18.2.1

All silane piping systems shall be designed, constructed, inspected, and tested per the following requirements and Section 10.

The design of the piping systems shall minimize mechanical fittings and maximize welded connections. See 10.1.2.

Seamless tubing pigtails shall be used rather than flexible hoses.

High pressure leak tests shall be conducted after each container is connected.

18.2.2

All pneumatic valves shall have plastic actuation tubing (acting as a fusible link) and shall be of fail-safe design.

18.2.3

All container and manifold valves shall be of packless design. If a threaded leak port is present, it shall be sealed with a gas-tight cap or plug. See 10.2.1.

18.2.4

The protection of process tubing, components, and valves shall be considered during design review.

18.2.5

Regulator bonnet vents shall be in accordance with 10.2.2.3.

18.3 Filling safeguards

18.3.1

To prevent overfilling a container, at least one of these safeguards shall be followed:

- Engineer controls to limit inventory in the source to less than the specified fill density of the cylinder to be filled;
- Single cylinders, tubes, or ton tanks filled to maximum gross or net weight initiating shutdown of supply shutoff valve. This is a system that shuts down the container filling when the specified fill weight is achieved;
- Integrating mass or volume flowmeter initiating shutdown of a supply shutoff valve;
- Fill a single cylinder, tube, or ton tank manually on a weigh scale with administrative controls such as an approved fill procedure to limit fill density in the filled container;
- Fill multiple containers on a single weigh scale by opening and closing one container valve at a time with administrative controls such as an approved fill procedure to limit fill density in the filled containers;
- Fill containers including modules, cylinder packs, multiple cylinders on a manifold, in a temperature controlled environment that maintains the temperature above the critical temperature. When loading manifolded containers, temperatures and pressures shall be allowed to equalize before isolating individual tubes or cylinders;
- Fill multiple containers on a manifold above their critical temperature with a single cylinder on a weigh scale as a control. When loading manifolded containers, temperatures and pressures shall be allowed to equalize before isolating individual tubes or cylinders;
- Transfer vaporized liquid from source container within the allowed warm-up time while product container is on the scale. Designers shall define the quantity of fluid to be transferred to prevent an overfill condition;
- Check weigh disconnected single filled cylinder or ton tank immediately after filling using an accurate scale to confirm fill contents; or
- Control filling process by weight reduction of source container. Check weigh filled cylinder or ton tank immediately after filling using an accurate scale to confirm fill contents.

18.3.2

Where the container fill operation is manual, it shall be attended at all times. Where the container fill operation is automated, safety and control measures shall be used to monitor for and respond to abnormal conditions.

18.3.3

Where the fill containers are filled on a scale or the source is on a scale, the scales shall be calibrated and certified at least annually. This period may be shorter where required by local regulations.

The source or fill container scales shall be checked with a standard calibrated weight. For example, for cylinders, cylinder packs, and ton tanks, this check can be conducted on a daily basis. For ISO modules, this check can be conducted on a biweekly basis.

18.3.4

Fill connections shall be designed so as not to affect the ability to determine the mass of product contained within the container. Fill connection influence shall be taken into consideration due to connection method, initial pressurization, or variations during filling.

18.3.5

In horizontal containers, tubes, or ton tanks, where the temperature is below the critical temperature, the product can be liquefied at the valve outlet, therefore a dip tube upward shall be installed to ensure gas delivery from a filled container.

18.4 Manufacturing/Filling plant storage

18.4.1

Manufacturing or transfilling plants are likely to handle a greater volume of containers than at a user site so special requirements can exist. In addition to storage requirements in other sections, the following requirements also apply.

18.4.2

Pyrophoric ISO modules storage and stacking requirements depend on whether the unit has PRDs or not.

ISO modules:

- ISO modules with PRDs shall not be stacked. Local regulations may limit nest sizes; and
- ISO modules without PRDs may be stacked two high. Local regulations may limit nest sizes.

Minimum distance criteria are specified in Table 4.

Additionally, other minimum distance criteria are:

- 50 ft (15 m) from inlets for air conditioning or ventilation equipment. This distance may be reduced if a gas monitor is used to isolate air inlet equipment; and
- Facilities need to provide adequate end-to-end and side-to-side module spacing to allow for safe handling, inspection, and maintenance activities.

18.4.3

If cylinders in pallets or cages, ton tanks, or other similar containers are to be stored in stacked or multi-level vertical storage systems, the following requirements apply in addition to the other requirements of this standard:

- Height restrictions—All cylinders and ton tanks types stored at elevated levels shall be confirmed to have passed a drop test for valve protection from the maximum storage height;
- Segregation—Storage of silane containers shall meet the requirements specified in Tables 5, 6, and 7. Inert gas containers may be stacked above or below silane gas containers;
- Earthquake and weather protection—Silane storage racks or systems shall be structurally designed for the appropriate seismic zone where installed. The storage racks or system shall be structurally designed for local conditions (wind, snow, rain, etc.). See 6.2.1.1.2 and 6.2.1.2;
- Fire protection—Racks or systems for the storage of silane containers shall meet the requirements as specified in 12.2.2 and shall be protected against fire exposure in accordance with local codes and regulations;
- Ventilation—Stacked storage racks shall be designed and installed to allow free ventilation and dispersion of any possible leaking gas; and
- Emergency response—For stacked storage racks, specific site conditions and emergency response shall be taken into account.

18.4.4 General requirements

Container handling equipment shall allow for safe movement and stacking, as applicable:
Surface of all storage areas and container handling roadways/aisles shall be rated for the maximum weight; and
Container storage area and aisle way slopes shall not exceed allowable tolerances for containers, stacks, and handling equipment.

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Unless otherwise specified, the latest edition shall apply.

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Property Loss Prevention Data Sheet 7-42, *Guidelines for Evaluating the Effects of Vapor Cloud Explosions Using a TNT Equivalency Method*, FM Global. www.fmglobal.com

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

SEMI S18-1102, *Environmental, Health, and Safety Guideline for Silane Family Gases Handling*, Semiconductor Equipment and Materials International (SEMI®). www.semi.org

Structures to Resist the Effects of Accidental Explosions, Department of the Army, TM 5-1300, Navy NAVFAC P-397, Air Force AFM 88-22. www.defense.gov

Analyses to Support Development of Risk-Informed Separation Distances for Hydrogen Codes and Standards, Sandia Report SAND2009-0874. www.sandia.gov

Tamanini, F. and Chaffee, J.L. *Ignition Characteristics of Releases of 100% Silane*, SEMATECH Technology Transfer 96013067A-ENG, March 7. 1996. www.semi.org

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Tokuhashi, K., Takahashi, A., and Kondo, S., *Spontaneous Ignition of Silane: Effect of Water*, 36th Symposium on Combustion (Japan). 1998, pp 761. www.combustioninstitute.org

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Appendix A—Personnel protection (Informative)

A1 Personal protective equipment

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

A1.1 Personal protective equipment for routine system operation

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

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

A1.2 Personal protective equipment for opening of process lines

Minimum PPE requirements for operations that involve opening of process lines and equipment in a silane system (e.g., cylinder change out, breaking fittings on a process line for maintenance, etc.,) include the same equipment as in A1.1 plus the following:

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

A1.3 Personal protective equipment for emergency operations

PPE for emergency response includes:

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

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

A2 Training

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

A3 Emergency procedures

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

A4 Operations and maintenance

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

A4.1 Operational instructions

There shall be printed operating instructions maintained at the operating location. Operating procedures shall be written and approved by knowledgeable personnel or persons knowledgeable of the hazards of silane, the function and use of equipment and controls, and the facility in which the system is installed. These operating instructions shall be subject to document and revision control.

A4.2 Maintenance

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

A5 Safety data sheets

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

Appendix B—Explanatory material (Informative)

Appendix B is not a part of the requirements of this standard but is included for informational purposes only. This appendix contains explanatory material that is numbered to correspond with the applicable text paragraphs within the main body of this standard.

B4.2 Properties—silane compressibility

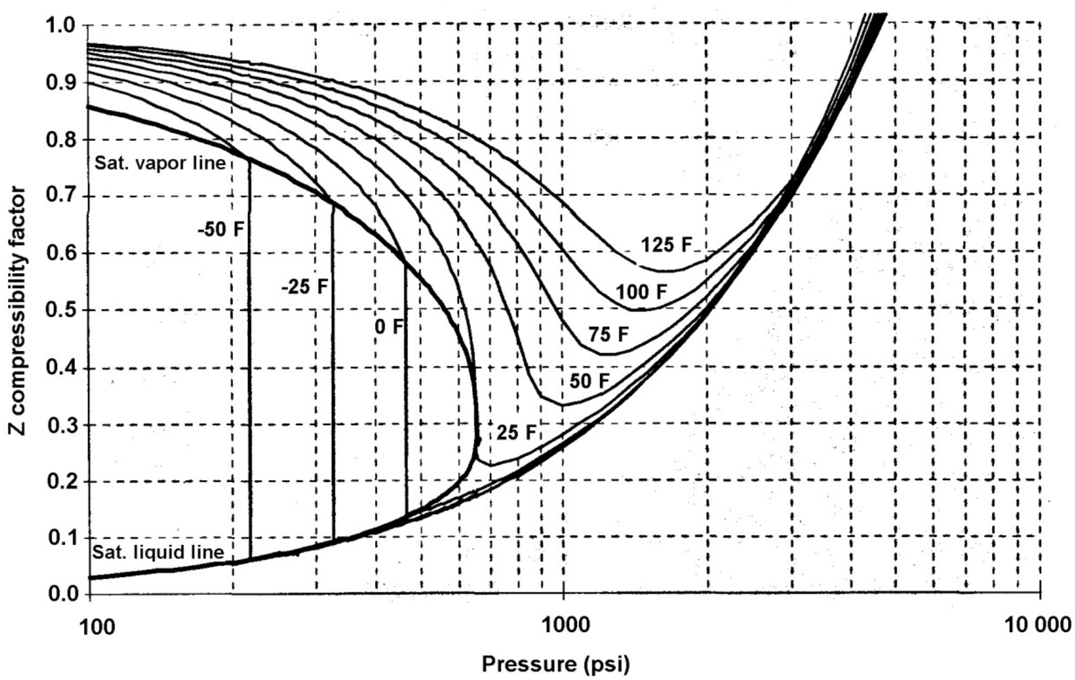


Figure B-1—Silane compressability

B4.3 Pyrophoric nature of silane

Autoignition of silane is not fully understood despite many years of research. Researchers such as Britton, Cruice, and Taminini theorized that a minimum velocity and atmospheric condition exists which would always cause an ignition but could not define what this was [12, 27, 28]. Chen's later studies showed that silane release without prompt ignition was caused by what was described as the quench of the reactive kernel from the scalar dissipation between the release silane gas and the ambient air [7, 29].

B18.1.1.2

A silane fire can impinge onto equipment and/or cylinders causing damage. The design of the system and room should consider methods of reducing flame impingement.

To mitigate heat and smoke damage, gas rooms may be designed to allow room heat to escape such as the use of low melting point panels in exterior walls or ceiling. See FM Global Property Loss Prevention Data Sheet 1-10, *Interaction of Sprinklers, Smoke and Heat Vents, and Draft Curtains* for design considerations [30].

B18.1.2

Gas leak alarms may start emergency ventilation for indoor silane fill rooms.

Room ventilation manual emergency off switches may be installed outside each gas filling room. These switches may be independent from the room ESO buttons. Room ventilation emergency off switches are intended for use during fire conditions to isolate ventilation and prevent fire propagation through the heating, ventilation, and air conditioning system.

B18.1.6

Some users may desire purging the emergency vent to prevent ignition of silane and blockage due to buildup of oxide.

B18.1.7

The optical flame detection system may have a proof test interval not to exceed one year. A proof test interval of six months should be considered. The proof test may use flame simulator (light with silane flame wavelength signature) to test the entire circuit. The optical flame detection and shutdown system should be a high-reliability design.

B18.1.8

All critical alarms should be remotely signaled to a continuously attended station.

B18.1.11

Continuous surveillance may be provided for the silane fill rooms during all silane fill processing (e.g., using closed-circuit television cameras displaying to a constantly attended station).

B18.2

If cylinder securing devices are installed for use during the filling operation a noncombustible chain is recommended versus nylon strap.

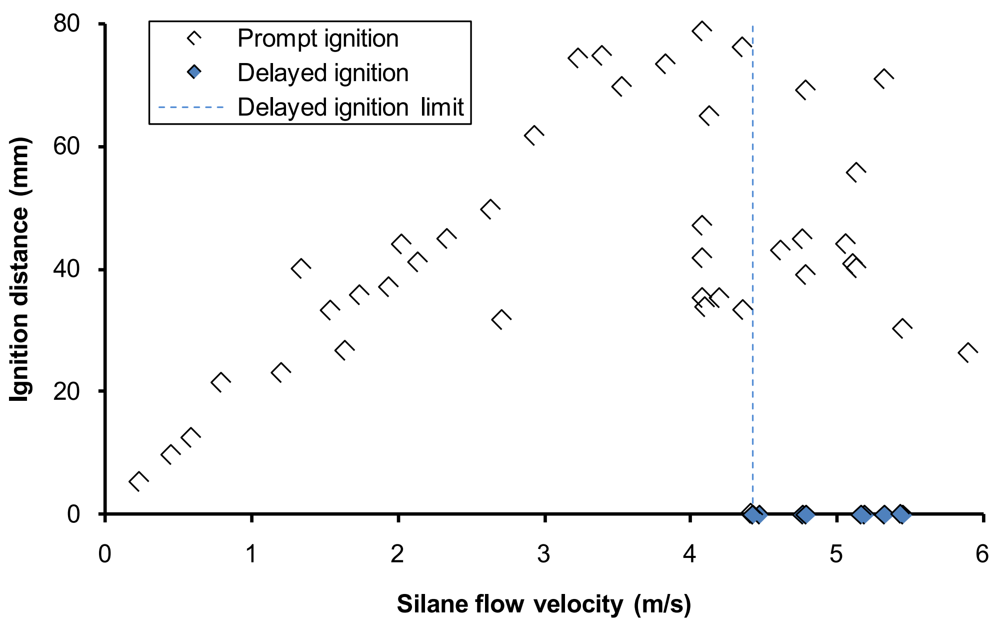


Figure B-2—Observed ignition distance for different silane flow velocity from 4.32 mm port connectors

This complex phenomenon is common in the autoignition of other flammables such as the high-speed jet of diesel fuel injected into hot air at temperatures above the autoignition temperature. This causes delayed ignition also known as knock in the engine [11, 30].

B18.2.1

Cylinder valve outlet adapters are typically used in gas fill systems to accommodate the various outlet connections used for silane. Their use should be limited where possible.

If mechanical fittings are necessary, face seal fittings should be used rather than threaded connections. Metal gasket face seal locks should be used wherever possible for silane fittings incorporated into the filling circuit, especially those fittings, which are subject to torsion/vibration or are not well supported on a metallic backplate/support structure.

One of the preferred methods is to perform an outboard helium sniff test of the pigtail connection conducted near the maximum cylinder filling pressure using a handheld instrument. This can be performed simultaneously with a gross-leak pressure decay test for time efficiency. A leak test gas may consist of 5% or 10% helium/nitrogen or argon mixtures for cost savings. The leak test method should have a leak detection sensitivity of at least $1x10^{-4}$ sccs leak rate.

Appendix C—Possible code interpretation for use of a low concentration mixtures of silane in nitrogen (Informative)

Silane concentration in compressed gas mixture	Minimum engineering controls	Maximum allowable quantity (MAQ)	Applicable fire code chapter (IFC 2012) and referenced standards [13]
<1.4%	Standard controls for non-flammable gases	No MAQ limit	Chapter 53: Compressed gases
1.4 – 4.5%	Standard controls for flammable gases	MAQ for flammable gases (dependent on occupancy class, Control Zone and floor level)	Chapter 58: Flammable Gases
>4.5%	All prescribed controls for pyrophoric gases as described in this document	MAQ for pyrophoric gases (dependent on occupancy class, Control Zone and floor level)	Chapter 64: Pyrophoric Materials, FM Global Property Loss Prevention Data Sheet: Silane

Appendix D—Thermal radiation (Normative)

This appendix provides the basis for Tables 5, 6, and 7. Distances for exposures other than listed in these tables shall be determined by engineering analysis using this appendix and subject to the approval by the AHJ. If it is desired to use distances based on overpressure, see Appendix E.

D1 Cylinders less than 50 L and basis for Table 5

The following is the basis for determining the distances to exposure in Table 5. The thermal radiation modeling assumptions are the same as listed in the notes in Table D-1:

- For public assembly—without PRD in use and storage based on NFPA 55, Table 7.6.2 [23]; with PRD in use based on the instantaneous initial peak flame of 1.6 kW/m^2 thermal radiation and the thermal dose being less than 100, due to the short duration of the flame;
- For property line—without PRD in use and storage based on NFPA 55, Table 7.6.2 [23]; with PRD in use based on the instantaneous initial peak flame of 9.5 kW/m^2 thermal radiation, since the duration is less than 10 s and the thermal dose being less than 100, due to the short duration of the flame;
- For buildings on-site, noncombustible nonrated construction—without PRD in use and storage based on NFPA 55, Table 7.6.2 [23]; with PRD in use and storage based on 25 kW/m^2 thermal radiation;
- For buildings with 2 hr and 4 hr fire rating—all packages are based on NFPA 55, Table 7.6.2 [23];
- For compatible materials or other silane nests—all packages are based on NFPA 55, Table 7.1.11.2 [23]; and
- For incompatible materials—without PRD in use and storage based on NFPA 55, Table 7.1.11.2 [23]; with PRD in storage and use based on 20 kW/m^2 thermal radiation.

Table D-1 provides thermal radiation data for cylinders with PRDs and can be used as guidance for site-specific engineering evaluation to determine appropriate separation distances or design of fire walls for other exposures.

Table D-1—Thermal radiation data for cylinders with pressure relief devices

Thermal radiation kW/m^2	Exposure	Minimum distance to exposure for cylinders with PRD ft (m)		
		Cylinder in use (peak flow) ft (m)	Cylinder in storage (peak flow) ft (m)	Cylinder in storage less than 10 000 ft^3 (283 m^3 or 381 kg) (average flow) ft (m)
1.6	Location where personnel with protective clothing are allowed to be continuously exposed [31].	29 (9)	48 (14)	28 (9)
4.7	Heat intensity in areas where emergency actions lasting up to 3 min are required [31].	25 (8)	46 (14)	27 (8)
6.3	Heat intensity in areas where emergency actions lasting up to 30 s are required [31].	24 (7)	46 (14)	27 (8)
9.5	Heat intensity at any location where people have access – exposure limited to up to 10 s, used for escape only [31].	23 (7)	45 (14)	26 (8)
37.5	Damage to process equipment [32].	21 (6)	44 (13)	25 (8)
Thermal dose $(kW/m^2)^{4/3}s$	The maximum thermal dose reached during the event.[1)]	15 $(kW/m^2)^{4/3}s$	5 $(kW/m^2)^{4/3}s$	5 $(kW/m^2)^{4/3}s$

NOTES

1 The data in this thermal radiation table is based on modeling with the following assumptions:

- A low wind speed of 1.5 m/s and F stability was selected;
- Calculations were made for 44 L size cylinders with 10 kg silane loading. The pressure at the start of the release was 1896 psi at 165 °F; and
- The accuracy of the silane radiation calculations was validated with silane flame testing conducted through CGA [3, 4].

2 For storage:

- The nested volume is equal to or less than 10 000 ft^3 (283 m^3 or 381 kg);
- Silane released through the PRD (rupture disk) and exited through two 1 in holes in the cylinder cap. The jets exiting the cylinder cap were assumed to be horizontal. Two flames are produced, each with 50% of the total flow and are 180 degrees apart;
- One cylinder has a premature PRD failure followed by a second cylinder with a PRD failure 1 minute later, with a maximum of two cylinders relieving at the same time. Justification of using a maximum of two cylinders relieving is based on historical incidents and current practice;
- The average flow column assumes a continuous average release rate of 2 cylinders, which compensates for rapidly decreasing flow, since 1 cylinder has a release time of approximately 2 minutes. The model could not use two flames so the data is for one flame with twice the average flow. This is used for guidance of building and other hazardous materials;
- The peak flow column assumes continuous flow at the peak release rate and shows instantaneous thermal radiation length at the start of the release. This is used for guidance of public assembly and property line, along with thermal dose;
- The maximum thermal radiation was taken with receptor heights which varied from 0 to 12 ft (0 to 4 m); and
- The relieving cylinders were those closest to the receptor.

3 For use:

- Silane released through the PRD (rupture disk) that has three exit holes 120 degrees apart. It is assumed one exit hole is pointing horizontally towards the receptor;
- Once cylinder is relieving. Flame plates between cylinders should prevent additional PRD releases; and
- The peak flow from one, horizontal PRD exit hole was used in the radiation calculations and shows instantaneous thermal radiation length at the start of the release. Using the flow from one horizontal hole was validated by testing to account for the thermal radiation from all three PRD holes.

4 Thermal dose:

- The thermal dose calculation includes the thermal radiation accumulation for the entire event, from full to empty;
- For storage, it was the accumulation of two cylinders relieving with the second cylinder starting 1 minute after the first; and
- For use, it was one cylinder relieving with one flame horizontal and one flame vertical.

[1)] A thermal dose of 100 would cause a first degree burn.

D2 Basis for Table 6

The following is the basis for determining the distances to exposure in Table 6. The starting condition of the silane containers used in the modeling was at 320 g/L fill density, 130 °F (54 °C) and 2400 psi (16 550 kPa). Thermal radiation was taken at the maximum distance with receptor heights that varied that can be seen in the following figures:

- For public assembly—without PRD based on 1.6 kW/m^2 for a pigtail release with .125 in RFO at continuous peak flow, horizontal release; with PRD based on 100 $(kW/m^2)^{4/3}$s thermal dose for a vertical PRD release on ISO modules/tube trailers and a horizontal PRD release on ton tank;

- For property line—without PRD based on 2.5 kW/m^2 for a pigtail release with .125 in RFO at continuous peak flow, horizontal release; with PRD based on 300 $(kW/m^2)^{4/3}$s thermal dose for a vertical PRD release on ISO modules/tube trailers and a horizontal PRD release on ton tank;

- For buildings on-site, noncombustible nonrated construction—without PRD based on 25 kW/m^2 for a pigtail release with .125 in RFO at continuous peak flow, horizontal release; with PRD based on 25 kW/m^2 for a vertical PRD release at continuous peak flow on ISO modules/tube trailers and a horizontal PRD release at continuous peak flow on ton tank;

- For buildings with 2 hr and 4 hr fire rating—all packages are based on NFPA 55, Table 7.6.2 [23];

- For compatible materials or other silane nests—without PRD based on 38 kW/m^2 for a pigtail release with .125 in RFO at continuous peak flow, horizontal release; with PRD based on 38 kW/m^2 for a horizontal PRD release at continuous peak flow on ton tank and used NFPA 55, Table 7.6.2 for a vertical PRD release on ISO modules/tube trailers since 38 kW/m^2 was not reached until an 18 ft (5 m) elevation [23]; and

- For incompatible materials—without PRD based on 20 kW/m^2 for a pigtail release with .125 in RFO at continuous peak flow, horizontal release; with PRD based on 20 kW/m^2 for a vertical PRD release at continuous peak flow on ISO modules/tube trailers and a horizontal PRD release at continuous peak flow on ton tank.

D3 Basis for Table 7

The following is the basis for determining the distances to exposure in Table 7. The starting condition of the silane containers used in the modeling was at 320 g/L fill density, 130 °F (54 °C) and 2400 psi (16 550 kPa). Thermal radiation was taken at the maximum distance with receptor heights that varied that can be seen in the following figures:

- For public assembly—without PRD based on NFPA 55, Table 7.6.2; with PRD based on 100 $(kW/m^2)^{4/3}$ s thermal dose for a vertical PRD release with 100% flow on ISO modules/tube trailers and a horizontal PRD release with 50% flow (since cylinder caps have a minimum of 2 holes) on ton tank [23];

- For property line—without PRD based on NFPA 55, Table 7.6.2; with PRD based on 300 $(kW/m^2)^{4/3}$ s thermal dose for a vertical PRD release with 100% flow on ISO modules/tube trailers and a horizontal PRD release with 50% flow (since cylinder caps have a minimum of 2 holes) on ton tank [23];

- For buildings on-site, noncombustible nonrated construction—without PRD based on NFPA 55, Table 7.6.2; with PRD based on 25 kW/m^2 for a vertical PRD release with 100% flow on ISO modules/tube trailers and a horizontal PRD release with 50% flow (since cylinder caps have a minimum of 2 holes) on ton tank [23];

- For buildings with 2 hr and 4 hr fire rating—all packages are based on NFPA 55, Table 7.6.2 [23];

- For compatible materials or other silane nests—without PRD based on NFPA 55, Table 7.6.2; with PRD based on 38 kW/m^2 for a horizontal PRD release with 50% flow (since cylinder caps have a minimum of 2 holes) on ton tank and used NFPA 55, Table 7.6.2 for a vertical PRD release on ISO modules/tube trailers since 38 kW/m^2 was not reached until an 18 ft (5 m) elevation [23]; and

- For incompatible materials—without PRD based on NFPA 55, Table 7.1.11.2; with PRD based on 20 kW/m^2 for a vertical PRD release with 100% flow on ISO modules/tube trailers and a horizontal PRD release with 50% flow (since cylinder caps have a minimum of 2 holes) on ton tank [23].

D4 Silane Trailers, ISO modules, and ton tank with pressure relief devices for public assembly and property line exposures

Thermal dose is the basis used for packages with PRDs for public assembly and property line distances to exposure. The basis for packages without PRDs is described in the next section. Thermal dose is a method of expressing the accumulation of thermal radiation over a period of time.

The equation for thermal dose is:

$I^{4/3}\,t$

Where:

I = Radiation heat flux in kW/m^2

t = Exposure time in seconds

This is a good method to use for silane releases through a PRD since the releases are very short. The entire contents of a tube or ton tank can be released in a matter of minutes. Some examples of release times follow. Using a constant peak thermal radiation level would overstate the harmful effects of a silane jet fire from a PRD release. The average thermal dose that would cause a first degree burn is 100 $(kW/m^2)^{4/3}s$ and this is the value used for exposures to public assembly. The average thermal dose that would cause a second degree burn is 300 $(kW/m^2)^{4/3}s$ and this is the value used for exposures to the property line. The average thermal dose that would cause a third degree burn is 1000 $(kW/m^2)^{4/3}s$ was not used in this standard but shown in the following figures for informational purposes. In the figures that follow, the thermal dose was calculated by taking the thermal radiation output at peak flow, from the model, then integrating each point for mass flow verses time for the duration of the release.

The silane trailer and ISO module releases are based on a vertical flame jet released from the PRD. Ton tank releases are based on a horizontal flame jet released from the PRD, with one flame at full flow for use and with one flame at 50% flow for storage since cylinder caps have a minimum of 2 holes 180 degrees apart. The thermal dose figures that follow can be used as a guide for a detailed, site-specific engineering evaluation to determine appropriate separation distances or design of fire walls or thermal radiation barriers for public assembly or property line exposures. The ISO modules or tube trailers with 0.85 in and 0.64 in PRD is for a 40 ft unit and with 0.45 in PRD is for a 20 ft unit. The release is vertical from the PRD. The ton tank is for a 450 L container with a horizontal PRD release. A different graph for storage and use is given for each typical PRD orifice size. The distance (ft) is the horizontal distance from the release point and the elevation (ft) is the vertical distance above ground level. The values listed on the curves of the figures are thermal dose units of $(kW/m^2)^{4/3}s$, i.e., 100 = 100 $(kW/m^2)^{4/3}s$.

Figures are also included to show typical time versus pressure of a PRD release. These will show the short duration of the flame jet and how quickly the pressure decreases. The flow is proportional to pressure and will follow the same pressure versus time curve.

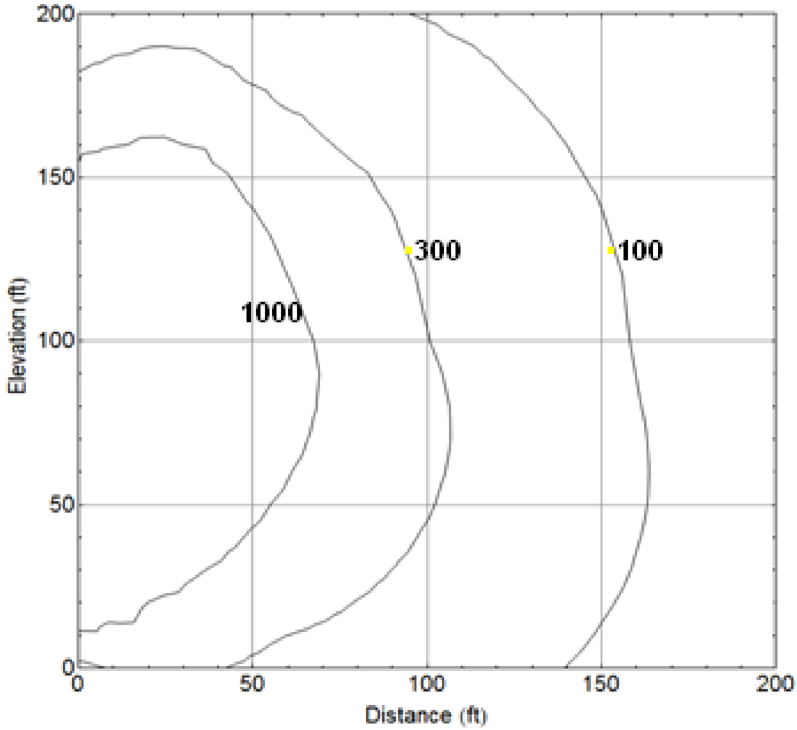


Figure D-1—Thermal dose for ISO modules or tube trailers with 0.85 in pressure relief device

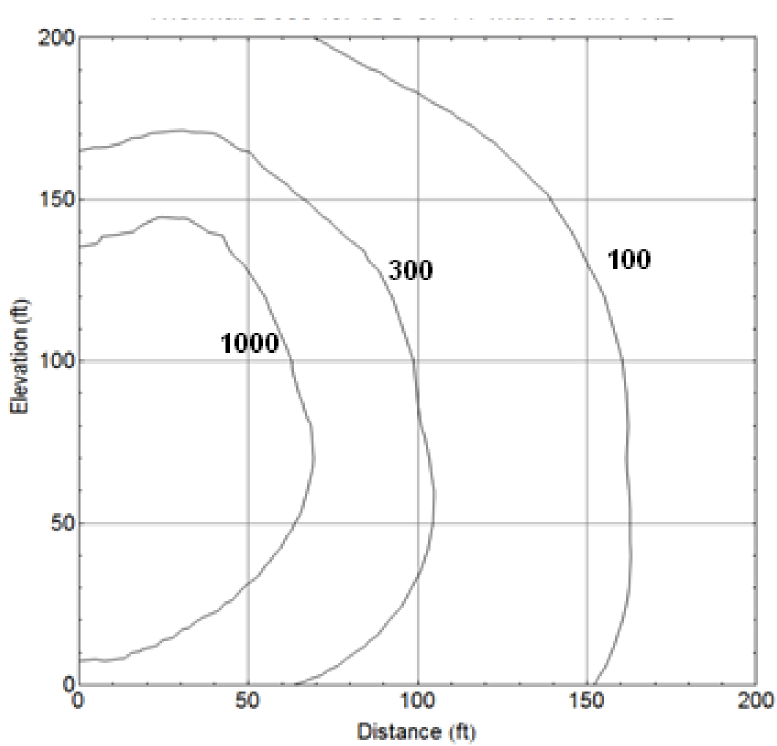


Figure D-2—Thermal dose for ISO modules or tube trailers with 0.64 in pressure relief device

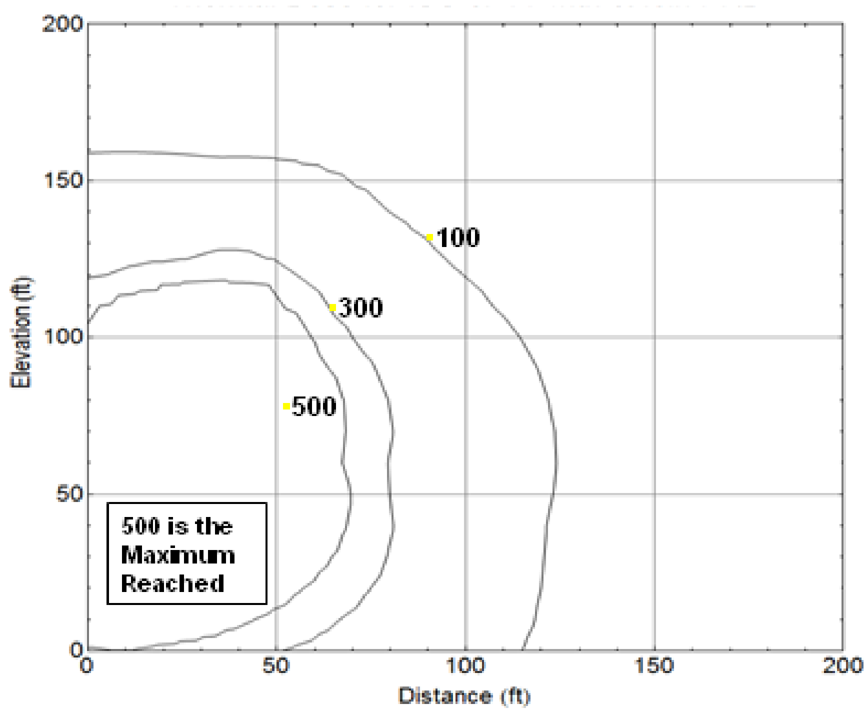


Figure D-3—Thermal dose for ISO modules or tube trailers with 0.45 in pressure relief device

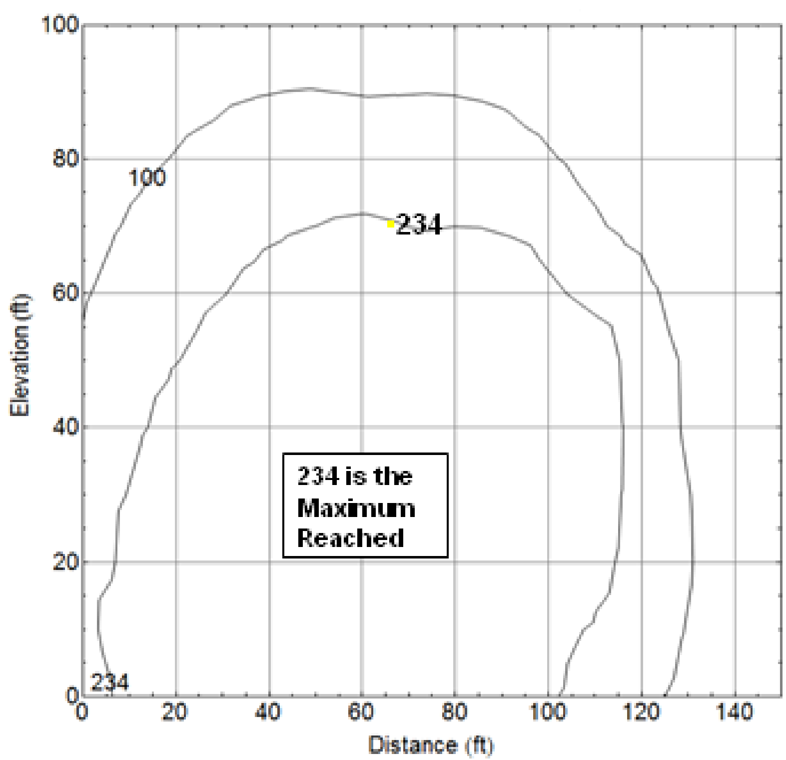


Figure D-4—Thermal dose for ton tank with 0.57 in pressure relief device, 100% flow for use

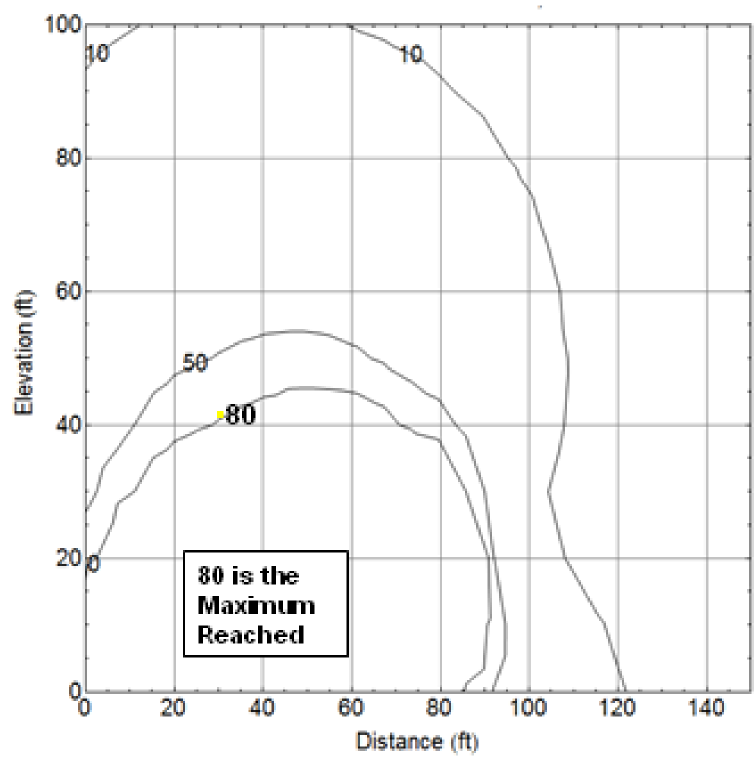


Figure D-5—Thermal dose for ton tank with 0.57 in pressure relief device, 50% flow for storage

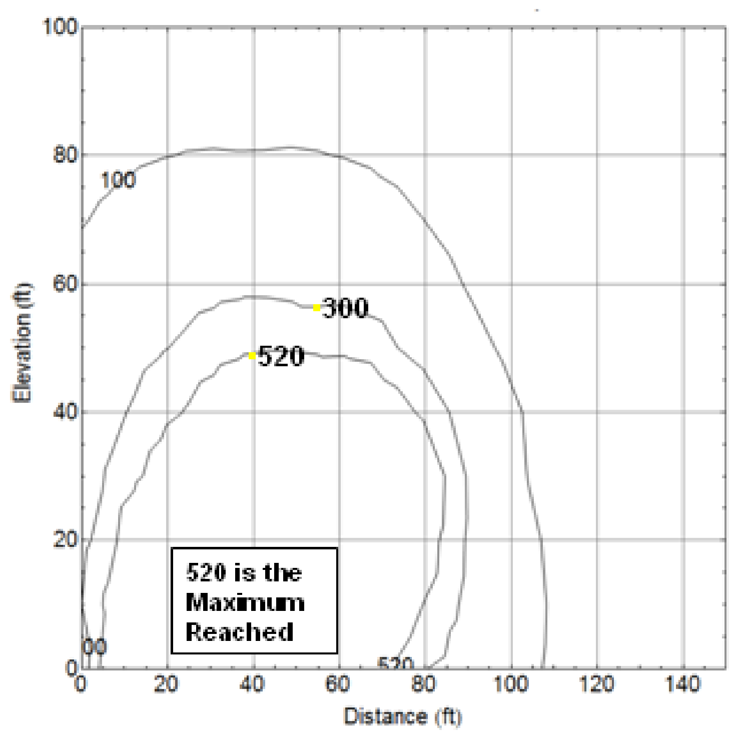


Figure D-6—Thermal dose for ton tank with 0.39 in pressure relief device, 100% flow for use

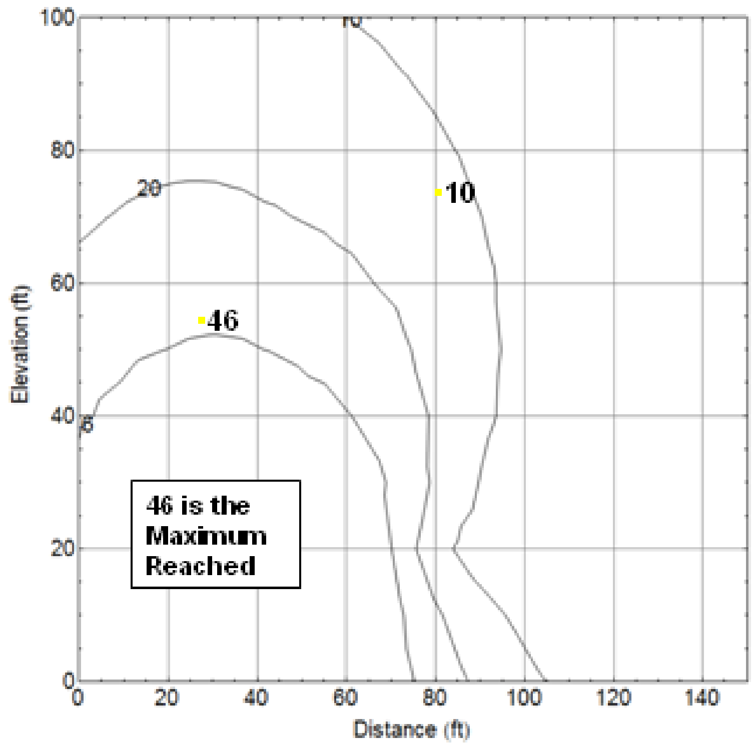


Figure D-7—Thermal dose for ton tank with 0.39 in pressure relief device, 50% flow for storage

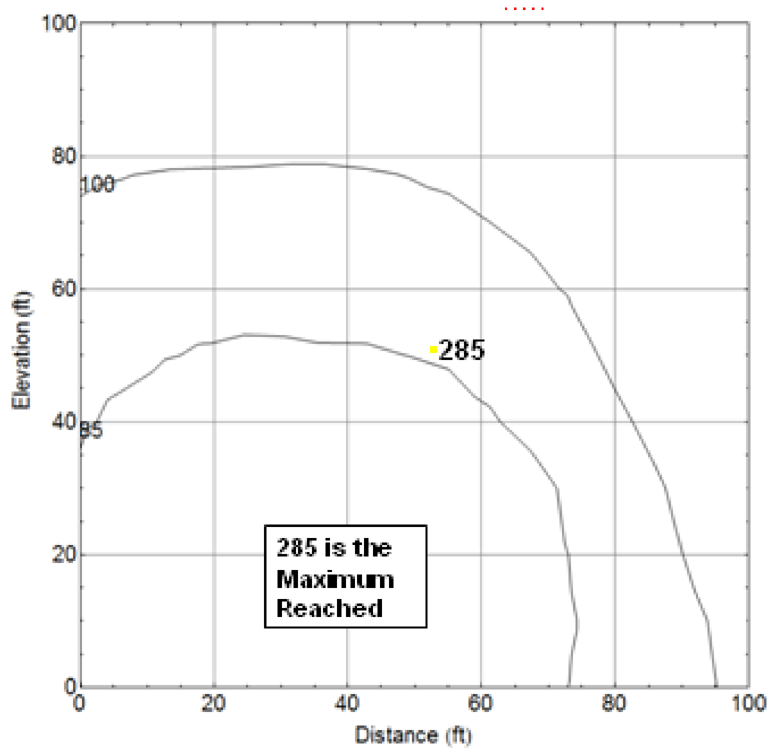


Figure D-8—Thermal dose for ton tank with 0.28 in pressure relief device, 100% flow for use

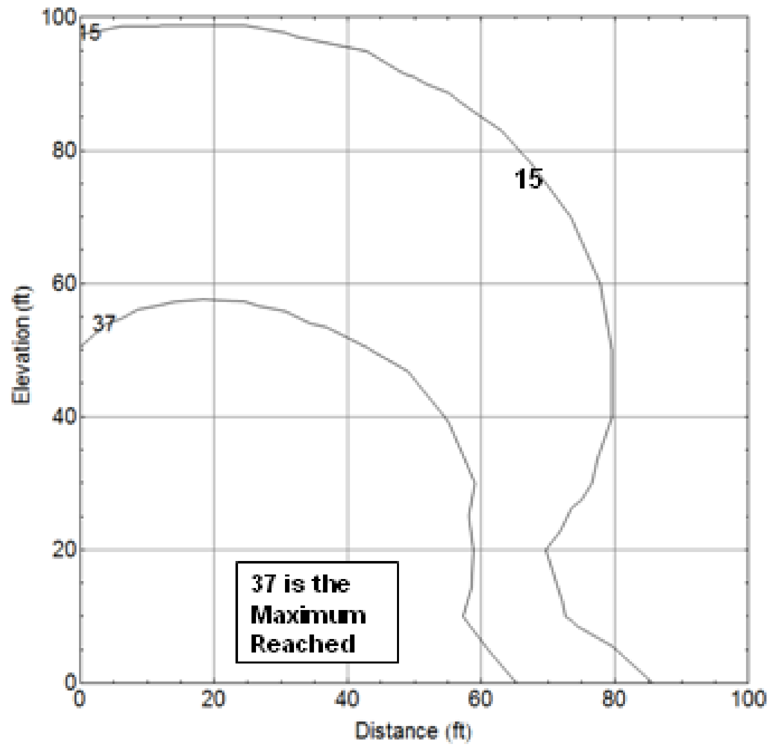


Figure D-9—Thermal dose for ton tank with 0.28 in pressure relief device, 50% flow for storage

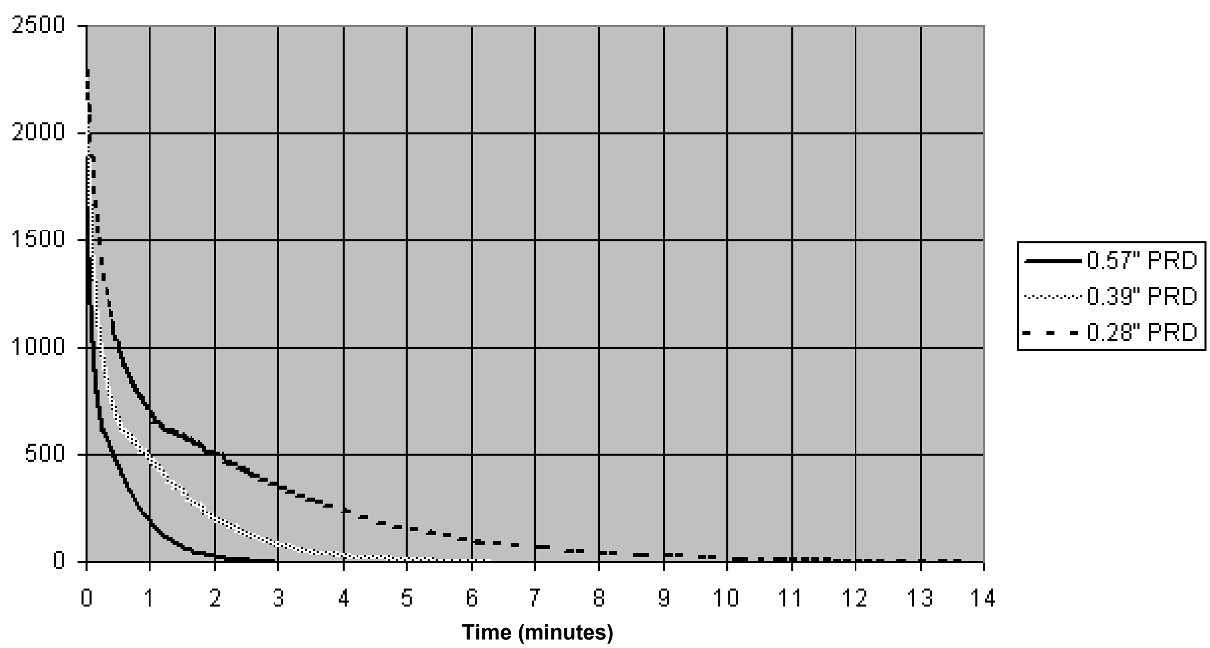
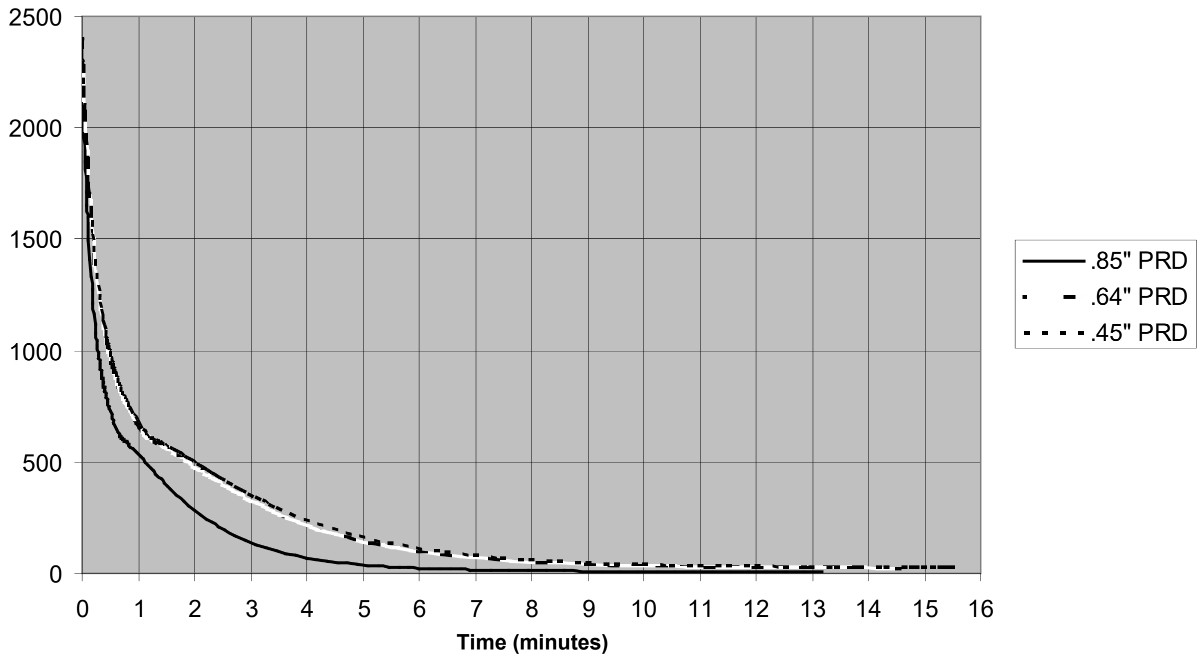


Figure D-10—Pressure relief device release time for a ton tank (450 L container)



NOTE—The curve for the .64 in and .45 in PRD is essentially the same because they are both sized for 50% flow capacity for the given tube size per CGA S-1.1 [21]. The .85 in PRD is sized at 100% flow capacity.

Figure D-11—Pressure relief device release time for tube in ISO container (40 ft tube for .85 in & .64 in pressure relief device and 20 ft tube for .45 in pressure relief device)

D5 Silane trailers, ISO modules, and ton tanks with pressure relief device for buildings and compatible and incompatible materials exposures and without pressure relief devices in use for all exposures

Thermal radiation is the basis used for buildings, compatible materials or other silane nests, and incompatible materials exposures for containers with PRDs. Packages without PRDs, in use (see Table 6), used thermal radiation for all exposures and are based on a pigtail release. The thermal radiation levels are for continuous peak flow rates. This is conservative for PRD releases since the flame jet is a short duration. Pigtail releases are much longer and using continuous peak flow is realistic. The flame jet model used to generate the figures was validated with the silane flame test conducted through CGA [3, 4]. The starting condition used for silane containers were 320 g/L fill density, 130 °F (54 °C), and 2400 psi (16 550 kPa).

The following thermal radiation figures may be used as a guide for a detailed, site-specific engineering evaluation to determine appropriate separation distances or design of fire walls or thermal radiation barriers. The silane trailers and ISO modules figures with 0.85 in and 0.64 in PRD is for a 40 ft unit and with 0.45 in PRD is for a 20 ft unit. The release is vertical from the PRD. The ton tank figures are for a 450 L container with a horizontal PRD release. All packages without PRDs assume a horizontal release. A different graph is given for each typical PRD orifice size. The X (ft) is the horizontal distance from the release point and the Y (ft) is the vertical distance above ground level.

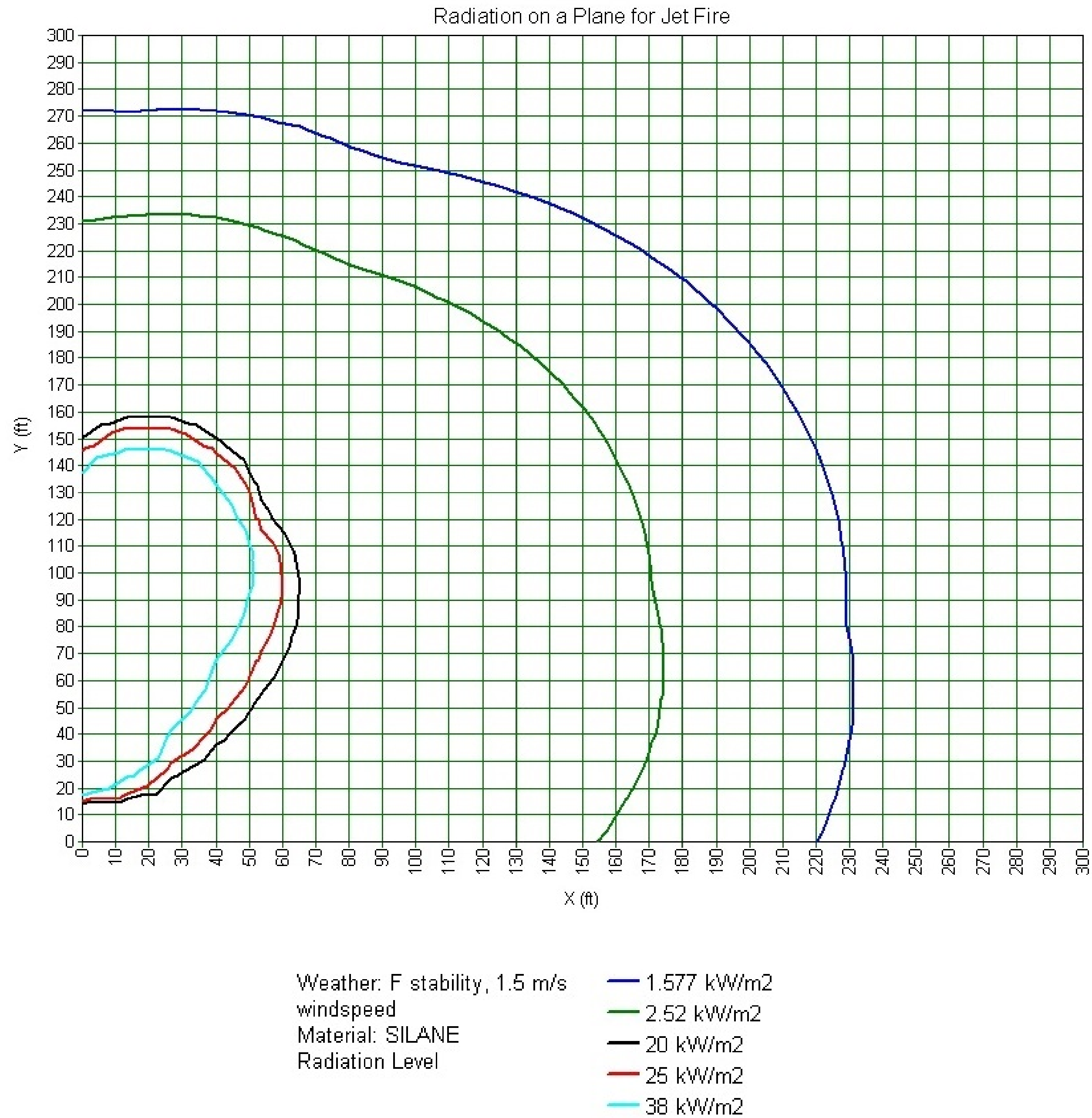


Figure D-12—Thermal radiation for tube trailer and ISO module with 0.85 in pressure relief device

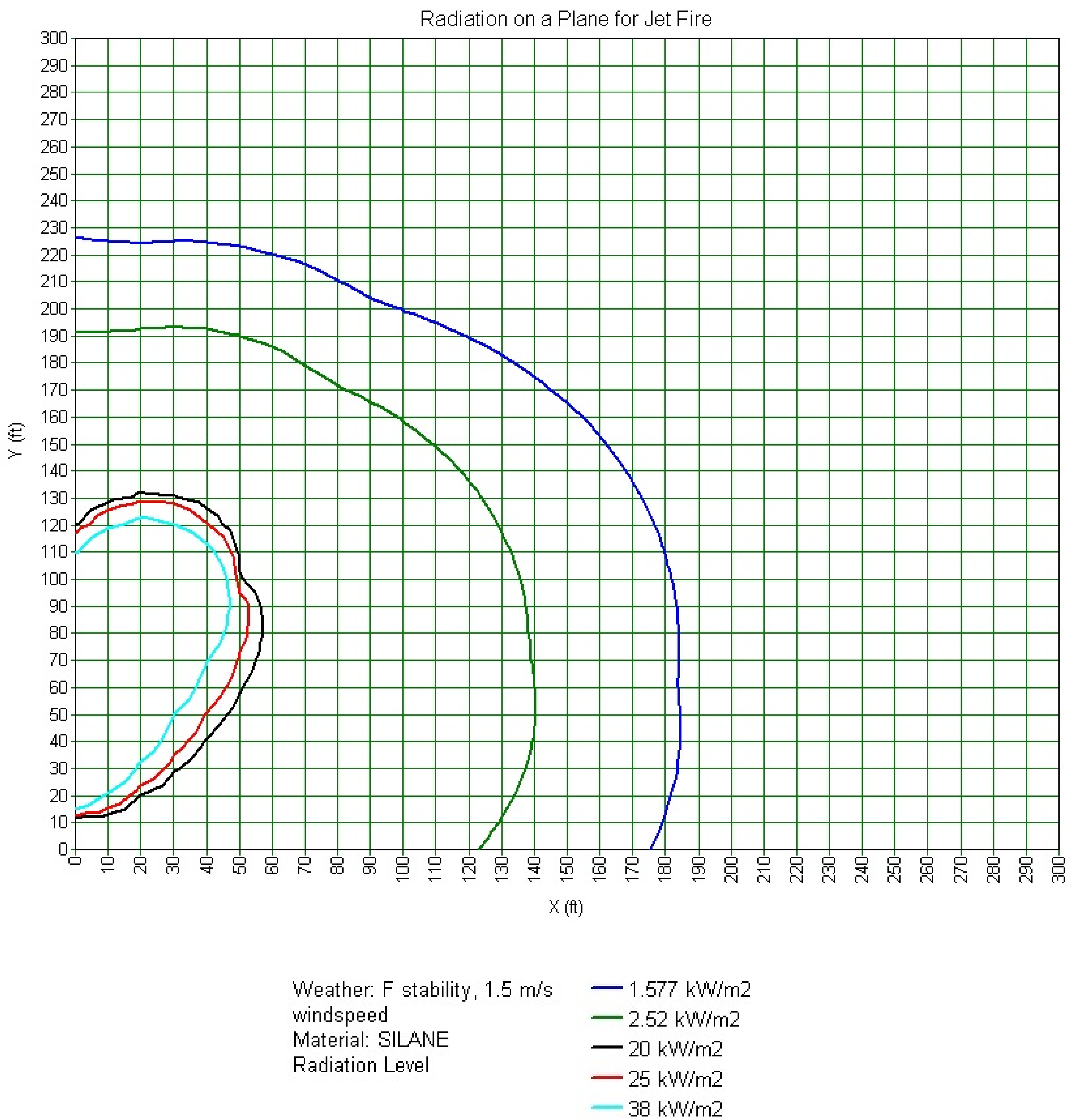


Figure D-13—Thermal radiation for tube trailer and ISO module with 0.64 in pressure relief device

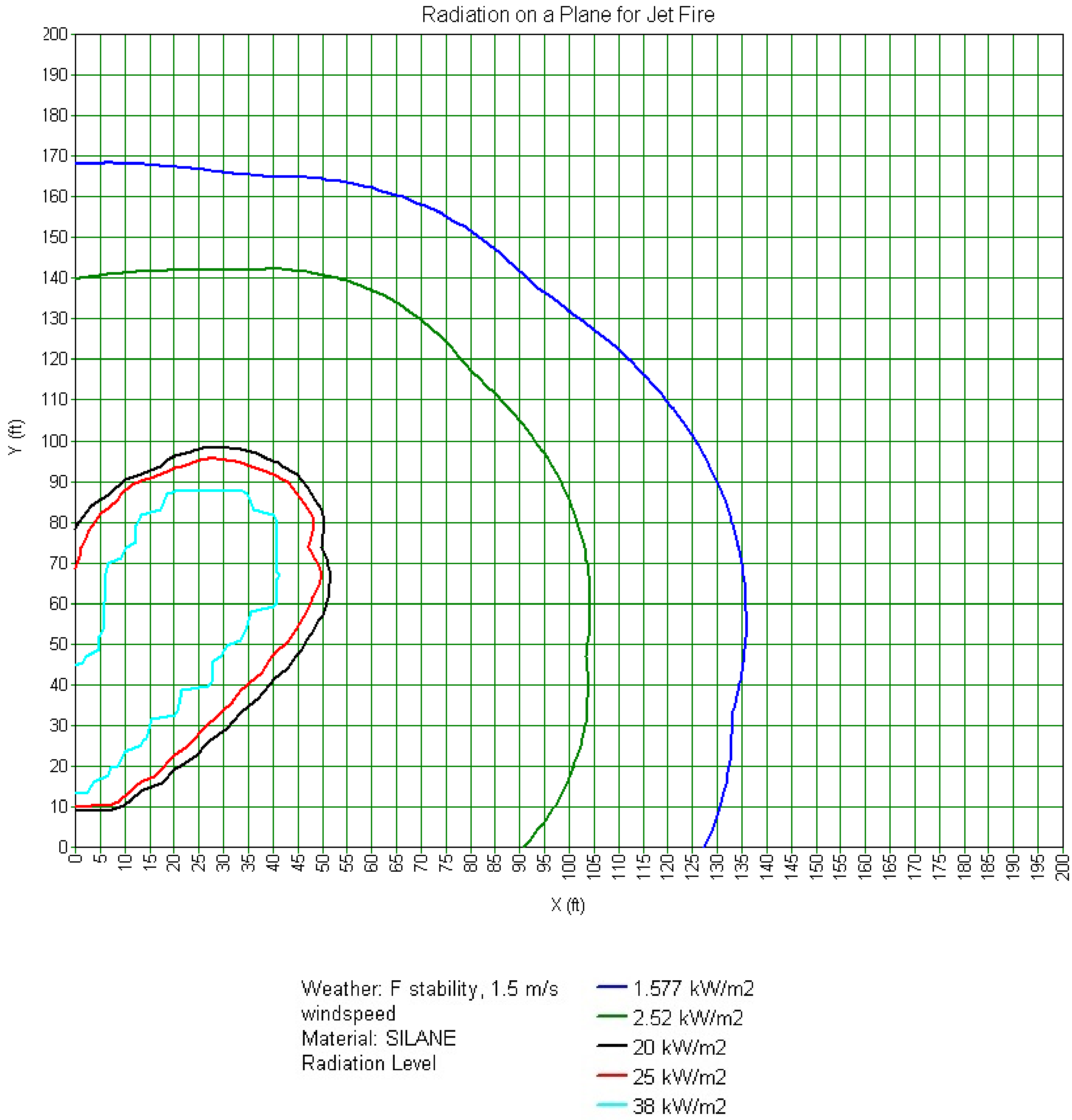


Figure D-14—Thermal radiation for tube trailer and ISO module with 0.45 in pressure relief device

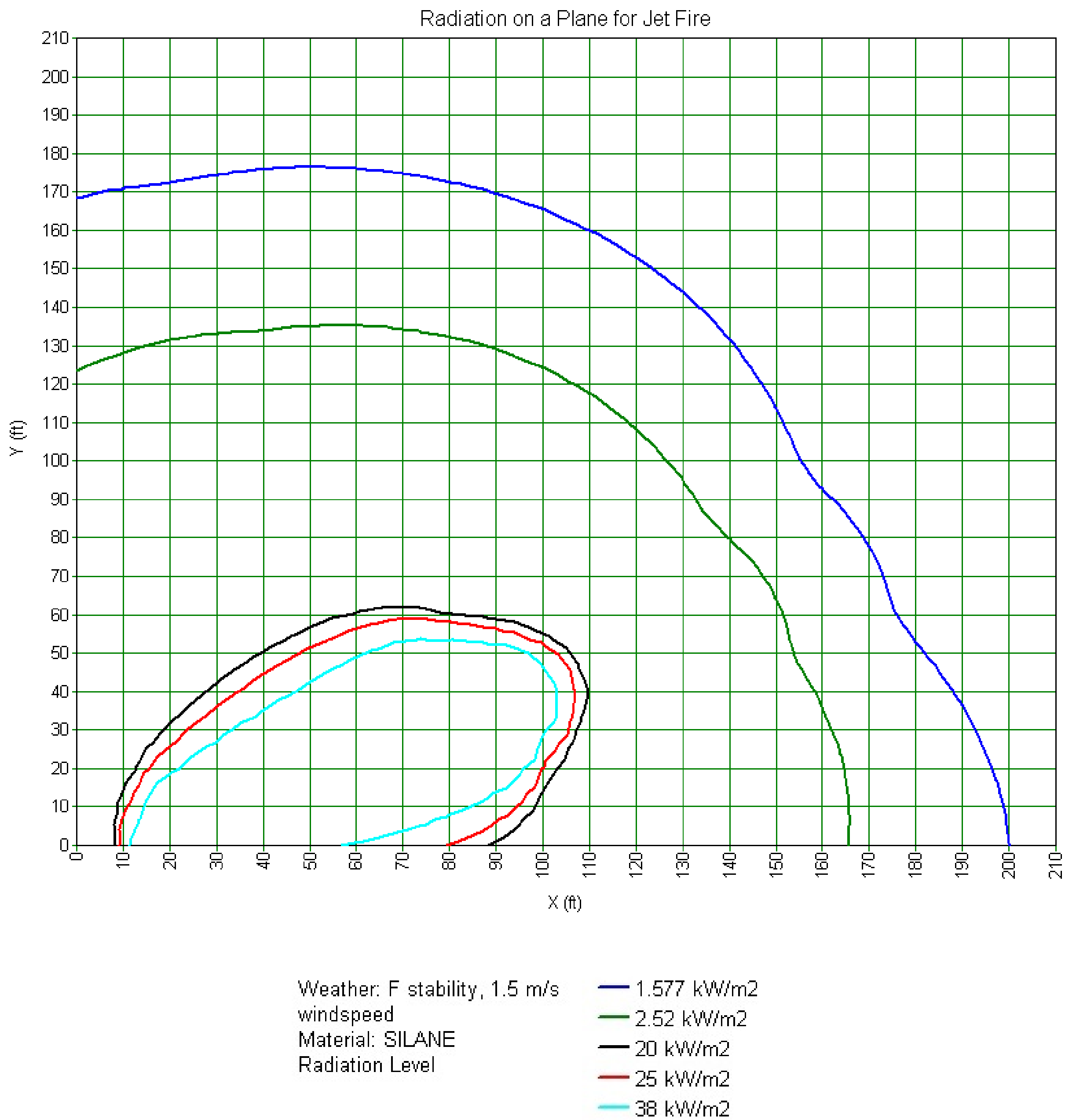


Figure D-15—Thermal radiation for ton tank (450 L) with .57 in pressure relief device, 100% flow for use

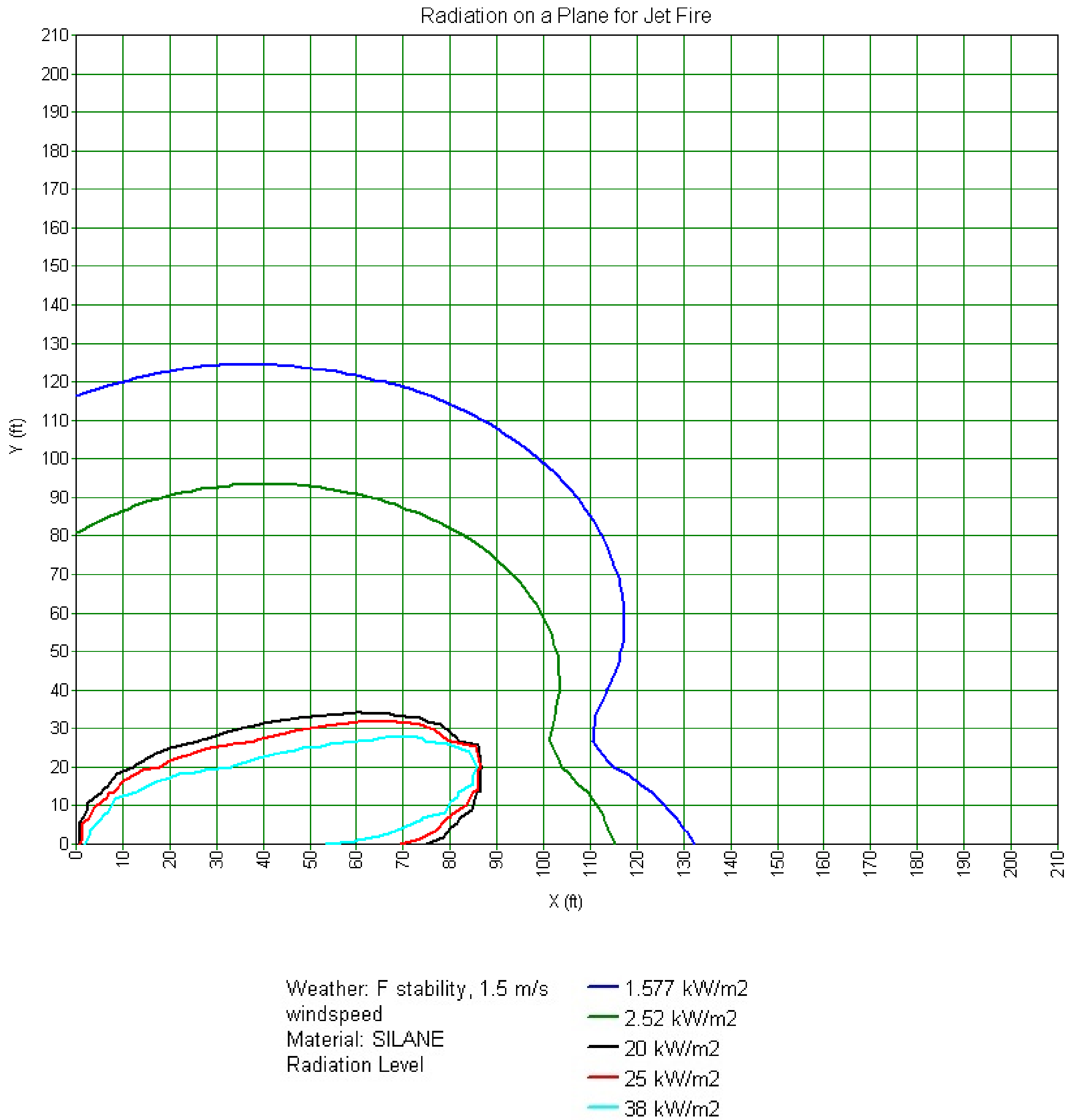


Figure D-16—Thermal radiation for ton tank (450 L) with .57 in pressure relief device, 50% flow for storage

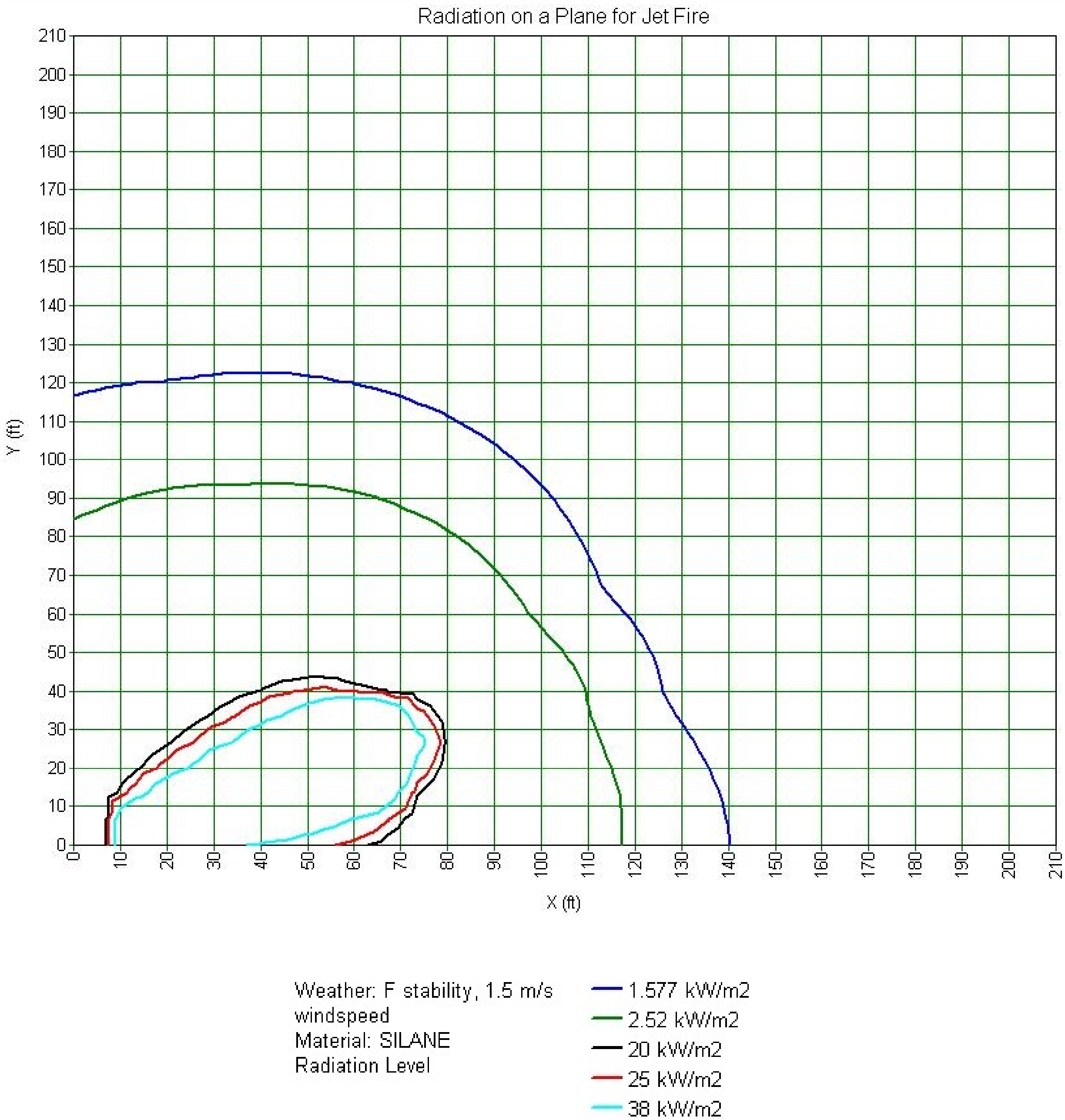


Figure D-17—Thermal radiation for ton tank (450 L) with .39 in pressure relief device, 100% flow for use

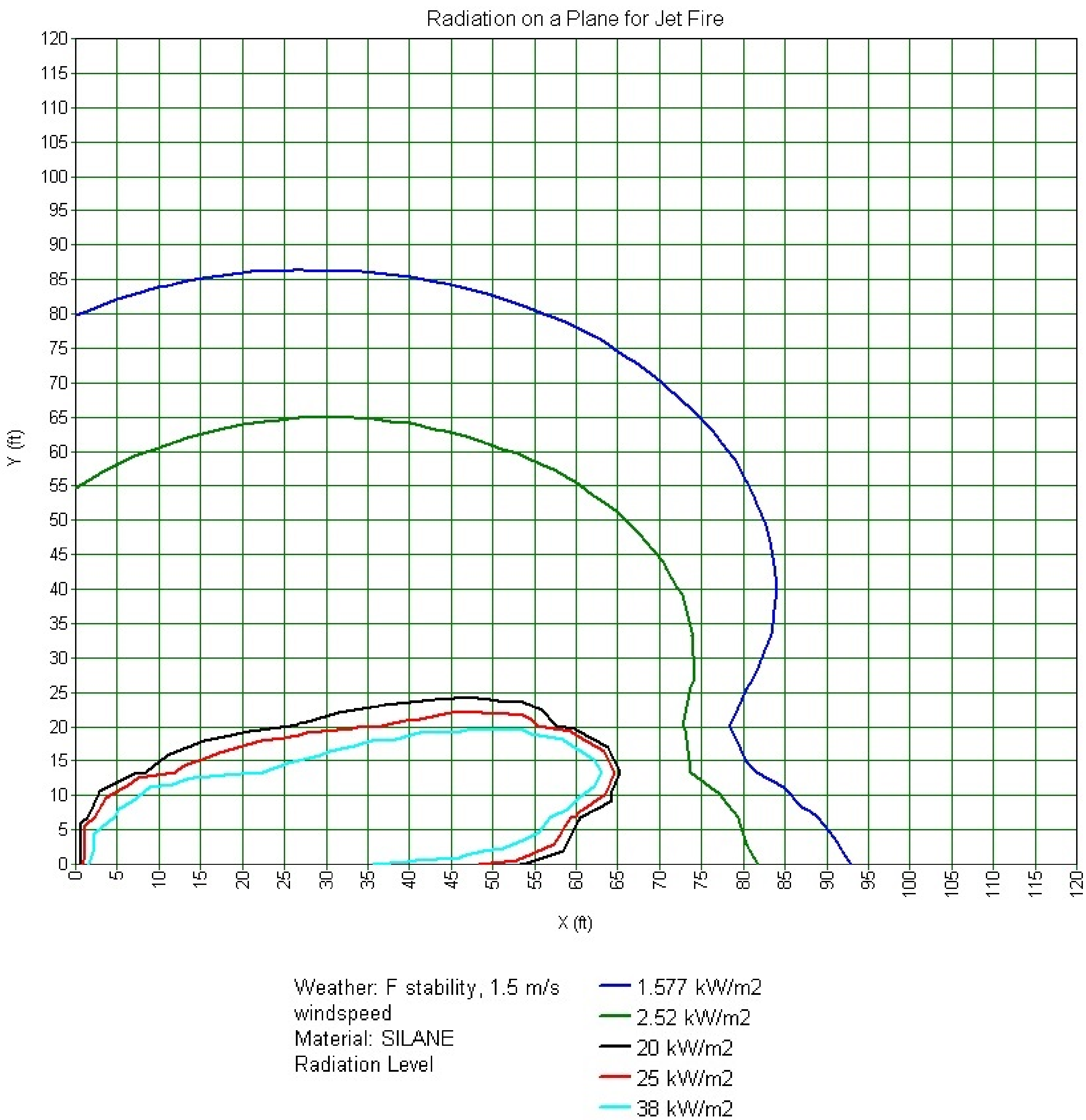


Figure D-18—Thermal radiation for ton tank (450 L) with .39 in pressure relief device, 50% flow for storage

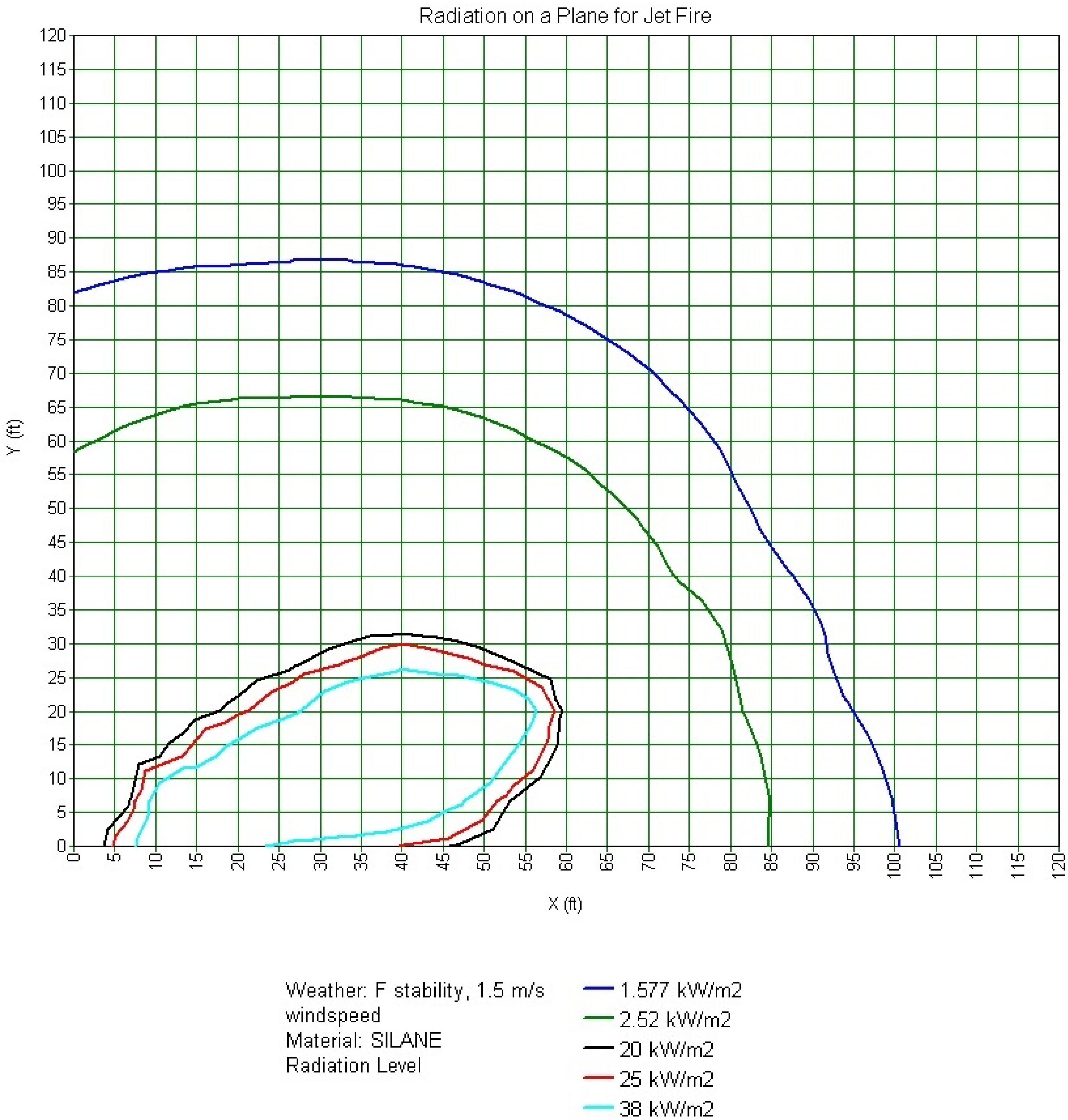


Figure D-19—Thermal radiation for ton tank (450 L) with .28 in pressure relief device, 100% flow for use

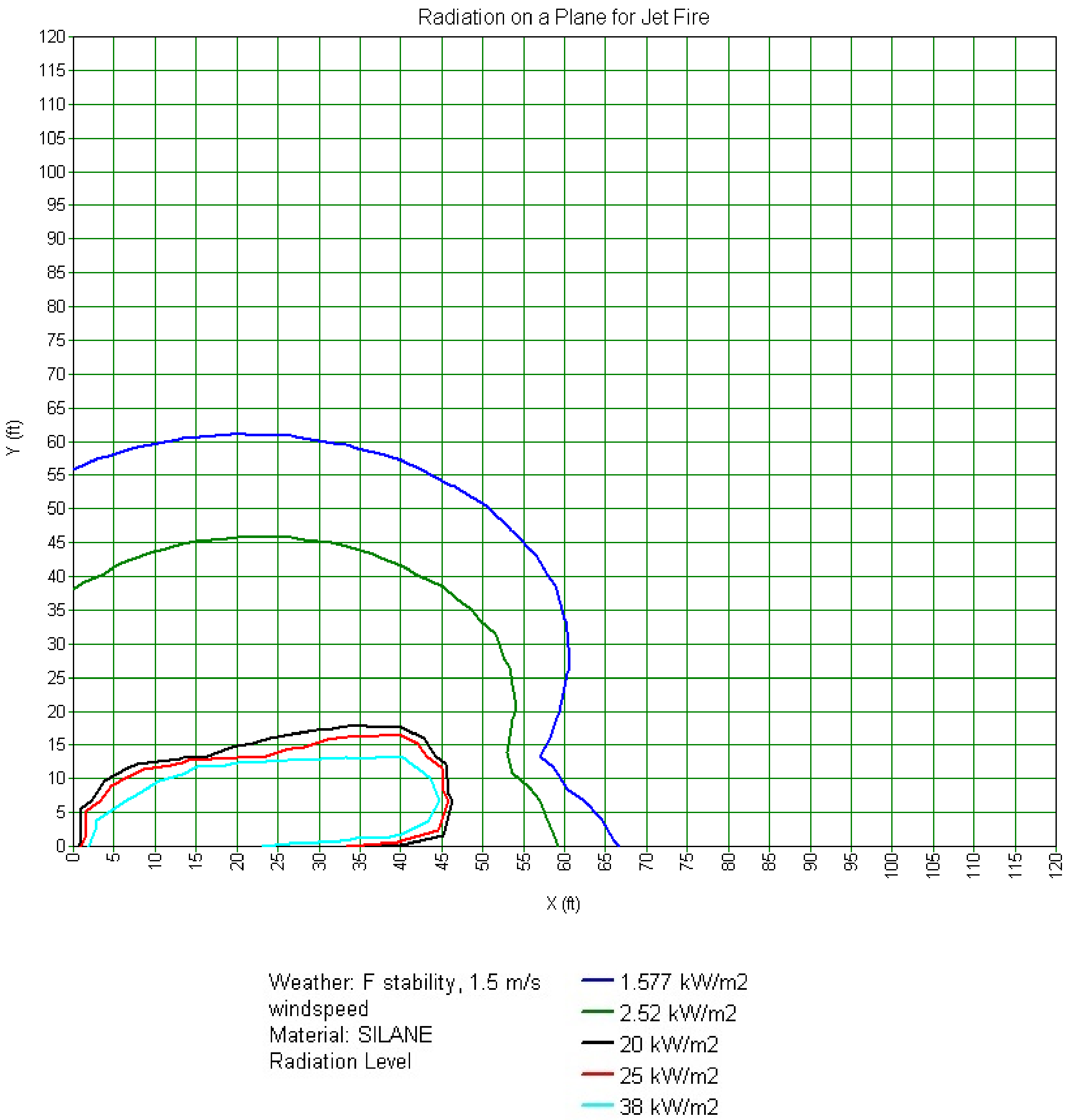


Figure D-20—Thermal radiation for ton tank (450 L) with .28 in pressure relief device, 50% flow for storage

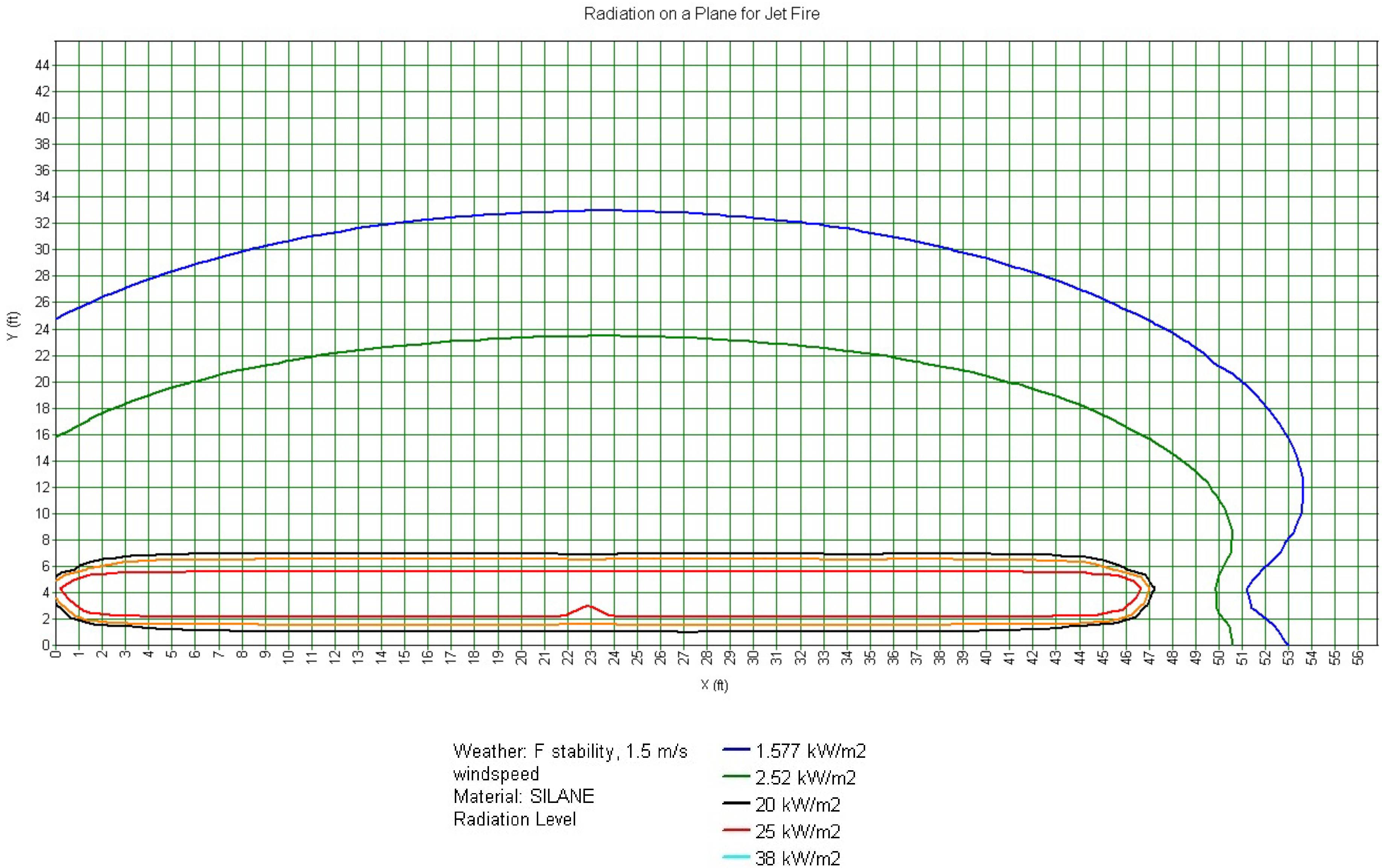


Figure D-21—Thermal radiation for package without pressure relief device and in use—pigtail release with 0.125 in restrictive flow orifice

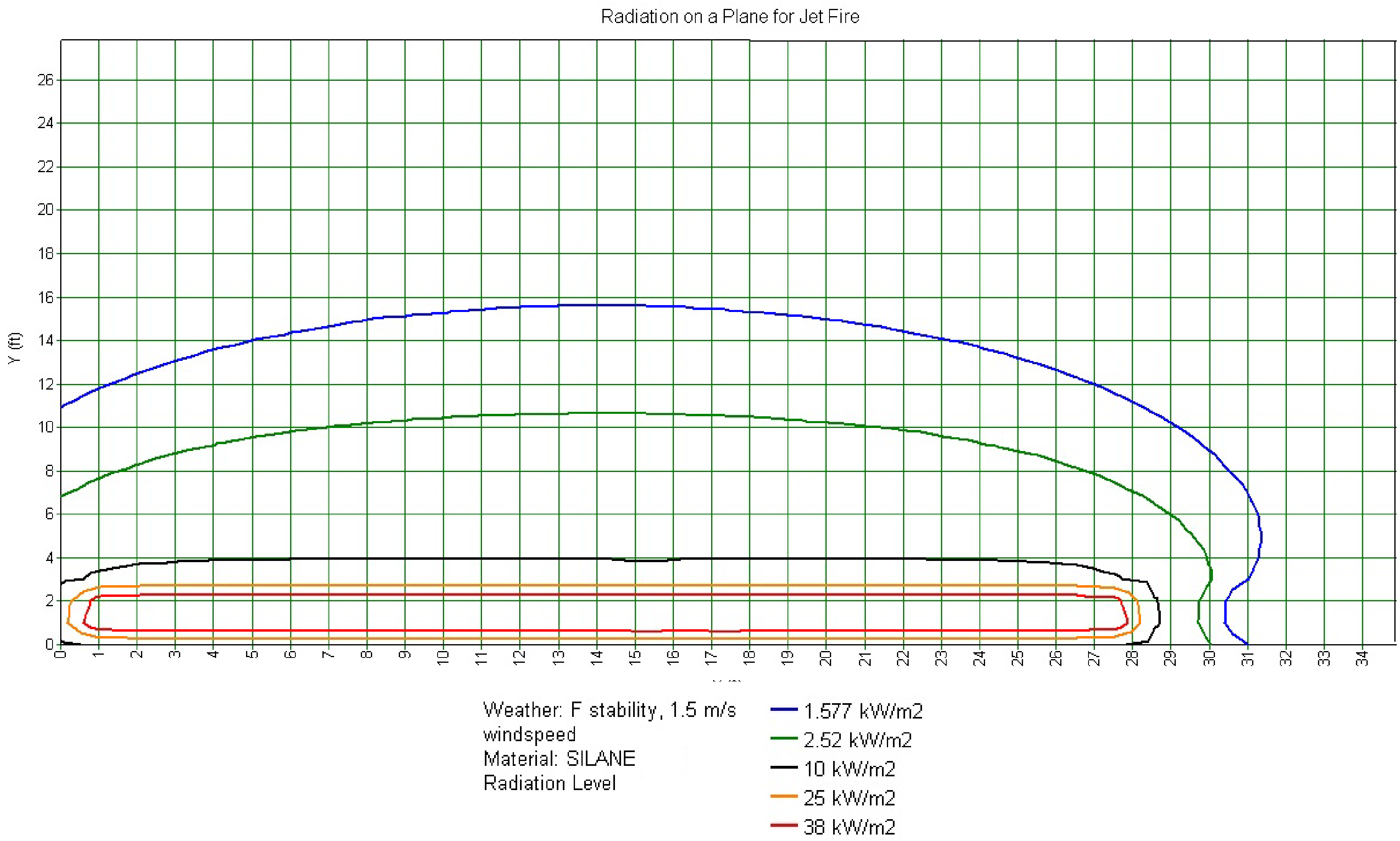


Figure D-22—Thermal radiation for package without pressure relief device and in use—pigtail release with 0.060 in restrictive flow orifice

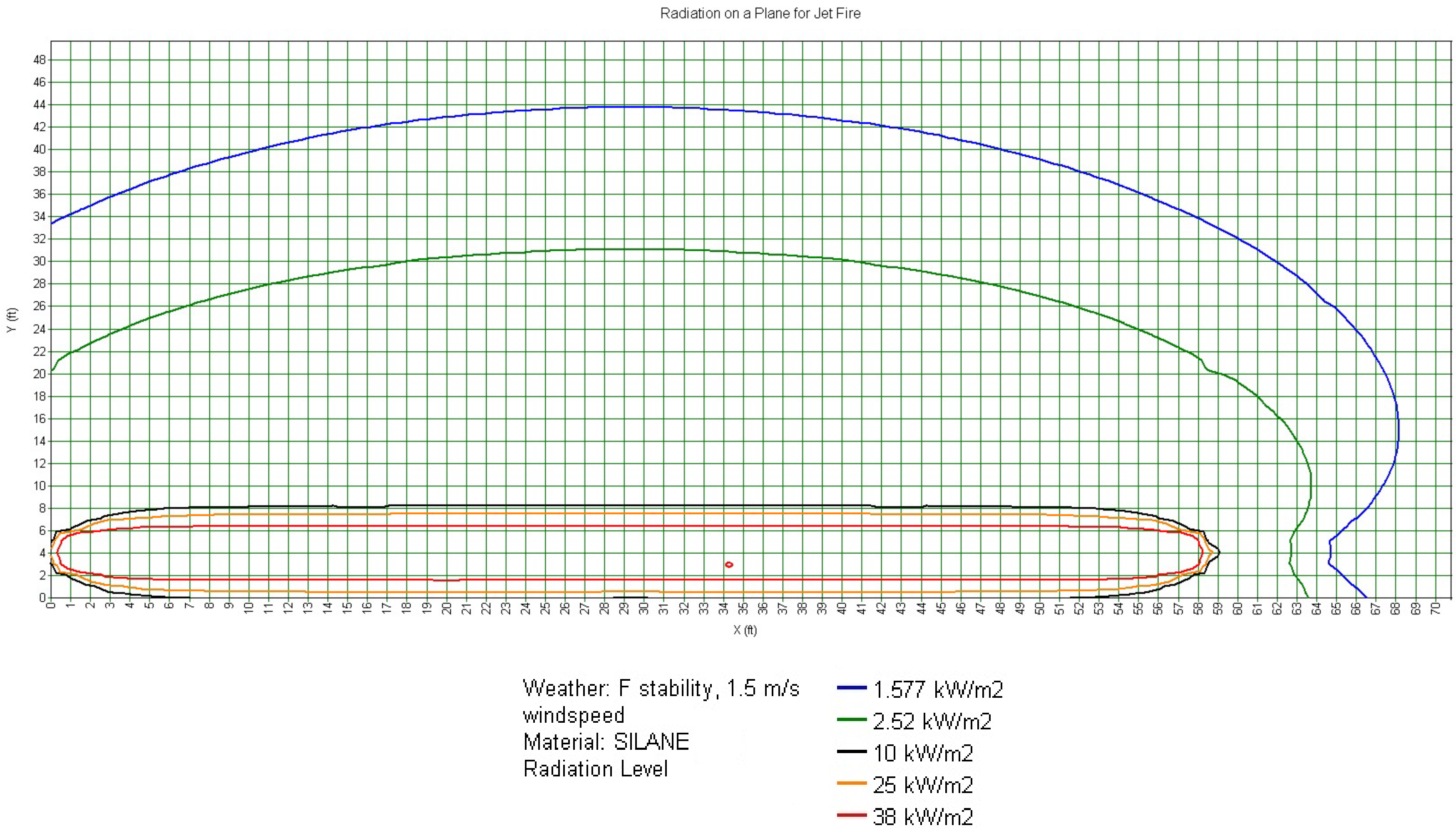


Figure D-23—Thermal radiation for package without pressure relief device and in use—pigtail release with no restrictive flow orifice

Appendix E—Guidance on overpressure based separation distances for bulk silane storage or use (Normative)

For installations that do have three levels of protections against pigtail pull-away accidents as specified in 6.3.2 and Table 6, no further considerations are necessary. Otherwise, a detailed site-specific engineering evaluation is required using the following overpressure guidance in addition to the requirements of Table 6.

Key items in the site-specific engineering evaluation are:
Conduct a hazard analysis to:

- Identify potential release sources;
- Estimate the release size and flammable mass in the silane cloud, including adjustment for obstructed discharge scenarios [33, 34, 35, 36];
- Use a blast model to predict overpressure and positive impulse loads as a function of flammable mass and distance from the source [33, 37, 38, 39];
- Correlate the severity of consequences for each release scenario [40, 41];
- Select tolerable levels of damage and production outage duration, if any;
- Consider risks to potential targets;
- Select an acceptable separation distance for overpressure; and
- Provide the greater separation for thermal (Tables 5, 6, and 7) or overpressure exposures.

Based on the methodology described in references 33, 37, 38, and 39, the following formulas and tables provide a method for estimating the flammable mass of a gaseous silane release and the distance to 1 psi (0.07 bar) overpressure in event of an outdoor explosion. The silane is assumed to be released as an unconfined jet that can be either free or obstructed by the presence of fixed obstacles (such as a solid plate) located directly in the jet's path. These formulas and tables should not be used where accidental silane discharges can be confined or partially confined by walls, roofs, or other structures.

E1 Flammable mass in outdoor unconfined jet releases of silane

Flammable mass, *m* (in kg), in a quasi-steady state jet release of silane can be calculated as follows:

(1) $m = c_1 d^3$

Where:

For PRD failures, *d* = PRD orifice diameter

For pigtail failures, *d* = Diameter of the RFO. If no RFO is provided, use an effective diameter of 4 mm for upstream valves up to 0.55 Cv and outlet connections up to 0.32 in (8.1 mm) internal diameter, regardless of the pigtail diameter

c_1 = Empirical coefficient determined by fill conditions and presence of obstructions to the jet [33]

If *d* is specified in mm, use Table E-1 to determine the value of c_1.

If *d* is specified in inches, use Table E-2 to determine the value of c_1.

Table E-1—Flammable mass coefficient c_1 when d is specified in mm

Fill density [1] (g/L)	Pressure psi at 70 °F (bar at 21 °C)	Unobstructed PRD releases	Obstructed PRD and all pigtail releases [2]
193	1000 (69)	2.6×10^{-4}	1.8×10^{-3}
320	1500 (103)	6.0×10^{-4}	4.2×10^{-3}
360	1865 (129)	6.9×10^{-4}	4.9×10^{-3}

1) Linear interpolation of c_1 versus fill density is acceptable.

2) Treat horizontal PRD and all pigtail releases as inherently obstructed.

Table E-2—Flammable mass coefficient c_1 when d is specified in inches

Fill density [1] (g/L)	Pressure psi at 70 °F (bar at 21 °C)	Unobstructed PRD releases	Obstructed PRD and all pigtail releases [2]
193	1000 (69)	4.2	29.5
320	1500 (103)	9.8	68.7
360	1865 (129)	11.4	79.8

1) Linear interpolation of c_1 versus fill density is acceptable.

2) Treat horizontal PRD and all pigtail releases as inherently obstructed.

Example: If a silane tube trailer has a fill density of 320 g/L and PRD diameter of 0.85 in (21.6 mm), the estimated flammable mass in the jet for a vertical unobstructed release using (1) and Table E-1 is:

$m = 6 \times 10^{-4} \times (21.6)^3 = 6.0$ kg, or

Using Table D-2:

$m = 9.8 \times (0.85)^3 = 6.0$ kg

If the release scenario from the same tube trailer involves a pigtail, with an upstream 1/8 in (3.2 mm) diameter RFO, the flammable mass is determined based on an obstructed release:

$m = 4.2 \times 10^{-3} \times (3.2)^3 = 0.14$ kg; or

$m = 68.7 \times (0.125)^3 = 0.14$ kg

E2 Distance to 1 psi (0.07 bar) overpressure resulting from an outdoor silane explosion

The distance to an explosion overpressure of 1 psi (0.07 bar) is conventionally assumed to be sufficient separation to limit potential building damage to an acceptable or tolerable level. This convention however is only a rough benchmark. Overpressure should not be used alone to select separation distances for buildings because damage levels can vary significantly depending on the building orientation, dimensions, and wall/roof construction as well as the size of the vapor cloud that generates the pressure wave. Lesser or greater distances than the 1 psi (0.07 bar) overpressure radius may be appropriate for some buildings, depending on construction type, exposed values, and criticality of the operations, as determined by a site-specific engineering evaluation.

For preliminary design purposes for exposures to buildings, the separation distance to 1 psi (0.07 bar) overpressure can be used as an estimator to estimate the approximate separation distance for moderate damage due to blast overpressure. The following tables and formulas provide a method for estimating the distance (D) to 1 psi (0.07 bar) overpressure.

E2.1 Distance, *D,* to 1 psi (0.07 bar) for unobstructed pressure relief device releases

For unobstructed, unconfined, vertical releases from tube trailer PRDs:

(2) D (in meters) = 27 x α_{PRD} x d (in millimeters)

(3) D (in feet) = 27 x α_{PRD} x d (in inches)

Where:

d = PRD diameter

α_{PRD} = Given in Table D-3 for representative tube fill densities

Table E-3—Coefficient α_{PRD} for use in distance formula with unobstructed, unconfined, vertical pressure relief device releases

Fill density [1)] (g/L)	Pressure psi at 70 °F (bar at 21 °C)	α_{PRD} for d (mm)	α_{PRD} for d (in)
193	1000 (69)	0.064	1.6
320	1500 (103)	0.084	2.1
360	1865 (129)	0.089	2.3
[1)] Linear interpolation of α_{PRD} versus fill density is acceptable.			

Example: If a silane tube trailer has a fill density of 320 g/L and PRD diameter of 0.85 in (21.6 mm), the estimated distance to 1 psi (0.07 bar) overpressure for a vertical unobstructed release is:

D = 27 x 0.084 x 21.6 = 49 m; or

D = 89 x 2.1 x 0.85 = 159 ft

By comparison, the minimum separation distance required in Table 7 to protect buildings against thermal exposure from the same tube trailer (in storage) is 18 m (60 ft) for a noncombustible building or 1.5 m (5 ft) for a 2 hr fire rated building.

E2.2 Distance to 1 psi (0.07 bar) for horizontal/obstructed pressure relief device releases

For horizontal PRD discharges, as is the case for ton tank (450 L) silane containers, the release will be inherently obstructed, which increases the flammable mass in the jet relative to an unobstructed discharge. The distance to 1 psi (0.07 bar) overpressure for obstructed releases can be determined using (2) and (3) with the coefficients in Table E-4:

Table E-4—Coefficient α_{PRD} for use in distance formula with obstructed pressure relief device release

Fill density [1)] (g/L)	Pressure psi at 70 °F (bar at 21 °C)	α_{PRD} for d (mm)	α_{PRD} for d (in)
193	1000 (69)	0.12	3.1
320	1500 (103)	0.16	4.1
360	1865 (129)	0.17	4.3
[1)] Linear interpolation of α_{PRD} versus fill density is acceptable.			

Example: If a ton tank has a fill density of 320 g/L and PRD diameter of 0.57 in (14.5 mm), the estimated distance to 1 psi (0.07 bar) overpressure is:

D = 27.1 x 0.16 x 14.5 = 63 m; or

D = 88.8 x 4.1 x 0.57 = 207 ft

By comparison, the minimum separation distance required in Table 7 (containers in storage) to protect buildings against thermal exposure from the same container and PRD diameter is 26 m (85 ft) for a nonfire-rated noncombustible building or 1.5 m (5 ft) for a 2 hr fire rated building.

By inspection of these two examples, the obstructed discharge from the smaller diameter but horizontal (obstructed) PRD on the 450 L container generates a stronger blast wave than the unobstructed discharge from the larger diameter PRD. The end result is an approximately 25% increase in separation distance to 1 psi (0.07 bar) overpressure for the smaller PRD. The flammable mass of the vapor cloud is 12.8 kg that corresponds to less than 10% of the total contents of a full 450 L container at the indicated fill density.

E2.3 Distance to 1 psi (0.07 bar) for flexible connector (pigtail) releases

Pigtail releases are assumed to be potentially obstructed. Determine the distance to 1 psi (0.07 bar) based on fill density and alpha coefficients in Table D4, using the RFO diameter. Distances to be used shall be calculated or 50 ft (15 m), whichever is greater.

Example: If a ton tank has no PRD, a fill density of 320 g/L, and RFO diameter of 0.125 in (3.175 mm), the estimated distance to 1 psi (0.07 bar) overpressure is:

D = 27 x 0.16 x 3.2 = 14 m (use 15 m); or

D = 89 x 4.1 x 0.125 = 46 ft (use a minimum 50 ft)

By comparison, the minimum separation distance required in Table 6 (containers in use) to protect buildings against thermal exposure from the same container is 40 ft (12 m) for a nonfire-rated noncombustible building or 1.5 m (5 ft) for a 2 hr fire rated building.

If there is no RFO, use an effective diameter of 4 mm for upstream valves up to 0.55 Cv and outlet connections up to 0.32 in (8.1 mm) inside diameter (ID).