COMPRESSED GASES IN PORTABLE CYLINDERS AND BULK STORAGE

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1.0 SCOPE

This data sheet recommends safeguards to protect property against the hazards of compressed gases in portable cylinders at end-user locations, such as manufacturing facilities, warehouses, and laboratories. Section 4.1 lists other data sheets that address the hazards of specific occupancies, gases, and fixed storage installations. Also follow applicable compressed gas codes and industry standards, as well as gas suppliers' recommendations for handling and storing cylinders.

Cylinder filling-operations and hazards to personnel are outside the scope of this document.

Refer to Data Sheet 7-55, *Liquefied Petroleum Gas (LPG) Storage in Stationary Installations*, for storage and use of liquefied petroleum gas (e.g., propane or butane) cylinders, in other than laboratories.

Refer to Data Sheet 7-108, *Silane*, for storage and use of pyrophoric gases.

Refer to Data Sheet 1-11, *Fire Following Earthquakes*, for additional recommendations for cylinders stored in earthquake-prone areas.

1.1 Changes

July 2023. Interim revision. Significant changes include the following:

A. Title changed to *Compressed Gases in Portable Cylinders and Bulk Storage*.

B. Incorporated recommendations for compressed gas cylinders used in laboratories.

C. Expanded the scope to include bulk storage and handling of liquefied “low flammability” gases used in manufacturing (e.g., 2L refrigerants).

2.0 LOSS PREVENTION RECOMMENDATIONS

2.1 Introduction

The recommendations in this data sheet include the following basic safeguards to help address fire, explosion, and other hazards associated with compressed gas cylinders:

- Loss prevention programs
- Hazard isolation
- Automatic fire protection
- Emergency preparedness

On-going management support is critical to the successful implementation of these safeguards.

Use FM Approved equipment, materials, and services whenever they are applicable. For a list of products and services that are FM Approved, see the *Approval Guide*, an online resource of FM Approvals.
2.2 Construction and Location

2.2.1 General

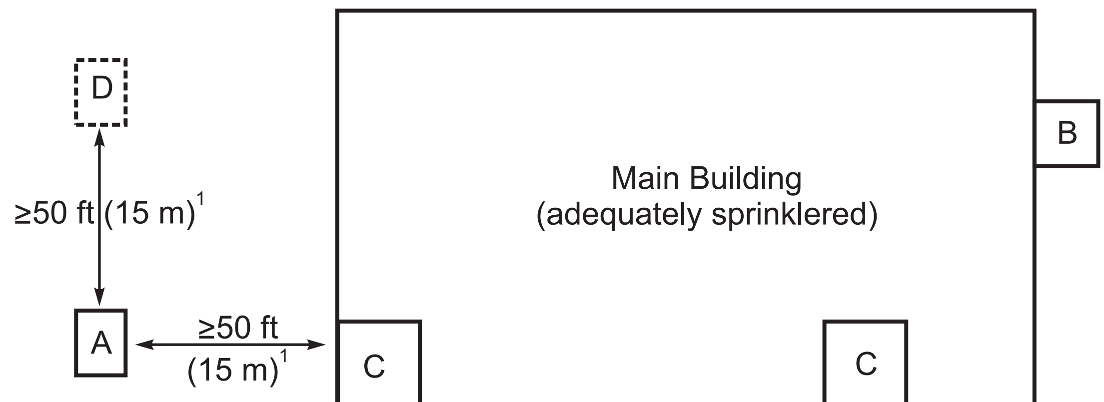
2.2.1.1 Restrict cylinders to designated areas located and constructed in accordance with Figure 1 and Table 1.

Table 1. Construction Types for Cylinder Locations:

Gas Flammability	*Cylinder Location (see Fig 1)*		
	A	B	C
Non flammable	NC	NC[1]	NC[1]
Flammable gases in metal cylinders	NC + DLC	FR + DLC	FR + DLC
Flammable gases in cylinder bundles	NC + DLC	Not recommended	
Pyrophoric gases[2]	NC + DLC	Not recommended for storage	
Flammable gases in composite cylinders[3]	NC + DLC	Not recommended for storage	
Cryogenic liquids	See Section 2.2.6		

NC = Noncombustible wall and roof construction
FR = Fire rating of at least 1 hour on roof and interior walls
DLC = Preferably use open pad with canopy in locations A and B. Otherwise, provide damage-limiting construction per DS 1-44

Note 1: FR if main building is of combustible construction.
Note 2: Follow DS 7-108, *Silane*, for location and construction of rooms for storage and dispensing of pyrophoric gases.
Note 3: Segregate composites from other cylinders. Individual cylinder dispensing in location B or C is acceptable if cylinder is located in a sprinklered area.



Key to locations
A. Detached open pad (with canopy), lean-to, or small building at grade level.
B. Pad (with canopy), lean-to, or cut-off room attached to a blank exterior wall.
C. Inside cut-off room on along an exterior wall. Cylinder transport into and out of the room is direct from outside the main building. The room is on the ground floor, at grade, and is not exposed to fire hazards such as indicated in 2.2.1.1.
D. Exposure to/from outdoor utilities, ignitable liquids, yard storage, process equipment, etc.

Note 1: Closer separation distance may be acceptable based on site-specific exposures.

Fig. 1. Cylinder storage and dispensing locations

2.2.1.2 Provide damage-limiting construction (DLC) per Data Sheet 1-44, *Damage-Limiting Construction*, for rooms and detached buildings in which cylinders containing flammable gas are stored or dispensed from. (DLC for detached buildings may be light, noncombustible pressure-relieving panels on all four walls and roof).

2.2.1.3 Do not allow spare cylinder storage in dispensing areas. One connected reserve cylinder is acceptable where necessary for operations purposes.

2.2.1.4 Install guardrails, bollards, or other substantial barriers to protect cylinders against physical damage where vehicular traffic is expected.

2.2.2 Separation of Gases Capable of Hazardous Interactions

2.2.2.1 Provide a solid, full-height partition wall between gases that are capable of hazardous interactions (i.e., flammable gases and oxygen, chorine, fluorine, and other oxidizers.)

2.2.2.2 If a solid partition wall is not feasible, use a space separation of at least 20 ft (6 m), or use a solid barrier that is at least 5 ft (1.5 m) high with a fire-resistance rating of at least 1/2 hour, extending at least 5 ft (1.5 m) beyond the end of storage.

2.3 Occupancy

2.3.1 Control of Cylinder Inventory

2.3.1.1 Provide labels indicating the name and hazardous chemical properties of the contained gas. Do not rely on color-coding schemes to identify contents and hazards of cylinders.

2.3.2 Housekeeping

2.3.2.1 Keep designated cylinder areas secured to prevent unauthorized access.

2.3.2.2 Conduct recorded housekeeping inspections to ensure cylinders are restricted to designated locations.

2.3.2.3 Limit the contents of cylinder storage rooms to the designated cylinders and any equipment or other non-combustible materials necessary for cylinder handling.

2.3.2.4 Protect cylinders against mechanical damage and keep their valve caps attached at all times during storage and transport.

2.3.2.5 Provide a means to brace and protect cylinders against falling or being knocked over.

2.3.2.6 Keep outdoor cylinders off the ground on a raised concrete pad or noncombustible rack.

2.3.2.7 Separate cylinder storage from dry grass, weeds, and other vegetation by at least 15 ft (4.5 m) of outdoor storage.

2.3.3 Ventilation

2.3.3.1 Provide continuous mechanical exhaust ventilation for areas where cylinders containing flammable, oxidizing, reactive, or corrosive gases are stored or are connected for dispensing. Provide all of the following ventilation system design features:

A. An average fresh air flow rate of at least 1 cfm/ft^2 (0.30 m^3 per minute per m^2) of floor area over the area of storage or use

B. Air exchange throughout the ventilated area

C. Exhaust pick-up within 12 in. (0.3 m) of the floor for heavier-than-air gases, or within 12 in. (0.3 m) of the ceiling for lighter-than-air gases

D. Continuous monitoring with an alarm to a constantly attended location in case of loss of ventilation

E. Labeled manual ventilation controls and emergency overrides located in an area that will be accessible to emergency responders in the event of gas leaks and other emergencies involving the cylinders and any connected process

F. 100% exhaust (no recirculation)

G. Discharge to outdoors at least 50 ft (15 m) from equipment or building air intakes and away from other exposures

2.3.3.2 If high-value property or production could be exposed by a gas release, and the cylinders cannot be relocated, provide ventilated gas cabinets arranged as described in Data Sheet 7-7.

2.3.3.3 Provide ventilation for pyrophoric gas cylinder storage and dispensing in accordance with Data Sheet 7-108, *Silane*.

2.3.3.4 Provide emergency treatment systems (scrubbers) designed to handle potential releases from cylinders containing corrosive gas where such releases could expose important production operations.

2.4 Protection

Provide sprinkler protection as recommended in this section to protect cylinders against exposure fires involving other cylinders and/or combustible materials of construction, as well as combustibles in the occupancy.

2.4.1 Cylinders Containing Flammable Gas

Provide sprinkler protection for the surrounding occupancy and construction as recommended in other applicable FM data sheets, but also meeting the following:

A. Hazard Category 2 for up to 10-15 standard size cylinders, or

B. Hazard Category 3 for greater number of cylinders.

See Data Sheet 3-26 for Hazard Category 2 and 3 protection criteria.

2.5 Flammable Gas Cylinders in Laboratories

2.5.1 General

2.5.1.1 Limit cylinders in laboratories to those connected for use.

The correct orientation of the cylinder is usually vertical to ensure the pressure relief valve does not contact any liquid in the cylinder.

2.5.1.2 Provide permanent labeling for all gases in cylinders. Do not rely on color-coding schemes to identify the contents and hazards of cylinders.

2.5.1.3 All cylinder service valves must be closed when end-use equipment is not in operation.

2.5.1.4 Secure cylinders using bracing, straps, or other appropriate restraints, so that pressure relief devices are in constant communication with the vapor space.

2.5.1.4.1 Secure individual cylinders using straps or other means that do not scratch or damage the paint or protective coating on cylinders.

2.5.1.4.2 Install cylinders so that pressure relief valve discharge does not impinge upon an adjacent cylinder, gas piping or combustible materials.

2.5.1.4.3 Do not connect any piping or fittings to pressure relief valves.

2.5.2 Gas Cabinets

2.5.2.1 Install flammable compressed gas cylinders in continuously-ventilated gas cabinets, or provide continuous mechanical exhaust ventilation systems in the laboratory room in accordance with Section 2.3.3.

2.5.2.2 Install one cylinder per unsprinklered gas cabinet. Gas cabinets with internal sprinklers can have up to two flammable gas cylinders.

2.5.2.3 Do not install incompatible gases (i.e., gases capable of hazardous interactions) in the same gas cabinet.

2.5.3 Ventilation and Exhaust

2.5.3.1 Install mechanical exhaust ventilation in accordance with Section 2.3.3.

2.5.3.2 Where flammable compressed gases are not installed in gas cabinets, provide gas detection systems interlocked with emergency ventilation to increase the ventilation rate to 2.5 cfm/ft^2 (0.75 m^3 per minute per m^2) of floor area if flammable gas is detected at 25% of the lower explosive limit (LEL). Provide manual activation for the emergency ventilation system immediately outside the door of the laboratory.

2.5.3.3 Locate exhaust pickups within 12 in. (0.3 m) of the floor for gases that are heavier than air. Locate exhaust pickups within 12 in. (0.3 m) of the ceiling for gases that are lighter than air.

2.5.4 Gas Detection

2.5.4.1 Install point gas detectors to minimize delay in gas detection and actuation of interlocks.

2.5.4.2 Select and locate gas detectors based on the gases being used. For example, where gases are lighter than air, detectors should be located within 12 in. (0.3 m) of the ceiling. Where gases are heavier than air, detectors should be located at within 12 in. (0.3 m) of the floor. See Data Sheet 5-49, *Gas and Vapor Detectors and Analysis Systems*, for more information.

2.5.5 Incompatible Gases

2.5.5.1 Where flammable gas cylinders are not installed in gas cabinets, separate incompatible gases (i.e., gases capable of hazardous interactions) by at least 20 linear ft (6 linear m).

2.5.6 Laboratory Fire Protection

2.5.6.1 Where flammable gas cylinders are not in gas cabinets, protect the laboratory as an HC-2 occupancy with sprinkler spacing of no more than 10 ft x 10 ft (3.1 m x 3.1 m) to ensure wetting of the cylinder surface. Do not use extended coverage sprinklers.

2.5.7 Gas Piping

2.5.7.1 Use metal piping, tubing, flexible connectors and equipment appropriate for the delivered gas and suitable for the maximum pressures and temperatures that may be encountered.

2.6 Equipment and Processes

The following are general guidelines. For additional safeguards, follow gas codes, equipment suppliers' technical manuals, and industry standards (e.g., AIGA, CGA, and EIGA).

2.6.1 Cylinders and Piping

2.6.1.1 Use only qualified gas suppliers.

2.6.1.2 Ensure cylinders are manufactured, inspected, and filled according to applicable codes and recognized gas industry standards.

2.6.1.3 Use metal piping and equipment appropriate for the delivered gas and suitable for the maximum pressures and temperatures that may be encountered.

2.6.1.4 Connect cylinders to end-use equipment using metal piping and metal flexible connections appropriate for the gas being conveyed.

2.6.1.5 Provide clear marking and labeling of cylinder manifold stations and piping:

A. Indicate the names of gases that are present and their direction of flow in piping.

B. Label emergency shut-off valves, direction to open/close valves, and warnings where flammable gases are present.

2.6.2 Process Safeguards

Apply the following recommendations where cylinders are dispensing hazardous gas to a manufacturing process, experimental apparatus, or other specialized end-use application.

2.6.2.1 Provide an emergency isolation system and other safeguards on the end-use equipment in accordance with a process hazard analysis and the appropriate data sheet (see Section 4.1).

2.6.2.2 Where possible, specify smaller cylinder sizes and lower fill pressures, and use restrictive flow orifices inserted in the cylinder valve.

2.6.2.3 Ensure all pipes and connected devices can be readily purged at process startup and shutdown without the formation of flammable mixtures or the release of flammable, corrosive, or oxidizing gases inside rooms, buildings, or process equipment.

2.6.2.4 Visually inspect regulators and accessible portions of gas piping prior to opening cylinder service valves. Check for signs of corrosion, discoloration, condensation, bulging and physical damage. If any of these conditions exist, lock out/tag out the cylinder and end-use equipment in accordance with established operating and maintenance procedures.

2.7 Operations and Maintenance

2.7.1 Cylinders

2.7.1.1 Establish documented operating procedures for cylinder receiving, handling, and storage.

2.7.1.2 Check cylinders for proper labeling, visible damage, leakage, and overfilling when the cylinders arrive onsite. Promptly return damaged or unmarked cylinders to the supplier.

2.7.1.3 Re-check cylinders for labeling, leaks, and damage prior to transferring them from storage to a dispensing area.

2.7.1.4 Ensure only authorized personnel are given access to cylinders.

2.7.1.5 Use chains or straps or other appropriate securement devices to prevent drops or roll-offs during manual handling and while transporting cylinders by hoist, crane, or truck.

2.7.2 Gas Dispensing

2.7.2.1 Establish documented operating and maintenance procedures for gas cylinder dispensing and connected piping, including transport to and from the process area, change-out at the cylinder manifolds, startup, supply of gas to connected processes, and purging of flammable and corrosive gases.

2.7.2.2 Ensure only authorized, trained personnel are given access to install or remove cylinders and operate or maintain cylinder dispensing stations.

2.7.2.3 Follow the gas suppliers' instructions for operating cylinder valves. Keep valve handles in place for quick emergency shutdown.

2.7.2.4 If a cylinder valve is hard to operate, affix a warning label and isolate the cylinder in a safe outdoor location. Promptly contact the supplier to have it returned.

2.7.2.5 Follow suppliers' specifications and directions for selection, installation, calibration, and proper setting of pressure regulators connected to cylinders and manifolds.

2.7.2.6 Operate and maintain pressure regulators in accordance with the manufacturers' instructions.

2.7.2.7 Use a lock-out, tag-out system for maintenance and repair work on gas cylinder manifolds and piping, as well as any connected processes.

2.8 Training

Provide formal hazard awareness training to help prevent and mitigate property damage and/or business interruption due to potential errors by personnel in handling compressed gas cylinders.

2.8.1 Employee Training

2.8.1.1 Create a hazard awareness training program for all employees who have access to areas where gas cylinders are received, stored, and connected to dispensing manifolds.

2.8.1.2 Provide training in cylinder hazards and related emergency response procedures for emergency response team members and security personnel.

2.8.2 Contractor Training

2.8.2.1 Ensure that contractors who have access to cylinders onsite are adequately trained in cylinder hazards and facility emergency notification procedures.

2.8.2.2 Ensure that all contractors who may introduce, store, or operate compressed gas cylinders onsite are adequately trained to perform the related activities and are familiar with cylinder policies as well as response procedures for cylinder emergencies.

2.9 Human Factor

As part of the facility's property conservation program, establish a written policy and create programs to manage the human factor hazards associated with compressed gas cylinders (refer to Data Sheets 10-0, *Human Factor of Property Conservation,* and 9-7, *Property Conservation).*

2.9.1 Supervision of Programs

2.9.1.1 Designate responsibility for implementing the cylinder loss prevention programs to qualified facility personnel.

2.9.1.2 Provide the designated personnel with appropriate training, resources, authority, and a management reporting channel.

2.9.2 Supervision of Contractors

2.9.2.1 Ensure that contractors' compressed gas cylinders (a) cannot be introduced onto the site without facility authorization and inspection, and (b) are restricted to designated work and storage areas per Section 2.2.

2.9.2.2 Apply all appropriate physical and human factor safeguards per this data sheet to any "temporary" cylinders that may be brought into the facility by contractors for use in testing, experiments, hot work, construction, or maintenance.

2.9.3 Inspections

Inspect designated cylinder areas in accordance with the recommendations in this section.

2.9.3.1 Periodically conduct documented inspections of all designated cylinder areas onsite to verify the following:

A. Housekeeping conditions are satisfactory.

B. Ventilation is in operation.

C. The number and size of cylinders does not exceed authorized limits for each area.

D. Cylinders are not stored outside of designated areas.

2.9.3.2 Arrange security rounds to include all designated areas.

2.9.4 Emergency Response and Pre-Incident Planning

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

2.9.4.1 Develop documented procedures to allow prompt and safe entry to buildings during emergencies such as fires, explosions, and gas leaks in cylinder storage areas, at manifolds, and on connected equipment.

2.9.4.2 Ensure emergency shutoffs for all cylinder dispensing and connected process equipment are well marked, labeled, and located for prompt access at the time of an emergency.

2.9.4.3 Prepare schematics to guide responders and indicate the location, type of gas, emergency access route, and emergency remote controls for processes and ventilation in designated cylinder areas.

2.9.4.4 Train and authorize designated operating personnel to implement the emergency shutdown of cylinder dispensing and process equipment.

2.9.4.5 Include the following information in the pre-incident plan with the local fire service (refer to Data Sheet 10-1, *Pre-Incident Planning,* for general recommendations on establishing and maintaining a pre-incident plan):

A. Designate a liaison to work with the local fire service; choose someone with sufficient knowledge of cylinder locations to enable prompt and efficient response.

B. Use the cylinder roster (see Section 2.3.1.2) or another method to document the designated areas for all portable cylinders authorized to be present on the site.

C. Conduct periodic training sessions for designated employees.

D. Also conduct a joint exercise (drill) involving the public agencies that would normally respond to emergencies.

E. Review the plan effectiveness and update as necessary following changes in designated cylinder locations, training sessions, and exercises.

2.9.5 Audits and Management of Change

2.9.5.1 Conduct periodic self-audits to verify that programs related to compressed gas cylinders are working as intended.

2.9.5.2 Establish documented procedures to manage the hazards of changes relating to compressed gas cylinders that are present onsite, such as the following:

A. Changes in cylinder storage and manifold areas

B. Changes in personnel

C. Modifications to existing processes

D. Installations of new equipment and processes

2.9.5.3. Provide management reporting channels to ensure audit findings that need corrective action are implemented promptly.

2.9.5.4 Maintain all documentation in a readily accessible location for use in training, hazard reviews, emergency situations, and loss prevention audits.

2.10 Ignition Source Control

The following ignition source controls are recommended for any areas where cylinders containing flammable gas may be present in storage or for dispensing.

2.10.1 General Safeguards

2.10.1.1 Prohibit smoking, open flames, and hot work in all rooms or buildings where cylinders containing flammable gas are stored or in use.

2.10.1.2 If hot work cannot be avoided, implement documented procedures to ensure cylinders are first removed and all piping and connected process equipment is verified to have been purged of flammable atmospheres.

2.10.1.3 Manage all hot work activity in accordance with Data Sheet 10-3, *Hot Work Management.*

2.10.1.4 When it is necessary to provide heating for a room or detached building containing flammable gas cylinders, use a steam or hot water heat exchange system, or a hazardous area-rated electrical heating system.

2.10.2 Electrical Equipment

See Data Sheet 5-1, *Electrical Equipment in Hazardous Locations,* for details on electrical ratings and gas groups.

2.10.2.1 Provide FM Approved hazardous location electrical equipment rated as follows:

A. Class I Division 2, or Zone 2 in rooms and other enclosed structures where cylinders containing flammable gas are stored.

B. Class I Division 1 or Zone 1 within 5 ft (1.5 m) of any point where flammable gas piping connections are regularly subject to being opened, such as dispensing stations during cylinder change outs.

2.10.2.2 Maintain at least 25 ft (7.5 m) of separation distance between ordinary electrical equipment and flammable gas dispensing stations.

Exception: cylinders located in ventilated cabinets and exhaust hoods.

2.11 Bulk Storage of Compressed Low Flammability Gases in Manufacturing Occupancies

This section applies to compressed or liquefied low-flammability gases, such as refrigerants having ASHRAE 34 2L flammability, in bulk tanks greater than 1000 gallon nominal water capacity, their associated piping and dispensing systems. The specific gases covered are assumed to have burning velocity less than 1 in./sec (25.4 mm/sec).

For use in closed refrigeration circuits, go to Data Sheet 7-13, *Mechanical Refrigeration*. Refer to Data Sheet 7-54, *Natural Gas and Gas Piping*, for compressed natural gas (CNG) and 7-55 for LP-Gas (Propane).

2.11.1 Location and Installation

2.11.1.1 Locate bulk tanks with minimum separation from important buildings as follows to mitigate the potential for large missile damage in the event of a boiling liquid expanding vapor explosion (BLEVE):

1. 25 ft (7.6 m) for container(s) having individual or aggregate capacity of ≤ 2000 gal (7.6 m^3)
2. 75 ft (23 m) for container(s) having individual or aggregate capacity of >2000 gal (7.6 m^3) and ≤ 60,000 gal (230 m^3)

2.11.1.2 Install bulk tanks on concrete saddles or fireproofed structural steel supports.

2.11.1.3 Ensure that the surface under the tank is level and of a material that can withstand rapid temperature changes associated with a cryogenic liquid spill.

2.11.1.4 Protect the tank area against tampering by chain-link type fencing. Do not use solid fencing or weather shelters enclosed for more than 50% of the perimeter that could impede dissipation of inadvertent releases due to undetected leaks or fugitive emissions during filling.

2.11.1.5 Protect bulk tanks against vehicular impact by steel bollards (minimum 6 in. [150 mm] diameter and 4 ft [1.2 m] height; maximum 4 ft [1.2 m] separation), berms, jersey barriers or equivalent.

2.11.1.6 Keep tank areas within the fencing clear of combustibles such as vegetation, pallets or incidental storage.

2.11.1.7 Protect tank areas against wildland fire exposures in accordance with Data Sheet 9-19, *Wildland Fire*.

2.11.1.8 Implement administrative procedures to prevent incompatible materials from being introduced into the tank.

2.11.1.9 Install a deluge system around the tank to provide wetting to the tank surface in the event of fire exposure to prevent a BLEVE.

2.11.2 Pressure Relief System

2.11.2.1 Design and size the relief system for the bulk tank in accordance with CGA S1.3, Pressure Relief Device Standards, Part 3 — Compressed Gas Storage Containers, or equivalent nationally-recognized standard or regulation. See also Data Sheet 12-43, *Pressure Relief Devices*.

2.11.2.2 Direct relief valve discharge upward and unobstructed to atmosphere.

2.11.2.2.1 Protect the relief valve (or riser) outlet against infiltration of rain or snow.

2.11.2.2.2 Provide a wind sock on site near the tank so wind direction can be monitored in the event of a release.

2.11.2.2.3 If release to atmosphere is prohibited by local regulation, design the relief discharge system to ensure no impediments to relief valve actuation and the design flow rate to the mitigation device (e.g., flare, catch tank, scrubber, etc.) is maintained at all times.

2.11.2.2.4 Where risers or mitigation devices are used, do not install manual shutoff valves downstream of the pressure relief valve or between the relief valve and the mitigation device.

2.11.2.3 Provide redundancy in the relief system to enable manufacturer-recommended inspection and replacement of relief valves while the tank is fully protected.

2.11.2.3.1 Install multiple relief valves connected to a single tank opening on a manual switching valve arrangement as shown in Figure 3 of Data Sheet 7-49, *Emergency Venting of Vessels*.

2.11.2.4 Where long-term compatibility of the refrigerant and the relief valve or system construction materials are not well known, inspect relief valves annually until compatibility is verified.

2.11.3 Outdoor Piping

2.11.3.1 Convey flammable gases from the tank using metallic, welded seamless pipe and welded fittings compatible with the material being handled.

2.11.3.2 Install a restrictive flow orifice or an excess flow valve in the piping system as close to the tank as practicable to limit the refrigerant release if a pipe fails.

2.11.3.3 Bury gas piping between the storage tank and the exterior of the building with at least 12 in. (300 mm) of cover, including final landscaping.

2.11.3.3.1 Provide buried piping with corrosion protection, either a factory-applied coating or a cathodic protection system.

2.11.3.3.2 Where aboveground piping is unavoidable, protect piping and supports from mechanical damage due to vehicular impact, landscaping equipment, etc.

2.11.3.4 Bring buried piping aboveground prior to entering the building and provide dielectric fittings to electrically isolate it from the interior piping system.

2.11.3.5 Install hydrostatic relief protection anywhere liquefied gas could get trapped between two shutoff or isolation valves in aboveground piping.

2.11.3.6 Where branch lines are larger than 2 inches (51 mm), equip each line with a restrictive flow orifice or excess flow valve to limit refrigerant release in the event of a piping failure downstream of the piping manifold.

2.11.3.7 Provide a seismic shutoff valve on piping systems located in FM 50- to 500-year seismic zones (see Data Sheet 1-11).

2.11.3.8 Establish a program of annual inspections of the piping and cathodic protection system (where applicable). Where aboveground piping is unavoidable, include provisions for removing sections of insulation to check for corrosion.

2.11.4 Interior Piping

2.11.4.1 Use metallic, welded, seamless pipe with welded joints and fittings.

2.11.4.2 Use noncombustible and nonabsorbent (e.g., cellular glass) pipe insulation if needed.

2.11.4.3 Arrange interior piping to provide the shortest practical route to the dispensing/charging area.

2.11.4.4 Label interior piping greater than 2 in (51 mm) nominal diameter with “FLAMMABLE LIQUID” or “FLAMMABLE GAS” as applicable and an arrow designating the direction of flow at intervals not exceeding 5 ft (1.5 m).

2.11.4.5 Install clearly-marked emergency shutoff valves that are accessible from floor level or equipped for remote actuation from floor level.

2.11.4.6 Provide hydrostatic relief protection anywhere liquefied gas could be trapped between two emergency shutoff or isolation valves. Direct relief piping outdoors to a safe location.

2.11.4.7 Establish a program for periodic inspection of interior piping for damage or corrosion, including under any insulation.

2.11.4.8 Install FM Approved fire safe shutoff valves at the entry to the building and near the dispensing/ charging areas. Interlock the shutoff valves to shut down in the event of sprinkler waterflow, activation of the emergency shutdown or gas detection at 25% of the LEL in the dispensing/charging area.

2.11.5 Dispensing/Charging Areas

For the purpose of this document, the dispensing/charging areas include any unit testing areas where connections between flammable gas piping systems are routinely made or broken.

2.11.5.1 Perform a process hazard analysis to determine suitable interlocks/process controls.

2.11.5.2 Enclose dispensing/charging areas to prevent flammable gas migration to other areas.

2.11.5.3 Provide fixed gas detectors, interlocked to actuate emergency shutdown if flammable gas is detected in the dispensing/charging area at no more than 25% of the LEL by volume. Maintain and calibrate gas detectors in accordance with manufacturer's instructions and Data Sheet 5-49.

2.11.5.4 Provide continuous mechanical ventilation at a rate not less than 0.5 cfm/ft^2 (0.15 m^3/min/m^2) to dissipate and remove refrigerant released when connections are made and broken (fugitive emissions). A recirculating arrangement is acceptable where gas detection located in the return air path will actuate dampers to divert airflow to full exhaust if the refrigerant concentration reaches 25% of LEL.

2.11.5.4.1 Where refrigerant is lighter than air, arrange mechanical ventilation with exhaust suction within 12 in. (300 mm) of the ceiling.

2.11.5.4.2 Where refrigerant is heavier than air, arrange mechanical ventilation with exhaust suction within 12 in. (300 mm) of the floor.

2.11.5.5 Provide dispensing/charging areas with damage limiting construction (DLC) designed in accordance with Data Sheet 1-44, *Damage Limiting Construction*, using ammonia as the representative gas.

2.11.5.6 Establish a program for periodic inspections of the dispensers and accessible piping using hand-held combustible gas indicators to identify leaks too small to be detected by fixed detectors. These inspections should identify emerging problems that would otherwise be hidden by the pipe insulation.

2.11.5.6.1 When maintenance on the system is required, establish an inerting and purging procedure in accordance with Data Sheet 7-59, *Inerting and Purging Vessels and Equipment*.

2.11.5.7 Ensure equipment used for flammable gas transfer, including packaged or site-erected dispensers, is rated for use in class 1, div 1 (zone 1) hazardous locations in accordance with Data Sheet 5-1, *Electrical Equipment in Hazardous (Classified) Locations*.

2.11.5.8 Install automatic sprinkler protection suitable for an HC-3 occupancy in accordance with Data Sheet 3-26, *Fire Protection for Nonstorage Occupancies*.

3.0 SUPPORT FOR RECOMMENDATIONS

Portable cylinders containing compressed gases are routinely used for many different applications, by and large without incident. However, as illustrated by several loss examples in Section 3.3, indoor releases from these cylinders introduce hazards of potential fire and explosion (flammable gases), increased rates of combustion (oxygen), widespread corrosion (chlorine), and interference with manual firefighting efforts (any gas).

Accidental releases from cylinders may occur as a result of leaking valves or manifold connections, or faulty regulators as well as overfilling, dropping, or rough handling. External exposures, such as impact by lift trucks or fire involving surrounding combustibles, may also cause releases.

An indoor release from a cylinder containing flammable gas can result in the accumulation of a flammable gas cloud inside a room or building, with high likelihood of ignition and a potential deflagration. On the other hand, oxygen cylinders exposed to a fire may overheat and release their contents, causing the fire to accelerate and burn out of control of the sprinkler system. In other cases, relief valves may fail to open and the fire-exposed cylinder may be over-pressurized to the extent of violently bursting and/or rocketing through the facility.

3.1 Location/Construction Safeguards for Portable Gas Cylinders

3.1.1 Flammable Gas Cylinders

A deflagration can occur in a room or building if loss of containment results in a gas-air mixture within the flammable range of the gas. To help mitigate the extent of property damage in the event of a deflagration, FM recommends the location and construction safeguards in Section 2.2.

3.1.1.1 Accidental Releases from Flammable Gas Cylinders

Accidental releases from gas dispensing manifolds and the connected end-use equipment can occur due to leaking connections or malfunction of control devices. Releases may also occur due to operator error during activities such as start-up and shutdown, purging, cylinder handling, change-outs, and making/breaking of high pressure connections.

3.1.1.2 Flammable Gas Cylinder Exposures to Main Facility Areas

Most buildings cannot withstand the internal pressurization caused by a deflagration, even if the amount of gas released can only fill 1 or 2% of the room or building volume with a flammable mixture. Consequently, even a seemingly “limited quantity” of compressed flammable gas, such as the contents of a single cylinder, can represent a deflagration hazard capable of causing significant damage to important equipment or structures. Locating flammable gas cylinders outside of and away from main buildings is recommended as an inherently safer good practice to protect important buildings, equipment and production operations.

3.1.1.3 Damage-Limiting Construction for Cutoff Rooms in Main Buildings

The volume of a typical room can readily be filled with a flammable mixture as a result of even a partial release of contents from a single standard cylinder. Damage-limiting construction (DLC), an engineered explosion-relieving design in accordance with DS 1-44, is therefore recommended to help mitigate damage to adjacent occupancy and buildings.

3.1.2 Nonflammable Gases

Nonflammable gases are potentially hazardous in fire situations where cylinders can be heated and over-pressurized by fires involving combustible construction or contents. In addition, the presence of any gas cylinders in the fire area might cause a delay in emergency response.

3.1.3 Space Separation

The recommended separation distance of 50 ft (15 m) between a detached cylinder storage structure and main building is a guideline to help reduce exposures to and from the cylinders for loss scenarios involving a single cylinder. This distance may not be adequate for extreme scenarios involving multiple cylinder ruptures due to a fire exposure.

3.2 Equipment and Processes

3.2.1 Cylinder Inspection and Requalification

In the United States, cylinders that are transported over public roads and highways must be inspected and tested according to Department of Transportation (DOT) regulations (49 CFR 180.205). Steel cylinders must typically be visually inspected and retested by hydrostatic pressurization every five years, but the regulations allow some steel cylinders to be retested at longer intervals; up to 12 years. Aluminum cylinders must typically be retested every five years.

The date and method of the last requalification must be marked on the cylinder. The key is to have suppliers confirm that cylinders are requalified at regular intervals as determined by local regulations and industry standards (see Section 2.6.1.9).

3.2.2 Inherently Safer Manifolds (Flammable Gas)

Deflagration hazards in rooms and buildings can be significantly reduced by using small cylinder sizes and installing restrictive flow orifices, where feasible for the process.

3.2.2.1 Smaller Cylinder Sizes

Standard-size cylinders contain more than enough gas to fill an entire room with a flammable mixture. Smaller cylinders, where feasible, can reduce the inherent potential severity of a deflagration. Some installations might be able to use smaller cylinder sizes without compromising operability.

3.2.2.2 Restrictive Flow Orifice (RFO)

In some applications, particularly in laboratories, very low flow rates will be needed, and use of an RFO might be feasible. For example, a cylinder fitted with an RFO might take several hours to empty, compared with just a few minutes if the cylinder valve is open all the way with unrestricted flow. To be considered reliable, the RFO must be installed in the cylinder valve outlet by the gas supplier. RFOs are commonly provided on gas cylinders used in semiconductor manufacturing. Gas suppliers will usually provide flammable gas cylinders fitted with restrictive flow orifices upon request by the customer.

3.3 Illustrative Losses

3.3.1 Deflagration in Food Warehouse Due to Leaking LPG Cylinder

A warehouse at a food processing facility contained 20 ft (6 m) high rack storage of food products. A small number of full LPG cylinders for forklift trucks were stored on a 5 ft (1.5 m) high cylinder rack located along an inside wall of the warehouse. An employee working in the adjacent main plant heard a loud “pop” and proceeded to the warehouse, where he observed a vapor cloud rising above the cylinder rack, accompanied by an almost simultaneous loud explosion and expanding fire ball. The steel deck roof was lifted by the overpressure, breaking the deck welds. A concrete block wall was also pushed out and damaged incoming power lines. The explosion and fire ball ignited fires in several in-process pallet loads located in the vicinity of the LPG cylinder storage, but outside of the racks. Two sprinkler elbows were broken by the roof deflection, but fortunately the sprinkler piping remained largely intact and the fires were controlled by building sprinklers and quickly extinguished by personnel and the local fire service.

3.3.2 Deflagration in a Leased Warehouse Due to an Overfilled LPG Cylinder

A tenant leasing storage space in an adequately sprinklered warehouse was separated from an adjacent (exposing) storage area by a concrete block interior partition wall. A full propane cylinder for a forklift truck was stored in an open area of the exposing section of the building. The cylinder is believed to have ruptured as a result of overfilling. A flammable vapor-air mixture formed and ignited, resulting in a deflagration that caused the interior separation wall to collapse onto the tenant’s storage. Sprinklers operated and helped limit the extent of fire damage, but smoke and soot spread throughout the building.

3.3.3 Forklift Truck LPG Fire and Deflagration at Metal Working Plant

An employee on the 3rd shift at a metal working plant was walking by the press shop when he noticed that a forklift truck was on fire. He went to notify the security guard to have him notify the public fire service. When the two next returned to the press shop, they found the forklift totally engulfed in flames. It was then decided that, due to the propane tank on the truck, the building should be evacuated. Immediately following evacuation and prior to the fire service arriving, a deflagration occurred. Activation of the building sprinklers contained the fire to the immediate area around the forklift. However, the deflagration damaged walls, flooring, ceilings, and roof structures in both the press shop and adjoining office areas.

3.3.4 Fire in Retail Store Stockroom Due to Leaking LPG Cylinder

A 20 lb (9 kg) spare propane cylinder for a floor-polishing machine was staged inside the stockroom of a retail store. Vapor began leaking from the cylinder and reached the pilot light of a nearby water heater and ignited. Flames flashed back to the cylinder and spread to the solid pile storage on the mezzanine overhead. Sprinklers operated and controlled further spread of fire until the fire service arrived and extinguished it. The store had to close for cleaning and repairs.

3.3.5 Chlorine Cylinder Leak Results in Production Shutdown

Chlorine gas leaked from a 150 lb (68 kg) cylinder that was located inside a small dispensing room inside a manufacturing area. An emergency response pre-plan was actuated and the leaking cylinder was capped, sealed, and removed by a properly trained Hazmat team. However, there was no direct access to the dispensing room from outside the building, so chlorine gas escaped into the main building area through the open door during the time the cylinder was being capped and removed. Corrosion damage occurred to work in progress as well as motors and equipment controls in the manufacturing area. The entire facility had to be evacuated and the operation was closed down for cleaning and repairs.

3.3.6 Oxygen Cylinders Exposed to Fire

An aircraft maintenance company had three oxygen cylinders chained upright to the wall of a 600 ft^2 (56 m^2) small parts storage room inside an unsprinklered building. Roof and external wall construction was insulated steel panel on steel frame. Internal walls were wood panel on wood frame. An electrical fire is believed to have started in a wall outlet and spread to the wood finish and combustible contents in the room. The public fire service was notified and responded promptly. As they approached the building, one of the oxygen cylinders ruptured and the cylinder fragments rocketed through the roof. The fire service backed away from the building and applied hose streams supplied by two water trucks. Fire consumed the small parts in storage as well as internal walls. Approximately 300 ft^2 (28 m^2) of metal panel roof was detached from the purlins. An internal wall was damaged by overpressure and fire, allowing fire spread into an adjacent parts storage room.

3.3.7 Acetylene Cylinder Detonation Due to Improper Handling by Contractor

One half of a newly constructed addition was partitioned from the unfinished half by a gypsum board wall fastened to aluminum/steel studs. Contractors working in the unfinished section were allocated tool storage areas and workshops. Indications are that detonation of an acetylene cylinder occurred due to improper handling by a contractor. In addition to a fatality, extensive building damage occurred.

3.3.8 Fire at Ethylene Cylinder Manifold Spreads Inside Pilot Plant

An ethylene cylinder failed and caught fire outside the brick wall of a lab and pilot plant area at a chemical facility. Neither were protected by sprinklers. Fire spread inside the lab. After the loss, the facility installed in-line excess flow valves and relocated the cylinders to a reinforced concrete lean-to outside the two labs in which flammable cylinders were located.

3.3.9 Hydrogen Explosion and Fire

Operator error during a manual purge of a hydrogen gas delivery system in a manufacturing facility caused the introduction of excessive hydrogen into ductwork conveying exhaust gases to the burn box (incinerator). A low level explosion occurred in the duct or in the burn box and fire developed in the downstream FRP ductwork, spreading smoke products throughout the manufacturing area. Root causes were identified as improper process design, lack of critical interlocks, and inadequate training for operators. Safety concerns resulted in a delay of 4.5 hours before the emergency responders entered the building.

3.3.10 Rupture of Equipment Connected to Laboratory Air Cylinder

A compressed air cylinder was installed in a manifold supplying an ion spectrometer. The researcher had retrieved the cylinder from the storage area along with a pressure regulator he thought would be appropriate for the application. After the researcher opened the air cylinder isolation valve, downstream gas drying canisters ruptured and fragments and debris were thrown around the room. A subsequent accident investigation determined the immediate cause to be improper selection of the regulator assembly. The root causes were identified as management issues, including poorly defined and enforced policy and inadequate procedures relating to laboratory compressed gas systems.

3.3.11 Operator Error Causes Explosion in University Research Laboratory

An operator replaced a hydrogen cylinder and opened a valve on the manifold in the wrong sequence, which resulted in high-pressure hydrogen entering and overpressurizing a vacuum system. Hydrogen gas from the cylinder flowed into a Plexiglas reactor enclosure, followed by an explosion that damaged the enclosure, the exhaust ductwork, and room ceiling tiles. Following the incident, an investigation was conducted, which identified the root cause as related to “the absence of a formal policy for the systematic oversight of gas handling and safety systems.” The investigation also resulted in recommendations for several engineering and human factor upgrades, including modifications to the gas delivery train and development of documented procedural checklists for gas system change-outs, purging, running, and shutdown. Training and authorization requirements were also recommended to be established for gas system operators.

3.3.12 Hydrogen Vapor Cloud Explosion Following Release from Cylinder Bundle

A flatbed trailer carrying portable gas cylinders was parked on a city street, opposite a six-story office building. The operator was off-loading argon gas cylinders to deliver to a customer. The operator later reported hearing a hissing sound, which he identified as coming from a bundle of 18 inter-connected hydrogen cylinders that were also present on the trailer. A hydrogen vapor cloud formed above the street and ignited, resulting in an explosion that heavily damaged the façade of the office building and broke additional windows on buildings within a radius of approximately 295 ft (90 m).

3.3.13 University Silane Cylinder Detonation

An explosion occurred during a student experiment with a chemical vapor deposition (CVD) system. In addition to causing two fatalities, the force from the explosion broke natural gas lines and ignited a fire that spread to flammable liquids also present in the lab. An investigation revealed that a silane cylinder detonated due to a reaction initiated by the introduction of nitrous oxide, which had flowed “in reverse” through a malfunctioning non-return valve.

3.3.14 Liquid Nitrogen Cylinder Explosion

A liquid nitrogen tank inside a university chemistry laboratory ruptured and caused extensive overpressure damage to walls, windows, and contents of the laboratory. The cylinder section rocketed and pierced through the concrete ceiling into the roof-top penthouse. Investigation of the incident revealed that the pressure relief device (PRD) on the internal tank was missing and the PRD opening was plugged. Corrective actions implemented by the university included: (a) conducting tank inspections as part of laboratory inspections, (b) developing an online training program for personnel working with cryogenics, and (c) retesting or replacing primary relief valves every five years.

4.0 REFERENCES

4.1 FM

Data Sheet 1-11, *Fire Following Earthquake*
Data Sheet 1-44, *Damage-Limiting Construction*
Data Sheet 3-26, *Fire Protection for Nonstorage Occupancies*
Data Sheet 5-1, *Electrical Equipment in Hazardous (Classified) Locations*
Data Sheet 6-9, *Industrial Ovens and Dryers*
Data sheet 6-10, *Process Furnaces*
Data Sheet 7-7, *Semiconductor Fabrication Facilities*
Data Sheet 7-13, *Mechanical Refrigeration*
Data Sheet 7-49, *Emergency Venting of Vessels*
Data Sheet 7-51, *Acetylene*
Data Sheet 7-54, *Natural Gas and Gas Piping*
Data Sheet 7-55, *Liquefied Petroleum Gas (LPG) Storage in Stationary Installations*
Data Sheet 7-59, *Inerting and Purging Vessels and Equipment*
Data Sheet 7-91, *Hydrogen*
Data Sheet 7-92, *Ethylene Oxide*
Data Sheet 7-108, *Silane*
Data Sheet 9-19, *Wildland Fire*

4.2 Other

Mattox, B. *Investigative Report on Chemistry 301A Cylinder Explosion,* Jan 29, 2006. Texas A&M University.

Moskowitz, et. al. ″Lessons Learned from a Hydrogen Explosion at a Photovoltaic Research Facility.″ *World Conference on Photovoltaic Energy Conversion,* 5-9 December 1994.

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Venetsanos, et. al. Source, Dispersion, and Combustion Modeling of an Accidental Release of Hydrogen in an Urban Environment. *Journal of Hazardous Materials,* A105 (2003) 1-25.

4.2.1 National Fire Protection Association (NFPA)

- NFPA 45, *Standard of Fire Protection for Laboratories Using Chemicals,* 2011
- NFPA 55, *Standard for the Storage, Use, and Handling of Compressed Gases and Cryogenic Fluids in Portable and Stationary Containers,* 2013
- NFPA 58, *Liquefied Petroleum Gas Code,* 2014

4.2.2 Compressed Gas Association (CGA)

- *Handbook of Compressed Gases,* 4th edition, Kluwer Academic Publishers, 1999
- CGA G-13-2006, *Storage and handling of Silane and Silane Mixtures*
- CGA G-4.4-2003, *Oxygen Pipeline Systems*
- CGA P-1-2008, *Safe handling of Compressed Gases in Containers*
- CGA P-12-2005, *Safe handling of Cryogenic Liquids*
- CGA S1.3, *Pressure Relief Device Standards*, Part 3 — Compressed Gas Storage Containers

4.2.3 European Industrial Gas Association (EIGA)

- IGC Doc 96/03/E, *Alternatives to Hydraulic Testing of Gas Cylinders*
- IGC Doc 123/04/E, *Code of Practice, Acetylene*

EIGA IGC documents are available for free from: EIGA IGC Documents

4.2.4 Air Products Safetygrams

- #10, Handling, Storage, and Use of Compressed Gas Cylinders
- #12, Regulator Selection, Installation, and Operation
- #13, Acetylene
- #23, Cylinder Valves
- #27 Cryogenic Containers
- #31, Cylinder Valve Outlet Connections
- #46, A Practical Guide to Restrictive Flow Orifices

These and many other Safetygrams are free from: Air Products Safetygrams

4.2.5 Chlorine Institute

- Chlorine Safety Stewardship Bulletin 2 (ll/17/04), *Check Lists for Packaged Chlorine User and Storage Sites*

APPENDIX A GLOSSARY OF TERMS

Cylinder bundle: Group of cylinders that are joined together in a common manifold and transported as one unit.

Dispensing: Piped delivery of the contained gas from a cylinder to the end-use equipment or process, such as a furnace or welding station.

FM Approved: References to ″FM Approved″ in this data sheet mean a product or service has satisfied the criteria for FM Approval. Refer to the *Approval Guide*, an online resource of FM Approvals, for a complete listing of products and services that are FM Approved.

Hydrostatic Relief Protection: Valves designed to relieve the hydrostaticpressure that can develop in sections of liquid piping between closed shutoff valves.

Ignitable Liquid: Any liquid or liquid mixture that is capable of fueling a fire, including flammable liquids, combustible liquids, inflammable liquids, or any other reference to a liquid that will burn. An ignitable liquid must have a fire point.

Laboratory: A facility where the containers used for reactions, transfers and other handling of chemicals are designed to be easily and safely manipulated by one person. A laboratory is a workplace where chemicals are used or synthesized on a nonproduction basis.

Liquefied petroleum gas (LPG): Material composed predominantly of commercial propane and/or butane, propylene, butylene, isobutylene, and butadiene.

Portable cylinder: Compressed gas container(s) of 100 gal water capacity (380 L water capacity) or less capable of being moved within a facility by means of carts or lift trucks.

APPENDIX B DOCUMENT REVISION HISTORY

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

July 2023. Interim revision. Significant changes include the following:

A. Title changed to *Compressed Gases in Portable Cylinders and Bulk Storage*.

B. Incorporated recommendations for compressed gas cylinders used in laboratories.

C. Expanded the scope to include bulk storage and handling of liquefied “low flammability” gases used in manufacturing (e.g., 2L refrigerants).

April 2014. This document has been completely revised. Major changes include the following:

A. Added human factor recommendations.

B. Added cylinder loss examples.

January 2012. Terminology related to ignitable liquids has been revised to provide increased clarity and consistency with regard to FM’s loss prevention recommendations for ignitable liquid hazards.

September 2002. Clarification was made to Table 2, Cylinder Data for Industrial Gases.

January 2000. This revision of the document has been reorganized to provide a consistent format.

September 1998. Reformatted.

May 1994. Technical revision.