Environmental Health and Safety

Compressed gas safety program

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Introduction and purpose

ASU strives to provide a learning, research and teaching environment free from recognized hazards. The university requires safe handling, use and storage of compressed gas cylinders to protect employees and students from potential physical and health hazards associated with using compressed gases in laboratories or other university locations.

Scope and application

ASU employees should understand compressed gas contents and the following guidelines:

- Emergency procedures.
- Health and physical hazards.
- Proper handling, storage and use.

ASU Environmental Health and Safety ensures compliance with the Occupational Safety and Health Administration compressed gas regulations in 29 CFR 1910.101 to 1910.105, 1910.110, 1910.111, the Compressed Gas Association requirements and the International Fire Code.

Compressed gas cylinders can present a variety of hazards due to their pressure or contents. This program covers requirements that must be followed when using all compressed gases.

Flammable and toxic gases defined in EHS 122: Compressed Gases require gas cabinet installation and maintenance approved by ASU EHS Fire Safety and Prevention besides the standard required work practices for inert gases. Additional controls and work practices include:

- Emergency shutoffs.
- Gas monitors.
- Leak testing procedures.
- Proper equipment design.
- Respiratory protection may be required for handling certain toxic and highly toxic gases.

This program provides information for storing, using and handling gases in pressurized portable containers and gas systems. The program's primary focus is on single gas uses and systems. Additional requirements may be applied to:

- Large, compressed gas facilities, storage areas or use areas.
- The use of multiple gases in a single control area or building.

All compressed gas permanent installations must follow the Capital Programs Management Group permitting process. All toxic, highly toxic, pyrophoric or flammable containers must include gas cabinet installation and maintenance approved by ASU EHS Fire Safety and Prevention. Email ASU EHS Fire Safety and Prevention to request approval.

Design installation requirements are based on the application and occupancy designation. Approved uses of flammable compressed gases are identified at the point of use by EHS and CPMG in evaluating regulatory compliance during inspections. Point-of-use identification includes approved gases and concentrations, quantity and approval date.

Responsibilities

Academic unit leadership

Academic unit leadership is responsible for establishing and implementing department information and training programs for their respective areas. It is acceptable to delegate this responsibility to the principal investigator, laboratory supervisor or manager, compliance officer or safety committee. It is the responsibility of the unit leadership, dean, director, chair or designee to:

- Acquire and provide adequate instruction for employees in compressed gas cylinder use and maintenance.
- Ensure that university policies are enforced, and safe work practices are followed.
- Understand the work area processes and hazards.

Environmental Health and Safety

EHS is responsible for the following:

- Assisting, advising and instructing university employees in compressed gas cylinder and gas systems care and handling. This includes providing training.
- Ensuring that university policies are enforced, and safe work practices are used.
- Providing gas system planning guidance for new construction and renovation.
- Reviewing and approving procedures for controlled toxic, highly toxic, flammable, pyrophoric or hazardous gases.

Fire Safety and Prevention

ASU Fire Safety and Prevention reviews permit requests for consistency with all applicable codes, standards and locally adopted specifications, including, but not limited to the following codes:

- ANSI/CGA G-13-2015 — Storage and Handling of Silane and Silane Mixtures.
- International Fire Code 2018.
- National Fire Protection Association:
  - 2 — Hydrogen Technologies Code.
  - 13 — Standard for the Installation of Sprinkler Systems.
  - 45 — Fire Protection for Laboratories Using Chemicals.
  - 55 — Compressed Gases and Cryogenic Fluids Code.
  - 72 — National Fire Alarm and Signaling Code.
  - 101 — Life Safety Code.

Contact ASU Fire Safety and Prevention for questions.

Responsible parties

EHS 005: Management Policy requires the university to be a quality model in environmental, health and safety. PIs, lab managers, and authorized designees will:

- Assist and review storage and installation procedures, ensuring safe work practices are used.
- Coordinate activities between compressed gas users and the EHS department.

ASU employees and students

- Obtain required training to work in the laboratory area safely.
- Perform work with compressed gases per ASU policies and prudent safe work practices.

Training requirements and competency assessment

ASU employees — faculty, staff, researchers and employees —who physically transport gas cylinders or make connections to compressed gas systems for use at ASU must complete the Compressed Gas Safety training.

Lab-specific training is adequate for connecting tubing or adjusting flow valves for pressures less than 30 psi, except for highly toxic and pyrophoric gases. EHS provides web-based Compressed Gas Safety training, which includes a mentorship component that requires each participant to demonstrate competency in handling and using compressed gases. The training is required upon initial assignment, and a recommended refresher is provided every three years.

ASU faculty members sponsoring graduate students, visiting researchers or other personnel not identified above are classified as qualified licensed contractors and must follow this policy. Different training programs may be acceptable, and EHS may give credit after verifying equivalency. Please email EHS for more information.

The PI or lab manager is responsible for the training program mentorship including operational training on specific compressed gas cylinder handling and hazards on campus.

EHS requires refresher training for the following conditions:

- Changes in cylinder systems or equipment types that would render previous training obsolete.
- Observation of unsafe work practices, safety rule violations or an incident involving compressed gas cylinder or equipment use.
- Observed behavior indicating the employee has not retained the required training.
- Workplace changes rendering previous training obsolete.

Personal protective equipment

Use the following personal protective equipment when working with compressed gas cylinders and systems:

- **Face protection**: You must wear proper face protection when additional hazards to the face exist, including cryogenic work, based on the material risk assessment.
- **Foot protection**: Use closed-toed shoes when moving or transporting cylinders for occasional cylinder movement. The frequent movement of compressed gas cylinders requires steel-toed shoes.
- **Gloves and clothing**: Wear long pants, gloves and long sleeves to protect against frostbite, corrosives or pinch points.
- **Respiratory protection** as needed.
- **Safety glasses or goggles**: Eye protection is always required when using, connecting and disconnecting gas regulators and lines.

Labeling requirements

Compressed gas cylinders must be legibly marked to identify the content with either the gas chemical or trade name by the gas supplier. Such marking shall utilize stenciling, stamping or labeling, and shall not be readily removable. The marking shall be located on the cylinder's shoulder whenever practical.

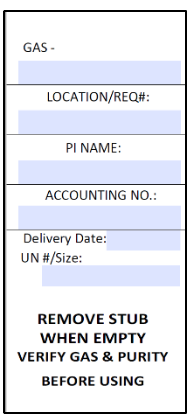
Color coding is not a reliable means of identification. Cylinder colors vary from supplier to supplier and labels on caps have no identification value as many caps are interchangeable. Only medical and diving gases have a color code system.

Gas cylinders not in working condition must be tagged "out of service" and returned to the supplier.

Gas cylinder identification requires the following:

- A durable label that cannot be defaced or easily removed.
    - The cylinder should be marked "contents unknown" and the supplier must be contacted regarding appropriate procedures for removal if the labeling on the gas cylinder becomes unclear or defaced so that the contents cannot be identified.
- Named contents.
- Label that includes the minimum Department of Transportation and OSHA regulation requirements:
    - Hazard classification symbols.
    - Pictograms or DOT placard.
    - Supplier information with the shipping name.
    - UN number.
- Warning statements.

Tags should be attached to gas cylinders with entry space for the user names and dates.


GAS -

LOCATION/REQ#:

PI NAME:

ACCOUNTING NO.:

Delivery Date:

UN #/Size:

REMOVE STUB
WHEN EMPTY
VERIFY GAS & PURITY
BEFORE USING

Proper storage of compressed gas cylinders

All compressed gas cylinders must be properly stored in compliance with OSHA, IFC and NFPA requirements. This protects them from external hazards such as physical impact, fire or explosion. Many cylinders are filled to pressures exceeding 2,000 psi. The cylinder becomes a projectile hazard in a container breach.

The following precautions should be taken for compressed gas cylinder storage:

- All cylinders must be stored upright and secured by chains, straps or racks to prevent them from failing whether empty or full. The only exception would be 40-pound forklift propane cylinders that must be used horizontally. These are stored horizontally in an open metal cage allowing the pressure relief device to function properly.
- All outside or inside cylinder storage areas shall be protected from extreme heat and cold and access by unauthorized personnel. Prevent indoor or outdoor temperatures from exceeding 125 degrees Fahrenheit or 52 degrees Celsius.
- Cylinders must be segregated by their content hazardous properties.
    - **Example**: Flammable gases must be stored separately 20 feet from all oxidizing, pyrophoric and corrosive gases or separated by a noncombustible partition extending not less than 18 inches above and to the sides of the stored material.
- Cylinders must be stored in dry, cool, well-ventilated and securely designated areas.
- Do not expose cylinders to corrosive materials such as corrosive gas or combustible materials.
- Prohibit smoking or open flames in oxidizer, highly toxic, toxic, pyrophoric or flammable gas storage areas.
- Provide adequate access for cylinder handling and material handling carts.
- Segregate full and empty cylinders, where practical, to minimize handling.
- Some gases may have a shorter lifespan and may include an end-of-life date on the label. Cylinders should be removed from service and picked up once the gas reaches its end-of-life.
- Store cylinders away from heavily traveled areas and emergency exits.
- Use a “first in first out” inventory control method. The first cylinder delivered to the lab is the first to be used
- Visually inspect stored cylinders on a routine basis. Look for leakage indications or problems at the valve.
    - Common signs of cylinder failure include hissing sounds coming from the cylinder, visible gas or vapor evacuation or a distinct or unusual smell.
    - Turn off potential ignition sources, evacuate and call 911 and then contact EHS at 480-965-1823 if a leak is detected or suspected.

Hazardous gases: University guidelines and the IFC restrict the volume of flammable, oxidizing, pyrophoric, toxic and highly toxic gas in a lab, room or location. Contact EHS at 480-965-1823 with any questions or for additional guidance. The volume of flammable, oxidizing or pyrophoric gases are kept to the minimum necessary for the work done. The maximum allowable quantities per control area are specified in IFC Tables 5003.1.1(1) through 5003.1.1(4).

The maximum lecture bottle quantity in a single fire control area should not exceed 20 and must be approved by ASU Fire Safety and Prevention. ASU strongly discourages nonreturnable, nonrefillable compressed gas cylinders or lecture bottles.

Flammable gases should be separated from all pyrophoric, oxidizing and corrosive gases by 20 feet, except as follows: The 20-foot distance shall be reduced without limit when separated by a barrier of noncombustible materials at least five feet high and has a minimum 30-minute fire-resistance rating.

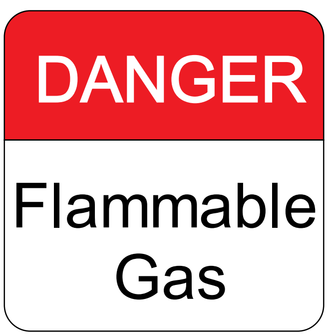
The 20-foot distance shall be reduced to five feet when one gas is enclosed in a gas cabinet or without limit when both gases are enclosed in separate gas cabinets. Cylinders without pressure-relief devices shall be stored separately from flammable and pyrophoric gases with pressure-relief devices. Pressure relief devices are now optional for silane, boron trifluoride, silicon tetrafluoride and hydrogen chloride.

The following are the additional requirements for flammable gas outdoor storage:

- All compressed gas cylinders shall be stored in an upright position.
- All flammable gas cylinders, full or empty, shall be handled similarly. Store empty cylinders separately from full cylinders.

- Always use non-sparking tools on compressed gas cylinders.
- Compressed flammable gas cylinders shall not be exposed to dampness, salt, corrosive chemicals or fumes that could damage the cylinders or valve-protective caps.
- Compressed flammable gas cylinders should not be placed where they could become part of an electrical circuit.
- Compressed flammable gas cylinders, whether full or partially full, shall not be exposed to or heated by devices that could raise temperatures above 125 degrees Fahrenheit or 52 degrees Celsius.
- Cylinders should not be stored within 10 feet of windows, doors or other openings nor should they be stored within 50 feet of ventilation intakes.
- Cylinders stored outside shall not be placed on the ground, earth or surfaces where water can accumulate.
- Leaking, damaged or corroded compressed flammable gas cylinders should be removed from service and the gas supplier notified.
- Signs should be posted in areas containing flammable gases communicating that smoking or open flames are prohibited within 25 feet of the storage or use area perimeter.
- Static-producing equipment located in flammable gas areas shall be grounded.
- Storage areas shall be kept clear of dry vegetation and combustible materials for a minimum distance of 15 feet.
- Storage areas shall be permitted to be covered with canopies of noncombustible construction.
- Storage areas shall be provided with physical protection from vehicle damage.

Signage required at compressed gas cylinder storage locations may include the following in the figures below. Specific requirements are identified by ASU Fire Safety and Prevention.



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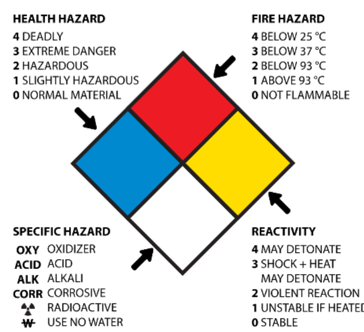

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Securing compressed gas cylinders

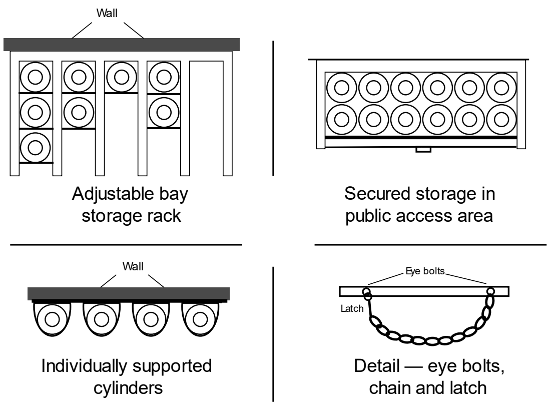
Cylinders must be secured in one or more of the following ways:

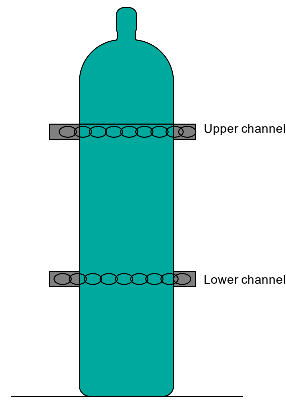
- Cylinders must be secured at a minimum of approximately two-thirds the height of the cylinder, above the midpoint, but below the shoulder. The preferable method of strapping or chaining is to secure them in two locations, one strap or chain two-thirds the height of the cylinder and another strap or chain one-third up from the bottom of the cylinder.
- With a noncombustible rack, framework, cabinet, approved strapping device, secured cylinder cart or other substantial assembly that prevents the cylinder from falling is required. Cylinder carts are for temporary use only.

- With a noncombustible, a two-point restraint system that secures the cylinder such as chains is required. Cylinder nesting is not an approved method to secure cylinders. Individual cylinders can use a bracket or saddle to support the cylinder.

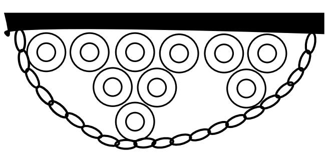
Gas cylinders must be secured to prevent falling due to accidental contact or vibration.

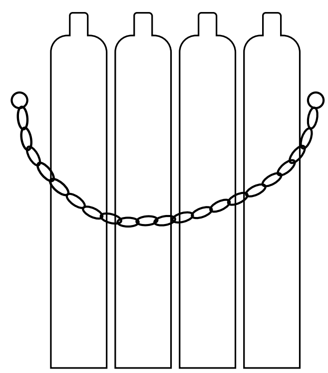
Recommended methods of securing cylinders



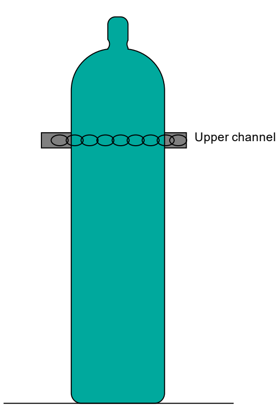


Not recommended methods of securing cylinders





Required methods of securing cylinders



Proper handling of compressed gas cylinders

Compressed gas cylinders should only be handled by those familiar with potential hazards and who can demonstrate safety precautions while working with cylinders. Cylinders are heavy and may be awkward to move. Improper handling can result in sprain, strain, falls, bruises or broken bones. Other hazards could occur due to mishandling, such as fire, explosion, chemical burns, poison and cold burns.

The following precautions must be taken when handling compressed gas cylinders:

- Always wear the appropriate PPE.
- Avoid dropping the cylinder.
- Check to ensure the cylinder valve is closed before removing the valve outlet cap.
- Move them on wheeled cylinder carts with retaining straps or chains. Lecture bottles must be stored vertically and secured in a crate, cylinder holder or with a mounted bracket.
- Open the cylinder valve slowly, directed away from your face.
- Transport them with protective caps in place. Do not lift the cylinder by the protective cap.

Avoid the following when handling compressed gas cylinders:

- Allowing grease or oil to contact any oxidizer systems, especially oxygen cylinders, valves, regulators, gauges or fittings. An explosion or fire can result. Oxygen cylinders and apparatus must be handled with clean hands and tools.
- Refilling compressed gas cylinders. It is only to be done by a qualified supplier of compressed gases.
- Rolling or dragging a cylinder more than a few feet as necessary to position the cylinder.
- Tampering with pressure-relief devices or removing the product or shipping hazard labels.
- Trying to catch a falling cylinder.

Proper use of compressed gas cylinders

Take the following precautions to prevent injuries caused by the improper use of compressed gases:

- Close the cylinder valve and release all pressure from the downstream equipment before disconnecting from any system.
- Disconnect the cylinder anytime an extended non-use period is expected. Cap the cylinder when not in use.
- Follow storage and handling requirements as indicated by safety data sheet documentation.
- Have emergency aid available depending on the type and hazards of the gas.
- Know and understand the gases associated with the equipment being used.
- Open the cylinder valve slowly and carefully after the cylinder has been connected to the process. Use check valves to prevent reverse flow into the cylinder.
- Prevent sparks and flames from contacting cylinders.
- Use non-sparking tools, such as brass, when working with flammable or explosive materials.
- Use regulators approved for the specific gas.

Avoid the following to prevent injuries caused by the improper use of compressed gases:

- Discharging the contents from any gas cylinder directly toward any person.
- Forcing cylinder valve connections that do not fit.
- Mixing gases in a cylinder.
- Permitting cylinders to become part of an electrical circuit.

Never do the following when using compressed gas cylinders:

- Strike an electrical arc. Cylinders shall not be placed where they might become part of an electric circuit.
- Use compressed gas in any confined space.
- Use compressed gas to dust off clothing. This could cause eye or bodily injury and create a fire hazard.
  - Clothing can become chemically saturated and burst into flames if touched by an ignition source such as a spark.

Do not attempt to force the cylinder's valve to turn if it does not open properly. The cylinder should be returned to the vendor or ASU Gas Services. Employees shall not attempt repairs on cylinders or cylinder valves or to force stuck or frozen cylinder valves open.

Use a returnable cylinder when hazardous gas sources are needed in lower volumes, including lecture bottles or small-sized gas cylinders.

The initial purchase cost per cubic foot may be lower when hazardous gases are purchased in full-sized cylinders. However, the overall cost of the experimental setup, which may require local ventilation, gas cabinets, stainless steel piping and purging systems, may offset the apparent savings from the bulk order.

Tubing and piping connections

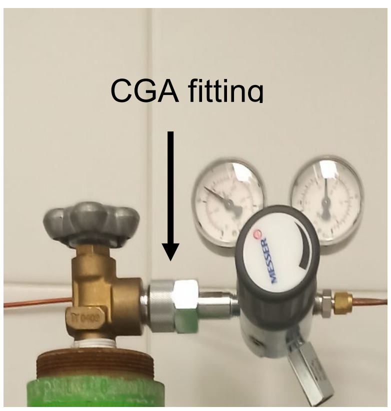
Hazardous gases must be dispensed using piping systems that are properly labeled, designed, cleaned and compatible with the gas. The burst pressure represents the mechanical strength limit of the tubing. The burst pressure of tubing and piping must be four times the maximum gas pressure after the second stage regulator.

The two-stage regulator should have pressure relief valves between stages. Exceptions may be made for short sections of tubing when it and the compressed gas cylinder are completely enclosed in a fume hood and low pressures and flow rates are used. All exceptions must be reviewed and approved by ASU Fire Safety and Prevention and EHS.

The following must be considered when handling tubing:

- Always clamp flexible tubing connections. Use a clamp rated for the maximum allowable pressure the connection is subjected to. Never use wire. This may cut the flexible tubing
- Always check tubing or piping connections for leaks when installing new cylinders as required for the gas type. Leak check procedures are to be identified in lab-specific standard operating procedures.
- Appropriately rated flexible lines are suitable for manifold and cylinder connections.
- Highly toxic, toxic, pyrophoric and flammable gases shall be piped using orbital weld stainless steel tubing except as follows:
  - All tubing is contained within an exhausted enclosure such as a fume hood or double-walled piping.
  - As exempted by ASU Fire Safety and Prevention.
  - As exempted in the ASU Chemical Hygiene Plan such as hydrogen generators.
  - Such tubing shall be installed with the appropriate gas sensors specific to the specialty gas and connected to an automatic shut-down system for such gas flow if required under permit review.
- Lecture bottles should have a standard valve and outlet connection rather than using an adaptor fitting where possible.

- Most flexible tubing deteriorates with age or exposure to chemicals or UV light. Replace flexible tubing if there are signs of discoloration, tears or cracks or if the tubing becomes brittle.
- Secure and support tubing or piping to keep it in place and to prevent uncontrolled rapid movement if a connection fails under pressure.
- Select flexible tubing compatible with the system's gas chemical and pressure properties when it must be used. Do not use flexible tubing for toxic, highly toxic or pyrophoric gases. Flexible tubing should only be used within the line of sight. Do not run flexible tubing through walls, ceiling spaces, doorways or other nonvisible pathways
- Shut-off valves are used at both ends of the gas tubing. The use of gas shut-off valves specific to the gas type and capable of handling the estimated regulated gas cylinder pressure should be considered. The system must be capable of handling cylinder pressure when no regulator is used.
- Teflon® tape is never used on cylinder connections or tube-fitting connections. Use Teflon tape only on tapered pipe threads where the seal requires the threads. All other connections have metal-to-metal face seals or gasket seals.
- Tubing and piping must be labeled with the content’s name, color-coded to denote the hazard and arrows to denote the flow direction. Write labels in bold text, large enough to be visible, legible and viewed from a normal approach. Refer to Appendix J for regulatory requirements.
- Use "hard" compatible piping whenever possible, such as copper and stainless-steel tubing instead of flexible or plastic tubing. Never use cast iron pipes or fittings.



Regulators

Use regulators that meet the requirements of UL 252 where applicable. The more commonly used standard is the CGA E-4 Standard for Gas Pressure Regulators, 2021 edition.

Regulators reduce high-pressure gas from a cylinder or process line to a lower usable level. Regulators provide additional safety measures by preventing fires or explosions, chemical or cold burns, poisoning or system over-pressurization. Regulators must be appropriate for the work’s pressure range and, ideally, should have a pressure rating twice as high as the operating pressure. The outlet pressure gauge should have a range of two times the outlet pressure.

F regulators are typically two-staged or there are two single-stage regulators used for fine pressure control of high-pressure cylinders. Two-stage regulators should have pressure relief between stages to protect the system from high pressure due to first-stage failure. Pressure relief shall be installed immediately after the first stage on two single-stage regulators. Only use regulators with the appropriate CGA connection, and never use an adapter.

Safety considerations include construction materials to ensure chemical compatibility and never using a regulator for unintended gases. The regulator must be ordered and constructed of the appropriate metals and can be properly cleaned if used for oxygen or oxidizer service. The product must be marked for oxidizer service.

Care must be taken when using left-handed threaded connectors. Do not force the connection onto the valve outlet or overtighten the connection. Check the nut for a notch indicating a left-handed threaded connection.

Valves on compressed gas cylinders

Compressed gas cylinders require the installation of at least one valve. This valve allows the cylinder to contain gases and gas to be filled or emptied from the cylinder. **The cylinder valve is the most vulnerable part of the compressed gas cylinder. Leaks can also occur at the regulator, cylinder stem and hose connection.**

System valve types

Check valves are mechanical valves that permit gases and liquids to flow in only one direction, preventing the process flow from reversing. Common valve types in gas systems include:

- Ball.
- Butterfly.
- Check.
- Diaphragm.
- Disk.
- Excess flow.
- Gate.
- Needle.
- Solenoid.

Valves can be made of plastic, stainless steel or other materials. Valves serve unique and specific purposes. It is important to select the specific valve type for your operation.

Precautions to consider when using valves include:

- A two-stage regulator has an inter-stage pressure relief device that vents if the maximum pressure is exceeded.
- Do not use the cylinder valve to regulate flow or pressure.
- Inspect the cylinder valve for damage and foreign materials before connecting it to the cylinder.
    - **Caution:** The valve and system **must** be designed to withstand the full cylinder pressure unless a regulator is installed.
- Open valves slowly to control pressure surges and heat of compression.
- The outlet pressure gauge should withstand pressures up to two times its intended use for maximum accuracy, safety and extended gauge life. Replace the gauge if it is damaged due to over-pressurization.

Never do the following:

- Drag, lift or move a cylinder using the valve or the hand wheel as a handle.
- Lubricate valves or their connections. This contaminates the system with a flammable material that can explode upon contact with oxygen.
    - Oxygen systems must be ordered, “oxygen cleaned”. This is an extensive process where the regulator and fittings are taken apart and cleaned using liquid or gaseous oxygen. They must be segregated from other compressed gas systems and preferably bagged to protect and isolate them after use.
- Tamper with a regulator or attempt to tighten or loosen the valve into or out of the cylinder.
- Use a damaged valve. Discontinue using a valve that operates abnormally such as becoming noisy or progressively harder to operate.
- Use an automatic operator, adapter, wrenches or other tools to obtain a mechanical advantage on hand-wheel-operated valves without reviewing all safety requirements.

Restrictive flow orifices

Restrictive flow orifices are installed in the cylinder valve outlet by the supplier and provide significant safety benefits for hazardous gases, including pyrophoric gases such as silane. The gas supplier must mark the cylinder to indicate that an RFO is installed and what size it is.

Do not look directly into the cylinder valve outlet to determine the RFO presence. Use a fiberoptic scope or mirror.

Rupture discs

A rupture disc is a metal safety device that ruptures at a defined pressure. This protects a pressurized vessel from over pressurization or potentially damaging vacuum conditions, such as with a compressed gas cylinder.

A rupture disc, or bursting disc, is designed to provide a leak-tight seal within a pipe or vessel until the internal pressure rises to a predetermined level and then bursts to prevent equipment damage. The ruptured disc must be replaced after it bursts. Rupture discs are used for inert gases such as helium, argon and nitrogen.

Vacuum pumps

Vacuum pumps operate by reducing the pressure within a container allowing atmospheric pressure to force gas out. Different types of vacuum pumps are each tailored to a specific application. The choice of vacuum pump depends on factors such as the required vacuum level and the type of gases involved.

Proper pump maintenance and suitable vacuum pump oil are crucial for ensuring the longevity and efficiency of these devices. Commonly used oils for vacuum pumps include mineral oils, synthetic hydrocarbon oils and silicon oils. However, hydrocarbon-based oil is incompatible with strong oxidizing and many reactive gases.

Vacuum pumps with inert lubricants and have never used oil-based lubricants must be used for applications with oxidizing and reactive gases. Vacuum pump selection varies based on application. Dry pumps may be required for safety reasons.

Vacuum pumps must be securely vented to a fume hood or other approved exhaust system with tubing that is compatible with the gases used. Exhaust lines must be as short as feasible. Vacuum pumps may require vented enclosures with detection if utilizing toxic, highly toxic, flammable or pyrophoric gases.

Specific requirements of compressed gas cylinders

Gases with poor warning properties such as colorless, odorless, tasteless, nonirritating, odor threshold near the toxic level or are used in enclosed areas must be reviewed for exposure hazards. General or mechanical ventilation, personal monitoring badges, handheld gas monitors or sensors and area monitors should be considered. Gas delivery systems must be designed with automatic shutoffs when the set points are exceeded.

Specific requirements for flammable, toxic, highly toxic and pyrophoric gases are identified in Appendix I, with examples of commonly used specialty gases identified in Appendix H. There are some exemptions for low concentrations of these gases. The manufacturer’s safety data sheet verifies the gas in question is no longer classified as flammable or pyrophoric, toxic or highly toxic.

Highly toxic gases may be exempted, only if the concentration is less than the applicable ACGIH threshold limit value for the corresponding compound.

Types of compressed gases

The types of compressed gas can be divided into three physical categories, each with unique characteristics.

Liquified gas

Liquified compressed gases are partially liquid under charged pressure and at a temperature of 68 degrees Fahrenheit or 20 degrees Celsius. The gas will liquefy at normal temperatures inside a cylinder when the pressure reaches the liquified gas vapor pressure. Liquid vaporizes and replaces gas removed from the cylinder keeping the pressure in the cylinder constant while liquid is in the cylinder. The cylinder weight is the only measurement used to determine the remaining content.

Common examples of liquified gas include:

- Anhydrous ammonia.
- Carbon dioxide.

- Chlorine.
- Nitrous oxide.
- Propane.

Non-liquified gas

Non-liquified compressed gases are packaged under a charged pressure and are entirely gaseous at a temperature of 68 degrees Fahrenheit or 20 degrees Celsius. These gases do not liquefy when compressed at normal temperatures or very high pressures. A pressure gauge is used to determine the cylinder content.

Common non-liquified gas examples are:

- Argon.
- Helium.
- Nitrogen.
- Oxygen.

Dissolved gas

Dissolved gases are non-liquefied compressed gases that are dissolved in a solvent. Acetylene is a common dissolved gas. Acetylene is normally dissolved in acetone. Free acetylene can undergo explosive decomposition when compressed or overheated.

Care should be taken when using acetylene for welding. Acetylene gas system pressures must not exceed 15 psig to prevent decomposition during use. Consult your supervisor before using acetylene.

Flammable, pyrophoric, toxic and highly toxic compressed gases

The following definitions apply for EHS 122: Compressed Gases, and this program:

Flammable gas is described as “a gas that, at ambient temperatures and pressures, forms a flammable mixture with air at a concentration of less than thirteen (13) percent by volume; or forms a range of flammable mixtures with air wider than twelve (12) percent by volume.” This is classified as Flammable Gas 1A under the Globally Harmonized System per the OSHA's Guidance for Hazard Determination.

Department of Transportation warning placard:
Category 2, flammable gas.

Ammonia has a flammable range of 16–25%, does not meet the above definition and is not labeled as a flammable gas. Ammonia can reach the flammable limit in an enclosed area when released. Several new refrigerant gases also do not meet this definition. OSHA now has a flammable gas 1B classification as a result. Class 1B is a gas with a lower flammability limit greater than 6% or a fundamental burning velocity of less than 10 cm/s. Refrigerant gas will be marked with a red stripe.

Pyrophoric gas is a flammable gas with an autoignition temperature in air at or below 130 degrees Fahrenheit or 54 degrees Celsius at one atmosphere of pressure. Pyrophoric gases should be treated with extreme caution as they can ignite instantly upon exposure to oxygen.

Toxic gas is a gas that is a gas at room temperature that meets one of the following categories:

- "Has a medium lethal dose (LD50) of more than 50 mg per kg, but not more than 500 mg per kg of body weight when administered orally to albino rats weighing between 200–300 grams each."
- "Has a median lethal dose (LD50) of more than 200 mg/kg, but less than 1,000 mg/kg of body weight when administered by continuous contact for 24 hours (or less if death occurs within 24 hours) with the bare skin of albino rabbits weighing between 2–3 kg each."
- "Has a medium lethal concentration (LC50) in air of more than 200 ppm, but less than 2,000 ppm by volume of gas or vapor or more… when administered by continuous inhalation for one hour (or less if death occurs within one hour) to albino rats weighing between 200–300 grams each" per OSHA's Guidance for Hazard Determination.

Highly toxic gas is a gas at room temperature that meets one of the following categories:

- "Has an LD50 of less than 50 mg/kg of body weight when administered orally to albino rats weighing between 200–300 grams each.
- Has an LD50 of less than 200 mg/kg of body weight when administered by continuous contact for 24 hours (or less if death occurs within 24 hours) with the bare skin of albino rabbits weighing between 2–3 kg each.
- Has an LC50 in air less than 200 PPM by volume or less when administered by continuous inhalation for one hour (or less if death occurs within one hour) to albino rats weighing between 200–300 grams each" per OSHA's Guidance for Hazard Determination.

Installing gas systems

Permanent installations of compressed gases must follow the Capital Programs Management Group permitting process and all toxic, highly toxic and flammable compressed gas cylinders must include the installation and maintenance of a gas cabinet approved by ASU Fire Safety and Prevention.

ASU Fire Safety and Prevention will specify installation requirements during the permit review process to include the following:

- Gas cabinets are required for all toxic, highly toxic, pyrophoric and flammable compressed gas installations except as identified in Appendix F. Requirements for gas cabinets are identified in Appendix I.
- Piping requirements such as those listed below.

Compressed gas piping, regulators and flow control equipment must be:

- Bonded to minimize sparks due to static discharge when using flammable or pyrophoric gas.
- Capable of withstanding gas supply pressures.
- Compatible with the gas's chemical and physical properties.
- Installed and operated by trained and qualified people familiar with the gas-specific hazards.

Leak tested upon installation and monthly thereafter around valve and regulator connections, and fittings as identified in the standard operating procedures.

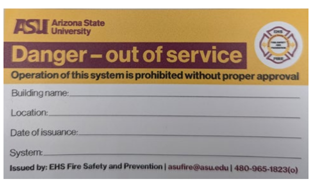
SOPs provide a means for safely purging the system and devices to prevent the backflow of gases or liquids into the gas storage cylinders when using hygroscopic corrosive gases, such as anhydrous hydrogen chloride.

All compressed gas cylinders must be fitted with a protective valve cap or guard while in storage unless the cylinder is not designed to accept a cap or guard. All cylinders must be secured in an upright position to prevent falling. Small non-refillable cylinders, or lecture bottles, should be secured in a device, cage or box designed for cylinders, 18 inches or smaller, when their use is unavoidable.

Portable compressed gas systems for hazardous gases[1] must be approved through the CPMG permitting process or any specificities identified in the ASU Chemical Hygiene Program. The PI may need to complete an SOP before using a particularly hazardous substance.

Approval for newly installed gas cabinets will take place during the project plan review by CPMG, EHS and ASU Fire Safety and Prevention. New cabinet and system installations must be leak-checked and alarm-tested before use.

Email EHS for proper lockout procedures to prevent further use of the cabinet or system if it is decommissioned or used, even temporarily. The cabinet needs to be retested for leaks and recommissioned if it is to be used again.



Cryogenic liquids

All cryogenic liquids should be used cautiously due to the potential for skin or eye damage because of the low temperature and the hazards associated with pressure buildups in enclosed piping or containers. Special hand and arm protection includes the use of cryogenic gloves. These gloves should be loose-fitted and are designed to protect human tissue from cold burns.

PPE for transferring cryogenic fluids includes:

- A full-face shield.
- Clothing that prevents the absorption of liquids such as thick sweaters, jackets and pants with cuffs.
- Full foot cover.

Cryogens are stored in specialized vacuum flask containers called dewars. Portable containers should only be used with sufficient ventilation. Do not place containers in a closet or enclosed space with no ventilation supply. The inert gas buildup in the area could generate an oxygen-deficient atmosphere.

Special vacuum jacket containers with loose-fitting lids should be used to handle small quantities. Containers provided by the gas supplier or owned and filled by ASU will have overpressure relief devices.

[1] Hazardous gases that require approval include materials that are flammable, pyrophoric, toxic and oxidizers.

Any piping system space, where cryogenic fluids may accumulate, must be protected by an overpressure relief device and where it vents must be properly ventilated. Tremendous pressures can result in piping systems as the liquid converts to gas. For example, one cubic centimeter of liquid nitrogen will expand its volume 700 times as it converts or warms to its gaseous state.

Cryogenic liquid containers should be filled slowly to avoid splashing. Cryogenic containers showing loss of vacuum evidence in their outer jacket — ice buildup on the outside of the container — should not be accepted from the gas supplier or filled by ASU. Contact with air or gases with a higher boiling point can cause an ice plug in a cryogenic container.

Refer to the Chemical Hygiene Plan for information on dewar safety.

Inert, oxidizers, pyrophoric or toxic compressed gas cylinders

Consult the safety data sheet for all gases. Some gases are:

- Anesthetic, such as nitrous oxide.
- Corrosive, such as hydrogen chloride.
- Highly reactive, such as anhydrous ammonia.
- Pyrophoric, such as phosphine.
- Toxic, such as chlorine.

Call EHS at 480-965-1823 if you are unsure how to control the dangerous properties of a particular compressed gas.

Inert gases

Inert gases are unreactive as they do not combine with other elements to form compounds. Inert gases are nonflammable and noncorrosive. Inert gases may displace oxygen and create the risk of asphyxiation if left to leak in a closed space. Care must be taken to prevent an oxygen-deficient atmosphere.

Equipment that uses nitrogen or other inert gases should use mechanical ventilation or exhaust monitoring to prevent asphyxiation in compliance with IFC 5307.2. Gas detection must be used to monitor leaks in areas where inert gases are used.

Oxidizers

Oxidizing gases can support and accelerate the combustion of other materials more than air does. Some examples of oxidizer gases include:

- Chlorine.
- Chlorine trifluoride.
- Fluorine.
- Nitric oxide.
- Nitrous oxide.

These gases' reactivity compared to 100% oxygen is summarized in the International Organization for Standardization regulation 10156. Oxidizing gases will cause many materials to burn violently although not combustible themselves. Never use grease, solvents or other flammable material on an oxygen valve, regulator or piping. Oxidizer use and storage shall comply with the International Fire Code Chapter 63: Oxidizers, Oxidizing Gases and Oxidizing Cryogenic Fluids.

Anesthetic gases, such as nitrous oxide, may cause a loss of sensation with or without the loss of consciousness. Fluorine and chlorine trifluoride, ClF3, systems must be oxygen cleaned, and fluorine passive. Avoid handling liquid ClF3. It is extremely reactive.

Oxygen systems must be purged and cleaned for oxygen service. They must be labeled for oxygen use and segregated from other systems.

Flammable gases

Flammable gases have the following characteristics and cautions:

- Flammable gases such as propane, hydrogen and acetylene always have a red label. Check the label for flammability.
- The flammable gas range needs to be recognized including all concentrations in air between the lower flammable limit, or LFL, and the upper flammable limit, or UFL.
  - Example: The flammable range for hydrogen is LFL=4% and a UFL=75%.
- The auto-ignition temperature is the minimum temperature at which gas and its vapors can spontaneously ignite in air.
  - Examples include silane or diborane, which have autoignition temperatures below ambient temperature.
- Flammable gas must be segregated from oxidizers and comply with IFC Chapter 58, Flammable Gases and Flammable Cryogenic Fluids.

Pyrophoric gases

Pyrophoric gas cylinders should be stored in a suitable exhausted location in compliance with IFC Chapter 64 with gas detection as specified in this program. Examples of pyrophoric gases include:

- Diborane.
- Disilane.
- Phosphine.
- Silane.

Compressed gas systems carrying pyrophoric gases shall be provided with an approved automatic shutoff valve that can be activated at each point of use and each source per IFC Chapter 64, Pyrophoric Materials, section 6403.1.1. Evacuate and restrict area access if a hazardous gas cylinder develops a leak.

Toxic gases

Toxic gas use may require gas monitoring, handling, storage, emergency procedures and additional facility considerations in compliance with IFC Chapter 60, Highly Toxic and Toxic Materials. A SOP must be developed and reviewed annually per the Chemical Hygiene Plan. Contact EHS if you plan to use toxic gases.

Reporting requirements

Maintain constant awareness of and respect for compressed gas cylinders and equipment.

Evacuate everyone out of the area and call 911 if the material in the cylinder is toxic, highly toxic, flammable or pyrophoric and you suspect a leak.

Compliance with all applicable ASU safety rules is mandatory, including:

- Accidents must be reported, and all injuries must follow the ASU injury reporting requirements. Incidents can be reported utilizing the Employee and non-employee incident report form.
- Employees shall report any safety concerns to their supervisor or EHS.
    - Report all suspected leaks immediately, close all valves and notify your supervisor immediately. Call EHS at 480-965-1823 after contacting emergency services and then reach out to the designated safety contact for your department.

Principle investigators, compressed gas safety training mentors and EHS are available to observe work practices and may periodically audit work practices. They will communicate their observations to affected employees and assist with preventing unsafe work practices from continuing if observed.

Compressed gas cylinder emergencies

Emergencies involving compressed gases are unlikely, provided recommendations are followed for their correct storage, handling and use. When problems do arise, they are usually due to:

- Earthquakes toppling the cylinders.
- Explosions in other areas.
- External fire threatens the cylinder.
- Flooding.
- Motor vehicle accidents.
- Toxic or inert gas leaks in gas systems.
- Unplanned chemical or other reactions.

Most leaks occur at the valve threads, pressure relief devices or the valve stem fitted on the top of the cylinder. Leakage in those areas is frequently due to dirt in the connection, loose packing or damaged connections or connection washers when the valve is initially opened.

Some leaks are easily rectified such as the connection leak. Close the cylinder valve and attempt to tighten the connection. Valve thread and pressure relief device leaks cannot be corrected and must be returned to the supplier. If cylinders are involved in any type of emergency, and if it's safe to do so, isolate the gas outdoors and away from sparks and heat or in a leaker gas cabinet.

All defective cylinders should be clearly labeled and returned to the supplier.

Appendix A

Definitions

Anesthetic gas: A gas that may cause loss of sensation with or without the loss of consciousness.

Check valve: Check valves are mechanical valves that permit gases and liquids to flow in only one direction, preventing the process flow from reversing. They must be provided when the backflow of hazardous materials could create hazardous conditions or accidental discharge of hazardous gases.

CGA: Compressed Gas Association.

Compressed gas: OSHA defines compressed gas as one of the following:

- "A gas or mixture of gases in a container, having an absolute pressure exceeding 40 psi at 70 degrees Fahrenheit (21.1 degrees Celsius).
- A gas or mixture of gases in a container, having an absolute pressure exceeding 104 psi at 130 degrees Fahrenheit (54.4 degrees Celsius) regardless of the pressure at 70 degrees Fahrenheit (21.1 degrees Celsius).
- A liquid having a vapor pressure exceeding 40 psi at 100 degrees Fahrenheit (37.8 degrees Celsius) as determined by ASTM D- 323-72" per OSHA's Guidance for Hazard Determination.

Compressed gas system: "An assembly of equipment designed to contain, distribute or transport compressed gases. It can consist of a compressed gas container or containers, reactors and appurtenances, including pumps, compressors and connecting piping and tubing" per IFC 2018, Chapter 2.

Corrosive gas: A gas that can cause visible destruction of, or irreversible alterations in, living tissue such as skin, eyes, the respiratory system or material by chemical action.

Cryogenic liquids or fluid: A fluid having a boiling point lower than -130 degrees Fahrenheit (-89.9 degrees Celsius) at 14.7 pounds per square inch atmosphere" per IFC 2018, Chapter 2.

DOT: U.S. Department of Transportation.

Excess flow control: "A fail-safe system or other approved means designed to shut off flow caused by a rupture in pressurized piping systems" per IFC 2018, Chapter 2.

Fire detection: A UV or IR sensor, a high sensitivity smoke detection or rate of rise temperature sensor that is provided in cabinets or installations containing pyrophoric or flammable gas.

Flammable aerosol: "An aerosol that, when tested by the method described in 16 CFR 1500.45, yields a flame projection exceeding 18 inches at full valve opening, or a flashback at any degree of valve opening" per OSHA's Guidance for Hazard Determination.

Flammable gas: "A gas that, at ambient temperatures and pressures, forms a flammable mixture with air at a concentration of less than thirteen (13) percent by volume; or forms a range of flammable mixtures with air wider than twelve (12) percent by volume" per OSHA's Guidance for Hazard Determination.

Flammable limits: The flammable vapor concentration in air, oxygen or other oxidants that will propagate a flame upon contact when provided with an ignition source. The lower explosive limit is the concentration below which a flame will not propagate. The upper explosive limit is the concentration above which a flame will not propagate. A change in temperature or pressure may vary the flammable limits.

Gas cabinet: “A fully enclosed, ventilated, noncombustible enclosure used to provide an isolated environment for compressed gas cylinders in storage or use. Doors and access ports for exchanging cylinders and accessing pressure-regulating controls are allowed to be included” per IFC 2018, Chapter 2.

Gas cabinets are required for all toxic, highly toxic, pyrophoric and flammable gas cylinders. “Gas cabinets shall be constructed with the following:

- Not less than 0.097-inch (No. 12 gauge) steel.
- Self-closing limited-access ports or noncombustible windows to give access to equipment controls.
- Self-closing doors.
- Interiors treated, coated or constructed of materials that are compatible with the hazardous materials stored” per IFC 2018, 5003.8.6.

The maximum number of cylinders in a single gas cabinet shall not exceed three.

“The average ventilation velocity at the face of gas cabinet access ports or windows shall be not less than 200 feet per minute (1.02 m/s) with not less than 150 feet per minute (0.76 m/s) at any point of the access port or window. Gas cabinets shall not be used as the sole exhaust means for any room or area” per IFC 2018, 6004.1.2.

Refer to Appendix I for specifications.

Hazardous gas: A gas that is included in one or more of the following hazard categories:

- Corrosive.
- Flammable.
- Health hazard.
- Oxidizer.
- Pyrophoric.
- Reactive.
- Toxic.

Refer to Appendix H for use and handling requirements.

Health hazard: “A classification of a chemical for which there is statistically significant evidence that acute or chronic health effects are capable of occurring in exposed persons” per IFC 2018, Chapter 2. This includes chemicals that are:

- Carcinogens.
- Corrosives.
- Irritants.
- Sensitizers.
- Toxic or highly toxic.

It also includes chemicals that affect target organs including the lungs, kidneys, nervous system, pulmonary system, reproductive system, skin or eyes.

Highly toxic gas: "A gas that is a gas at room temperature that has one of the following three characteristics:

- Has a median lethal dose (LD50) of 50 mg or less per kg of body weight when administered orally to albino rats weighing between 200 and 300 grams each.
- Has a LD50 of 200 mg/kg of body weight when administered by continuous contact for 24 hours (or less if death occurs within 24 hours) with the bare skin of albino rabbits weighing between two and three kilograms each.
- Has a medium lethal concentration (LC50) in air of 200 PPM by volume or less when administered by continuous inhalation for one hour (or less if death occurs within one hour) to albino rats weighing between 200 and 300 grams each" per OSHA's Guidance for Hazard Determination.

Ignition source: Anything that provides heat, sparks or flames sufficient to cause combustion or an explosion.

Inert gas: “A gas that is capable of reacting with other materials only under abnormal conditions such as high temperatures, pressures and similar extrinsic physical forces. Within the context of the code, inert gases do not exhibit either physical or health hazard properties as defined (other than acting as a simple asphyxiant) or hazard properties other than those of a compressed gas” per IFC 2018, Chapter 2.

Incompatible: Materials that could cause dangerous reactions from direct contact with one another.

Laboratory: A facility or room where potentially hazardous chemicals, biological agents or energy sources are used for scientific experimentation, research or education such as lasers, high voltage and radiation.

Lower flammable limit: “The minimum concentration of vapor in air at which propagation of flame will occur in the presence of an ignition source. The LFL is sometimes referred to as LEL or lower explosive limit” per IFC 2018, Chapter 2.

Mass flow controller: A device used to measure and control the gas flow rate.

Mechanical exhaust: Mechanical exhaust systems that use a powered device for exhausting contaminants from a workplace vessel or enclosure, such as a motor-driven fan or air or street venturi tube.

NFPA: National Fire Protection Association.

OSHA: The Occupational Safety and Health Administration of the U.S. Department of Labor is a federal agency with safety and health enforcement authority for most U.S. industries and businesses.

Oxidizing gas: “A gas that can support and accelerate combustion of their materials more than air does” per IFC 2018, Chapter 2.

Oxygen deficiency: Oxygen monitors typically alarm when a breathable atmosphere contains less than 19.5% oxygen. **Note**: Normal air contains 20.9% oxygen.

Physical hazard: A chemical in which there is scientifically valid evidence that it is:

- An organic peroxide.
- Corrosive.
- Explosive.

- Flammable.
- Oxidizing.
- Pyrophoric.
- Self-heating.
- Self-reactive.

Purge panel: System to evacuate or purge hazardous gas lines to facilitate safe cylinder removal and installation and to aid in removing air impurities before flow to the reactor.

Pyrophoric gases: Gases "that will ignite spontaneously in air at a temperature of 130 degrees Fahrenheit (54.4 degrees Celsius) or below." Specific gases may not ignite in all circumstances per OSHA's Guidance for Hazard Determination.

Restrictive flow orifice: A safety device placed in the cylinder valve outlet intended to limit the release rate of hazardous gas to a maximum specified range in the event of an inadvertent valve opening or the failure of the system downstream from the valve outlet. RFOs must be installed by the supplier or manufacturer. ASU employees are not allowed to install RFOs.

Safety data sheet: "Information concerning a hazardous material which is prepared in accordance with the provisions of DOL 29 CFR Part 1910.1200 or in accordance with the provisions of a federally approved state OSHA plan" per IFC 2018, Chapter 2.

STP: Standard Temperature and Pressure in chemistry is defined as 0 degrees Celsius or 32 degrees Fahrenheit and 1 atmosphere of pressure or 101.325 kPa or 29.92 inches of mercury.

Toxic gas: A gas that is poisonous or capable of causing injury or death, especially by chemical means, as defined in EHS 004: Definitions. A toxic gas is a gas at room temperature and meets one of these criteria:

- "Has a median lethal dose (LD(50)) of more than 50 mg, but less than 500 per kg of body weight when administered orally to albino rats weighing between 200 and 300 grams each; as an LD(50) of more than 200 mg/kg, but less than 1,000 mg/kg of body weight when administered by continuous contact for 24 hours (or less if death occurs within 24 hours) with the bare skin of albino rabbits weighing between two and three kilograms each;
- Has a medium lethal concentration (LC(50)) in air of more than 200 PPM, but less than 2,000 PPM by volume or less when administered by continuous inhalation for one hour (or less if death occurs within one hour) to albino rats weighing between 200 and 300 grams each" per EHS 004: Definitions.

Treatment system: A treatment system is installed when required by IFC 6004.2.2.7 for toxic and highly toxic gases. These systems are designed to handle an accidental full-cylinder gas release and reduce the maximum allowable discharge concentrations to one-half the immediately dangerous to life and health concentrations at the discharge point to atmosphere pressure. The release rate will be calculated by the maximum valve flow as determined by the manufacturer if the cylinder is equipped with a restrictive flow orifice. The release rate will be five minutes for non-liquified gases and 30 minutes for liquified gases without an RFO.

Unstable, or reactive: "A material, other than an explosive, which in the pure state or as commercially produced, will vigorously polymerize, decompose, condense or become self-reactive and undergo other violate chemical changes, including explosion, when exposed to heat, friction or shock, or in the absence of an inhibitor, or in the presence of contaminants, or in contact with incompatible materials" per IFC 2018, Chapter 2.

Gases become dangerous when:

1. They undergo an exothermic self-sustaining decomposition reaction that transitions to a detonation in the cylinder.
2. The reaction byproducts exceed the cylinder's working pressure.

Determining what gases exhibit this behavior is not an easy task. Predictions based on high positive formation heat are not accurate. High decomposition energy is also not a predictor.

Filling these cylinders with gases known to decompose exothermically considers these hazards to ensure the cylinder will not rupture under normal environmental temperature or pressure conditions. Shelf life is not an issue.

These key gases are known to decompose exothermically:

- Acetylene.
- Germane.
- Nitric oxide.
- Nitrous oxide.
- Tetrafluorohydrazine.

Nitrogen trifluoride can undergo a self-sustaining decomposition reaction if a fire is heating the cylinder. 1450 psig has been selected as a fill pressure to reduce the potential of sudden adiabatic compression heat, triggering the decomposition reaction when the cylinder valve is opened.

Some gases have stabilizers to control this reaction but can become ineffective over time. These stabilizers typically have a shelf life:

- **1, 3 Butadiene**: Stabilized.
- **Chlorotrifluoroethylene**: Stabilized.
- **Ethylene oxide**: Typically mixed with a halocarbon gas.
- **Hydrogen cyanide**: Stabilized.
- **Tetrafluoroethylene**: Stabilized.
- **Vinylacetylene**.
- **Vinyl bromide**: Stabilized.
- **Vinyl chloride**: Stabilized.

Diborane is one of the few gases that will slowly decompose to the high boranes and hydrogen at a room temperature of 70 degrees Fahrenheit. The decomposition rate increases with temperature. The DOT regulations require the cylinder fill limits to consider this decomposition and resulting cylinder pressure.

Pure diborane is typically shipped in cylinders chilled to dry ice temperatures to have a high fill density. These cylinders are shipped under special permits and must arrive within a certain time limit. Pure diborane is normally not sold to users, only mixtures.

Under high temperatures or pressures the following gases can also polymerize:

- **Ethylene**: Ethylene monomer.

- **Propylene**: Propylene monomer.

Active sites such as rust on the cylinder walls can catalyze a slow decomposition reaction with some gases. These are not self-sustaining but can continue until the cylinder is compromised. Hydrogen fluoride and hydrogen bromide can react over time with rust to form the byproduct hydrogen. This reaction is slow but steady. This is not a problem as the excess pressure is vented when the valve is opened, and the gas is used normally. These cylinders have suddenly ruptured due to the excessive hydrogen pressure of <3,000 psig after extended storage of 20-plus years.

Upper explosive limit: The highest gas or vapor concentration in the air that can produce ignition or explosion.

Water-reactive: "A chemical that reacts with water to release a gas that is either flammable or presents a health hazard" per OSHA's Guidance for Hazard Determination.

Appendix B

Hydrogen

Hydrogen generators are preferred over hydrogen gas cylinders. Refer to ASU's Chemical Hygiene Plan for additional information.

Hydrogen has several unique properties that make it potentially dangerous. It has an extensive flammability range, LEL 4%–UEL 74.5%, which makes it easier to ignite than most flammable gases. Hydrogen's temperature increases during expansion, unlike most other gases. Many hydrogen fires result from the self-ignition of a sudden hydrogen release through ruptured disks or other pressure relief valves — a combination of ruptured disk and a fusible metal device on a cylinder.

Observe the following guidelines for hydrogen use and storage:

- Adequate ventilation should be provided and maintained throughout the area where hydrogen cylinders are used.
- Gas cabinets are required for hydrogen cylinders.
- Hydrogen burns with an invisible flame. Caution should therefore be exercised when approaching a suspected hydrogen flame.
- Hydrogen embrittlement can weaken carbon steel, therefore cast-iron pipes and fittings should not be used.
- Joints in piping and tubing should be made by welding or brazing or with flanged, threaded, socket, slip or compression fittings for gaseous hydrogen service. Brazing materials should have a melting point above 1000 degrees Fahrenheit or 538 degrees Celsius.
- Limit the number of hydrogen cylinders stored in the lab when not used.
- Locate the cylinders 25 feet from open flames and other ignition sources.
- Open the cylinder valve slowly. The static charge generated by the escaping gas may cause it to ignite if a cylinder valve is opened too quickly.
- Piping, tubing, fittings, gaskets and thread sealants should be suitable for hydrogen service at the pressures and temperatures involved. Refer to the American Society of Mechanical Engineers Code for Process Piping, ASME B31.3.
- Provide 20 feet of separation from Class I, II and IIIA flammable liquids, oxidizing gases and readily combustible materials.
- **Provide 50 feet of separation from other flammable gas storage.**

Appendix C

Acetylene

Acetylene is a flammable gas with a normal explosive range with air of 2.3–80% acetylene. Special cylinders used for acetylene contain a porous material and acetone in which the gas dissolves and becomes practically stable. The porous filler dissolves the acetone and eliminates large voids where decomposition might occur. Acetylene is highly reactive and is widely used in chemical processes because it tends to break down and release energy. The oxyacetylene flame temperature, 5400–6300 degrees Fahrenheit or 3000–3500 degrees Celsius, is the highest for any commercially practical gas mixture.

The minimum autoignition temperature for acetylene-air mixtures is about 571 degrees Fahrenheit or 300 degrees Celsius. Catalytic impurities such as rust, scale, silica gel, charcoal or potassium hydroxide can substantially lower the ignition temperature. The presence of copper, silver or mercury acetylides combined with light shock can result in the ignition or decomposition of acetylene at room temperature.

Acetylene cylinders are filled with a solid media that acts as a flash arrestor. They are 8 or 8AL specification cylinders. They are filled to a maximum pressure of 250 psig.

Observe the following guidelines for acetylene use and storage:

- Do not handle cylinders roughly, subject cylinders to hydrostatic tests or take any other action that can create large voids in the mineral filler.
- Do not withdraw acetylene from a cylinder or manifold at a rate greater than one-seventh of the total cylinder capacity per hour. Provide additional cylinders if needed to supply higher demand without exceeding this rate.
- Keep acetylene cylinder valves closed when the gas is not used and open the valves only 1 ½ turns when used.
- Provide separate storage locations for acetylene, oxygen or chlorine cylinders. A gas-tight non-combustible partition can separate a storage area for this purpose.
- Store and use cylinders in an upright position to prevent loss of acetone or dimethylformamide.
- Use a pressure regulator at the individual cylinder discharge or manifold to reduce the gas pressure to less than 15 psi, or 105 kPa.
- Use wrought-iron or steel pipe and steel or malleable-iron fittings. Welded joints are preferable because of the reduced probability of leakage. Alloys containing more than 67% copper should not be used for piping, valves or fittings, except for a torch tip, which is pure copper.

Appendix D

Liquified petroleum gas

Liquified petroleum gases are gases at atmospheric pressures and normal temperatures although they are transported and stored as liquids. They are as hazardous as other combustible gases, with the added danger that they are heavier than air. They tend to remain in low places for longer periods and have little or no natural odor.

The discharge from tank relief valves can create a large torch fire if ignited. The intense, radiated heat may seriously expose buildings and contents. The discharge from tank relief valves may travel hundreds of feet and settle in low-lying areas or enter below-grade building openings if the ignition is delayed. Ignition may result in an explosion if the gas enters a building. The resulting flashback to the tank may involve other structures and contents once ignited.

Observe the following guidelines for LPG use and storage:

- All cylinders with a 4–40-pound propane capacity fabricated after 1998 must be equipped with an overfill prevention device as a secondary protection means against overfill. Note: the primary means is determining the fill limit by weight. Cylinders equipped with OPDs have a triple-notched valve hand wheel with the letters “OPD.” **Note**: This is only for consumer use, forklift units cannot be OPD.
- Cylinders should not be filled past their rated capacity. The weight limit is usually specified on the cylinder. The pressure relief valve may release propane as the cylinder warms if it has been overfilled.
- Cylinders should be kept away from heat sources as the heat can build up pressure inside the cylinder and may cause the pressure relief valve to release propane.
- Cylinders that show visible rust or damage shall not be refilled.
- LPG Containers should be stored outside buildings at least 10 feet from any doorway or other opening with the following exceptions:
    - A container with a maximum 2.5-pound water capacity or one pound of LPG may be used for hand torches or similar appliances.
    - A container with a maximum 12-pound water capacity or 5 pounds of LPG may be used for temporary demonstration purposes.
- Never use propane from a cylinder without a regulator except for forklift cylinders. Protect the regulator connector from scratches and dents. Ensure the regulator vent is clean and pointed downward and protected.
- The cylinders should be kept in a secure upright position with the valves closed and the thread caps secured when transported, stored or used.
- Used cylinders must be retrofitted with UL-listed OPDs when requalified. Forklift cylinders have the standard cylinder valve with a CGA 555 outlet and dip tube for liquid withdrawal.
- When disconnecting cylinders, whether full or empty:
    1. First close the shut-off valve.
    2. Then disconnect the cylinder.
    3. Snugly seal the valve with a plug, cap or approved quick-closing coupling.

Appendix E

Oxygen

Oxygen is neither combustible nor explosive. However, the intensity of any ordinary fire or explosion increases as the oxygen amount in the surrounding air increases. Materials, such as grease or oils that produce intense fires with air, burn in an enriched oxygen atmosphere with explosive violence. Explosions have occurred in oxygen pressure gauges due to adiabatic compression heat when the system is suddenly pressurized.

Observe the following:

- Compounds containing oil should not be used. Gaskets should be made entirely of noncombustible material.
- Do not use oil or grease for lubricating valves, gauge connections or other parts of the oxygen system.
- Separate oxygen cylinders from cylinders or manifolds containing flammable gases and other combustible or easily ignited materials such as wood, paper, oil and grease. Gas-tight fire partitions having at least one-half-hour fire resistance ratings are suitable as cutoffs.
    - **Note**: This does not apply to properly arranged and safeguarded oxygen and acetylene tanks used for cutting and welding torches.
- Systems must be designed for oxygen service. There should be no quick-opening valves.
- The system must be clean for oxygen service and must be labeled.
- Type K, L, or ASTM B-88 copper tubing may be used in medical oxygen gas systems. Brazed fittings should be used for three-fourths inch, or 19 mm, and larger tubing. Flared-type tubing fittings may be used in smaller sizes where the fitting is visible in the room.
- Use extra-heavy steel or nonferrous pipe and fittings if the oxygen pressure is over 150 psi, or one MPa. Standard-weight pipe and fittings are satisfactory for lower pressures. Cast-iron fittings should not be used.
- Use welded joints whenever possible. Threaded joints should be carefully made using litharge and glycerin or proprietary materials compounded for oxygen service if necessary.

Appendix F

Pyrophoric gas

A pyrophoric gas has an autoignition temperature in air at or below 130 degrees Fahrenheit or 54.4 degrees Celsius. Ignition may be instantaneous or delayed. Spontaneous or instantaneous ignition or combustion occurs when a substance reaches its autoignition temperature without an external heat application.

An example of a pyrophoric gas is silane with an autoignition temperature of -148 degrees Fahrenheit or -100 degrees Celsius. Silane has caused major losses due to fires in ducts, gas cabinets and supply systems and explosions in ducts, vacuum pumps and cross-contaminated cylinders. These incidents have occurred in research facilities.

The hazards are pyrophoric fires, explosions or deflagrations and vapor cloud autoignition. These conditions can occur depending on leak location, excess flow control and shutdown of the silane gas. Pyrophoric fires are never to be extinguished. The gas supply must be shut down promptly by interlocks tied into the fire protection and detection system because an unignited pyrophoric gas build-up has the potential for delayed ignition and detonation.

Follow ANSI and CGA G-13 for guidance.

Many highly toxic gases are also pyrophoric such as diborane or phosphine.

Observe the following guidelines when storing or using pyrophoric gas:

- All process systems components and equipment should be adequately purged using a dedicated inert gas cylinder.
- Emergency backup power should be provided for all electrical controls, alarms and safeguards associated with the storage and process systems.
- Minimally sized pyrophoric gas cylinders must be kept in approved gas cabinets.
- Order cylinders with the smallest restrictive flow orifice as practicable, 0.006 inches and not to exceed 0.010 inches.
- Two-cylinder cabinets shall have a fire separation plate between them.

Pyrophoric gas flow, purge and exhaust systems should have redundant controls that prevent pyrophoric gas from igniting or exploding or reducing the amount being released. These controls include:

- Automatic gas shutdown.
- Dilution of process effluent with inert gas and ventilation.
- Controlled combustion of process effluent.
- Excess flow valves.
- Flow orifices.
- Mass flow controller sizing.
- Process bypass line elimination or control.
- Vacuum-pump inert-gas purging.
- Ventilation monitoring.

Remote manual shutdown devices for pyrophoric gas flow should be provided outside each gas cabinet or near each gas panel. Automatic shutdown devices for pyrophoric gas flow activated by interlocks tied into fire protection and detection should be provided and may be required under ANSI and CGA G-13 requirements.

Appendix G

Gas monitoring and detection

The use of flammable and highly toxic compressed gases, as defined in this guideline, that are not considered a closed system must be used within ventilated enclosures such as a laboratory hood or glove box, or the use of real-time gas detection may be required. The use of emission control devices such as burn boxes or scrubbers is addressed as part of the permit review process or the Prior Approval Assessment, as applicable.

Exception: Acetylene may be used in designated hot work areas approved by the ASU Fire Safety and Prevention.

Alarms and setpoints for flammable and highly toxic gases

Gas detection will be installed at the storage location, typically within a gas cabinet, and within the room conveying the flammable and toxic gases unless the tubing used to convey the gas from its storage location to the point of use is continuous non-combustible tubing. This tubing has orbital welds and no fittings unless a variance is granted or all fittings are contained within a manifold equipped with local exhaust ventilation, that has been leak-checked.

Gas detection within the room itself should be placed at a location likely to detect any leakage such as near an air return, if required. Flammable gas detection shall comply with the International Fire Code Chapters 53 and 58. Gas detection systems should be set to alarm as follows:

1. **Gas release alarm** — at the threshold limit value level for toxic gases and 25% of LEL for flammable gases. It activates building fire alarm system horns and strobes. There may be flexibility with smoke fans, such as with the Biodesign Institute.
2. **Gas warning alarm** — half of the TLV for toxics and 5% of the LEL for flammables. It sends a trouble signal to the fire alarm panel and the ASU Police Department. It also contracts the security company for certain buildings to contact the lab or the EHS on-call representative to investigate.
3. **Gas monitor trouble alarm** — same as number two above.

Alarm set points must be communicated to ASU Fire Safety and Prevention. They are the “authority having jurisdiction.” Additional guidance or higher alarm levels may be approved on a case-by-case basis. Alarm set points at MacroTechnology Works are generally set at a half of TLV for toxics and 10% LEL for flammables. There are no warning alarm points. Projects involving alarm points should be reviewed with MTW EHS.

Oxygen detection and monitoring requirements

Normal oxygen levels range between 19.5 and 20.9%. Serious health effects or death by asphyxiation can occur quickly when oxygen levels are unsafe, below 16% or fires above 21%. Liquified cryogens and inert gases can displace oxygen and create low oxygen levels in confined spaces or poorly ventilated areas. Many sources of liquid cryogens and inert gas exist in teaching and research facilities, including MRI or NMR magnets, including:

- Analytical instruments.
- Anaerobic incubators.
- Argon.
- Carbon dioxide.

- Helium.
- Nitrogen.
- Some -80-degree Celsius freezers.

Cylinder, tank and dewar failures, magnet quenches or sudden releases from pressure relief valves can overwhelm standard ventilation systems. Gas volumes are limited, and potentially asphyxiating gases quickly dissipate in most research environments. Air exchange rates in many labs are relatively high, 6-15 ACH, further minimizing the risk of low oxygen levels. Cryogen tanks and compressed gas systems are designed as “fail safe,” venting slowly rather than rupturing.

All these features reduce the need for detection equipment. However, rooms or spaces containing inert gas or other sources of oxygen depletion should be evaluated by an industrial hygienist safeguard added to protect users and those potentially entering these spaces if warranted.

An oxygen monitoring device shall be the first measure when this evaluation indicates. It should be installed indoors where compressed gases or cryogenic liquids are stored and dispensed in a manner that could create the potential for oxygen displacement and could present an asphyxiation hazard to occupants.

The following factors should be used in determining if a device should be installed at a minimum:

- Air changes per hour in the room or area.
- Device failure probability.
- Device safety features.
- Gas location.
- Gas volume used.
- Manufacturer, or magnet, guidance.

The 2016 NIH Design Requirements Manual section 12.3 notes that both **“carbon dioxide manifold rooms and nitrogen holding rooms must include oxygen level monitoring alarms” in particular.**

Note that oxygen sensors may become saturated over time with continuous exposure to high concentrations of other gases. Additionally, compressed gases or cryogenic liquids shall not be located or dispensed indoors without proper ventilation as determined by a hazard assessment sufficient to prevent oxygen levels from falling below 19.5%.

The oxygen monitoring device installation will rely on the manufacturer’s specific requirements and the following recommendations. Some of these requirements may include the following:

- All laboratories, with oxygen monitoring, are responsible for equipment maintenance and calibration.
- EHS will be notified of each oxygen monitor installation and will include the:
  - Installation date.
  - Monitor purpose, including asphyxiant gases or cryogenics present.
  - Physical location including, building and room number and lab registration number.
  - Responsible party for unit maintenance and calibration.
- Ensuring the device’s display is accessible. Alarms are local only with signage identifying the actions to take if an alarm or warning strobe is activated. This must include instructions on notifying building support staff, ASU Police Department and EHS.
- Installing the device close to an area where a leak would most likely occur. Sensors for monitors will be installed in locations that are either typical breathing zone height, at approximately 4.5 feet

above the floor or other locations considered representative of room air. The sensor may be installed just above floor level in locations with mechanical ventilation limitations for gases heavier than air.

Oxygen monitors are required in locations where simple asphyxiants and cryogenic liquids are used if in locations where catastrophic release will lower oxygen levels below 19.5% by volume, or where operations involving the generation or oxygen release of oxygen may produce an atmosphere above 23.5% by volume.

Perform a leak test of the oxygen monitoring devices' sample lines, system components and fittings.
A low oxygen alarm shall be installed along with the monitoring device to alert people in the surrounding area of a hazardous condition as per the manufacturer's recommendation. The device shall also be interlocked with an emergency exhaust fan or ventilation system located at the monitored location where applicable. An alarm will trigger an emergency ventilation of the space. Alarms installed during new construction, or building alteration, should include a blue light inside and outside the room or area and an audible warning to notify occupants.

The alarm location will be specified during the permit review or prior approval process.

OSHA specifies that a hazardous atmosphere may include one where the oxygen concentration is below 19.5% or above 23.5%. The device alarm and warning levels should be set according to these oxygen concentration levels. A normal atmosphere contains approximately 21% oxygen and 79% nitrogen.

Maintenance and use

Any maintenance or repair on the monitoring device should only be performed by the manufacturer or manufacturer's representative using manufacturer-specific replacement parts, or by personnel authorized and trained to conduct maintenance and repair by either the department management or EHS. Most oxygen monitoring devices require minimal periodic maintenance.

Follow the manufacturer's recommendations on calibration, maintenance and sensor replacement.

The installation, testing and maintenance costs for oxygen monitors and associated engineering controls shall be the department's responsibility or the responsibility center using cryogens or asphyxiant gases.

Appendix H

Specialty gas use and handling requirements

This table is for reference only and is not all-inclusive. All proposed gas uses are subject to compliance review. Building sprinklers and smoke detection can be room or exhaust duct locations per building design. Smoke detection can also exist as very early smoke detection system, or VESDA, typically used for pyrophoric liquid ampoules.

Gas	Formula	Category	Monitor required	Monitoring ½ TLV	Full TLV	IDLH	LEL percentage	UEL percentage	Gas cabinet required	Building Sprinkler system	Sprinkler in cabinet	Manual EMO	Fire and smoke detection	Building fire alarm system	Emergency power back	Check valves	Excess flow valve	Leaking cylinder	Abatement systems	Welded piping
Acetylene	**C_2H_2**	EF, Asp	Evaluate	5% LEL	50% LEL	NE	2.5	100		X			X							
Ammonia[2]	**NH_3**	T, F	Yes	12.5 ppm	25 ppm, 35 PPM STEL	300 ppm	15	28	X	X	X	X	X	X	X	X	X	X	X	X
Argon	**Ar**	Inert, Asp	Evaluate	Asp	NA	NA	NA	NA												
Arsine[2]	**AsH_3**	HT	Yes	0.025 ppm	0.05 ppm	3 ppm	5.1	78	X	X	X	X	X	X	X	X	X	X	X	X
Boron Trichloride[2]	**BCl_3**	T, C	Yes	0.4 ppm, (LDL)	0.7 ppm C*	0.7 ppm C*	NA	NA	X	X	X	X		X	X	X	X	X	X	X
Boron Trifluoride[2]	**BF_3**	T	Yes	0.5 ppm	1 ppm C*	25 ppm	NA	NA	X	X	X	X		X	X	X	X	X	X	X
Carbon Dioxide	**CO_2**	Inert, Asp	Evaluate	2500 ppm Asp	5000 ppm	40,000 ppm														
Carbon Monoxide	**CO**	T, F, Asp	Yes	13 ppm	25 ppm	1200 ppm	12.5	74	X	X	X	X	X	X						
Chlorine[2]	**Cl_2**	HT, C	Yes	0.05 ppm	0.1 ppm, 0.4 ppm STEL	10 ppm	NA	NA	X	X	X	X		X	X	X	X	X	X	X
Diborane[2]	**B_2H_6**	HT, EF	Yes	50 ppb	100 ppb	15000 ppb	0.8	88	X	X	X	X	X	X	X	X	X	X	X	X
Dichlorosilane[2,3]	**SIH_2Cl_2**	T, EF	Yes	0.5 ppm	1 ppm	NE	4.1	99	X	X	X	X	X	X	X	X	X	X	X	X
Digermane[2]	**GE_2H_6**	T, F	Yes	0.1 ppm	0.2 ppm	NE	0.5	100												
Disilane[2]	**Si_2H_6**	EF, Pyro	Yes	2.5 ppm	5 ppm	NE	0.2	NE	X	X	X	X	X	X	X	X	X	X	X	X
Ethane	**C_2H_6**	EF, Asp	Evaluate	NE	NE	NE	1.8	8.4	X	X	X	X	X		X	X	X			
Ethylene[2]	**C_2H_4**	T, F	Yes	5% LEL	50% LEL	NE	2.7	36	X	X	X	X	X		X	X	X			
Fluorine[2]	**F_2**	T	Yes	0.05 ppm	0.1 ppm	25 ppm	NA	NA	X	X	X	X		X	X	X	X	X	X	X
Germane[2]	**GeH_4**	HT, F, Pyro	Yes	100 ppb	200 ppb	NE	Pyro	Pyro	X	X	X	X	X	X	X	X	X	X	X	X
Gallium trichloride	**$GaCl_3$**	C	No	NE																
Germanium Tetrafluoride	**GeF_4**	T	Yes	1.5 ppm	3 ppm C*	30 ppm	NA	NA	X	X	X	X		X	X	X	X	X	X	X
Helium	**He**	Inert	No																	
Hydrogen[2]	**H_2**	F	Yes	5% LEL	50% LEL	NE	4	75	X	X	X	X	X	X	X	X	X	X	X	X
Hydrogen Bromide[2]	**HBr**	C	Yes	1 ppm	2 ppm C*	30 ppm	NA	NA	X	X	X	X		X	X	X	X	X	X	X
Hydrogen Chloride[2]	**HCl**	T, C	Yes	1 ppm	2 ppm C*	50 ppm	NA	NA	X	X	X	X		X	X	X	X	X	X	X
Hydrogen Fluoride[2]	**HF**	T, C	Yes	0.25 ppm	0.5 ppm, C* 2 ppm	30 ppm	NA	NA	X	X	X	X		X	X	X	X	X	X	X
Hydrogen Selenide[2]	**H2Se**	HT	Yes	0.025 ppm	0.05 ppm	1 ppm	NE	NE	X	X	X	X		X	X	X	X	X	X	X
Hydrogen Sulfide[2]	**H2S**	T	Yes	0.5 ppm	1 ppm STEL 5 ppm	100 ppm	4	44	X	X	X	X		X	X	X	X	X	X	X
Methane[2]	**CH_4**	F	Yes	NE	NE	NE	5	15	X	X	X	X	X	X	X	X	X	X	X	X
Nitrogen	**N_2**	Inert, Asp	No																	
Nitric Oxide[2]	**NO**	HT	Yes	13 ppm	25 ppm	100 ppm	NA	NA	X	X	X	X		X	X	X	X	X	X	X
Nitrous Oxide	**N_2O**	T, O	Yes	25 ppm	50 ppm	NE	NA	NA	X											
Nitrogen Trifluoride	**NF_3**	T, O	Yes	5 ppm	10 ppm	1,000 ppm	NA	NA	X	X	X	X		X	X	X	X	X	X	X
Octafluorocyclobutane	**C_4F_8**		No	NE	NE	NE	NA	NA												
Oxygen	**O_2**	O	No	NE	NE	NE	NA	NA		X				X						
Ozone	**O_3**	HT	Evaluate	0.025 ppm	0.05 ppm	5 ppm	NA	NA	X	X	X	X		X	X	X	X	X	X	X

Phosgene	**$COCl_2$**	HT	Yes	0.05 ppm	0.1 ppm C* 0.02 ppm	2 ppm	NA	NA	X	X	X	X		X	X	X	X	X	X	X
Phosphine[2]	**PH_3**	HT, Pyro	Yes	25 ppb	0.05 ppm C* 0.15 ppm	50 ppm	1.79	Pyro	X	X	X	X	X	X	X	X	X	X	X	X
Silane[2]	**SiH_4**	Pyro	Yes	2.5 ppm	5 ppm	NE	Pyro	Pyro	X	X	X	X	X	X	X	X	X	X		X
Silicon Tetrafluoride	**SiF_4**	T, C	Yes	1.5 ppm	3 ppm	30 ppm	NA	NA	X	X	X	X		X	X	X	X	X	X	X
Stibine	**SbH_3**	HT	Yes	0.05 ppm	0.1 ppm	5 ppm	NE	NE	X	X	X	X		X	X	X	X	X	X	X
Sulfur hexafluoride	**SF_6**	Asp	Evaluate	500 ppm	1000 ppm	NE	NA	NA		X						X	X	X	X	X
Tetrafluoromethane	**CHF_3**																			
Tetraethyl orthosilicate	**TEOS**	F	Yes	5 ppm	10 ppm	700 ppm	0.9	5.75	X	X	X									
Trimethylboron[2]	**$(CH_3)_3B$**	HT, T, F, WR, Pyro	Yes	3 ppm	7 ppm		0.5	NE	X	X	X	X	X	X	X	X	X	X	X	X
Trichlorosilane	**Cl_3HSi**	EF, Pyro	Yes	NE	NE	NE	1.2	90.5	X	X		X		X	X	X	X	X	X	X
Tungsten Hexafluoride	**WF_6**	T, C	Yes	1.5 ppm	3 ppm		NA	NA	X	X	X	X		X	X	X	X	X	X	X

Notes for specialty gas use and handling

[1] Not required if all cylinders are used in exhausted gas cabinets or in a designated hot work area.
[2] Must have doubled-contained piping.
[3] Detection levels are set in accordance with another byproduct gas or chemical, HCL, TMB and TEOS.

Gas monitoring point locations: Located anywhere with mechanical fittings, i.e., gas cabinet or valve manifold boxes, tool valve boxes and additional point detection in tool and abatement exhaust, operator, gas room and abatement breathing zones.

Table definitions

- **Asp**: Asphyxiant.
- **C**: Corrosive.
- **C***: Ceiling or a level not to be exceeded during the work day.
- **EF**: Extremely flammable.
- **F**: Flammable.
- **HT**: Highly toxic.
- **IDLH**: Immediately dangerous to life and health. An IDLH level enforced may differ with the fire authority having jurisdiction. Investigate before using these numbers for your operation.
- **LEL**: Lower explosive limit percentage.
- **NA**: Not applicable.
- **NE**: Not established.
- **O**: Oxidizer.
- **Ppm**: Parts per million concentrations.
- **Pyro**: Pyrophoric.
- **Rec**: Recommended.
- **RFO**: Restricted flow orifice. Recommended for Toxic, Highly Toxic and Pyrophoric.
- **STEL**: Short-term exposure limit.
- **T**: Toxic.
- **UEL**: Upper explosive limit percentage.
- ***1**: Monitoring may be required depending on the use and circumstances. Call EHS at 480-965-1823 for more information.

Appendix I

Gas cabinets

Gas cabinets are required for the use of any amount of toxic, highly toxic, corrosive, flammable or pyrophoric gas at ASU except where quantities of toxic, corrosive or flammable gases are in cylinder sizes of 40 cubic feet or smaller and where quantities of highly toxic or pyrophoric gases are lecture bottle size only. The gas cabinet is designed to contain an exhaust to a safe location any accidental release and protect the gas cylinder from physical damage.

Gas cabinet selection

Gas cabinets are often manufactured for the highest hazard level, purity needs and automation. A gas cabinet with a small cylinder, used intermittently and in small quantities, with minimal purity concerns, corresponds to Figure 1 below. A gas cabinet for a highly toxic or pyrophoric gas requiring high purity will require a higher control level, as specified in Figure 2. Email ASU Fire Safety and Prevention for gas cabinet reviews and approvals per the fire code.

Figure 1 describes the basic gas cabinet construction requirements.

Gas panel

The gas panel or manifold is an assembly of gas piping, regulators and devices designed to safely dispense gas at controlled flow rates. The gas panel is constructed with mechanical fittings, which must be kept within the exhaust gas cabinet enclosure. There can be no mechanical connections on systems containing hazardous gases unless they are in an exhausted enclosure except for purge cylinders. Figure 1 presents a simple gas panel with minimum purge capabilities required for all toxic, highly toxic and pyrophoric gases.

Local exhaust ventilation

Gas cabinets will require an exhaust system connection. The manufacturer determines the local exhaust ventilation amount required for cabinet operation. The minimum average face velocity is 200 feet per minute, fpm, or 150 fpm at any point across the access port per Chapter 60 of the IFC. This usually equates to a volumetric flow rate of 150 cubic feet per minute, cfm, for a single-cylinder cabinet. Most manufacturers require at least 200 cfm, and some may require 300 cfm or more, depending on the cabinet size. Valve manifold boxes, purifier cabinets and equipment panel cabinets should be exhausted at four to five air changes per minute.

The ductwork materials must be compatible with the intended gases, such as galvanized steel versus stainless steel, and not made from a combustible material. The duct installation shall include an exhaust-controlling device, preferably a blast gate.

The blast gate should be located as far away from the cabinet as possible but before any upstream branch within the same workspace so that it can be easily accessed. Blast gates should not be installed on bypass ducts. Refer to NFPA 92 for more information.

The standard-size gas cabinet exhaust connection is six inches. The exhaust air shall not be recirculated into occupied spaces but exhausted to the roof in a manner protective of both people working on the roof and those walking nearby.

In addition, for toxic and highly toxic gases, a calculation will need to be performed to determine if the gas concentration is less than half the immediately dangerous to life and health concentration in a realistic worst-case gas release. These requirements may drive the need for an air-scrubbing device or restricted flow orifice. Refer to the treatment systems section below for more information. Furthermore, the exhaust should not be located where it could result in containment re-entrainment into occupied spaces through doors, windows, heating, ventilation and HVAC air intakes.

Cabinet exhaust inlets and outlets shall be designed to sweep the entire volume well. The inlet louver should be adjustable to aid in balancing the exhaust and achieving the required static pressure in the cabinet and duct.

Gas cabinet installation

Approval must be obtained from EHS and ASU Fire Safety and Prevention after gas cabinet selection and before purchase.

Location

Hazardous gas cabinets should not be installed outdoors unless physically secured behind locked fencing or walls and never near a public way. Gas cabinet areas should be limited to authorized employees, except under direct user control. Gas cabinets cannot be stored in hallways used for exit access. Avoid placing cabinets in heavy traffic areas which would restrict gas cylinder changes.

Treatment systems

A treatment system will be installed to handle accidental full-cylinder gas release for toxic and highly toxic gases. The system should reduce the maximum allowable discharge concentrations to one-half of IDLH concentrations at the atmospheric discharge point. The release rate will be calculated by the maximum flow from the valve as determined by the manufacturer if the cylinder is equipped with an RFO. The release rate will be considered five minutes for non-liquified gases and 30 minutes for liquified gases without an RFO.

A treatment system is not required when an approved gas detection system and approved automatic-closing fail-safe valves are located immediately adjacent to the cylinder valve for toxic gases.

Purge and vacuum venturi vent gas

An inert gas must be supplied to the gas cabinet for toxic, highly toxic and pyrophoric gas panel purging and, if present, the vacuum venturi vent. A mixture of 10% helium-90% nitrogen is recommended for the purge gas to facilitate system leak checking.

The gas supply purge must be at least 85 psi for cycle purging. The venturi vent pulls a vacuum on the panel to ensure an inert atmosphere in pyrophoric vent lines. Purge gases cannot be shared between incompatible hazardous gases, such as an oxidizer and a flammable gas. Panel purge gases shall be delivered from a cylinder source and not from house nitrogen or other house gases. Venturi vent gas typically uses a house nitrogen source.

Automatic sprinkler

A gas cabinet containing hazardous gas located in an occupancy area must have fire suppression and detection connected to the facility’s automatic sprinkler system. This is not required if the gas cabinet is in an approved gas distribution room or outdoors.

Operation

Standard operating procedures must be developed before operation begins and approved by EHS and ASU Fire Safety and Prevention. These must detail the safe gas cabinet operation procedures. These procedures shall address the following, at a minimum:

- Installation, removal and securing gas cylinders inside the cabinet.
- Maintenance requirements, including gas detection equipment calibration and ventilation checks.
- Purging the manifold.
- Response to alarm activation.
- Safe equipment shutdown protocols.

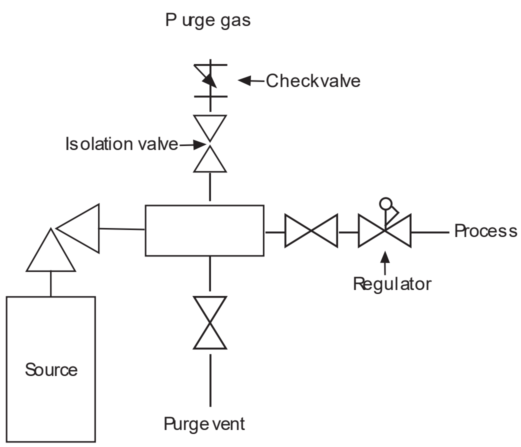


Figure 1

Gas cabinet specification with minimum purge capability

The gas cabinet is designed to provide an exhaustive enclosure for gas cylinders. It is required for all toxic, highly toxic, flammable and pyrophoric gas cylinders. The cabinet must meet the following:

- Accept the output of hazardous gas monitors, such that upon detection of a leak, the controller will enact a shut-off gas flow and provide a local visual and audible alarm when required.
- An EMO must be hard-wired to the respective unit and can trigger a cylinder shutdown and indicate the action via a visual and audible alarm.
- Constructed of 12-gauge steel.
- Exhaust flow monitoring.
- Exhaust ventilation provides an average of 200 linear feet per minute across any open access port with no reading less than 150 lfpm.
- Have a purge panel for evacuating and venting gases from process lines for corrosive, toxic, highly toxic and pyrophoric gases.
- Fire detection for pyrophoric gases.
- Fire suppression and detection in the form of a wax-coated sprinkler head to be connected to the facility's automatic sprinkler system.
- Maximum of three cylinders per cabinet.
- Provided with self-closing limited-access ports or windows to give access to controls when feasible.
- Self-closing doors.
- Treated, coated or constructed with materials compatible with stored materials.

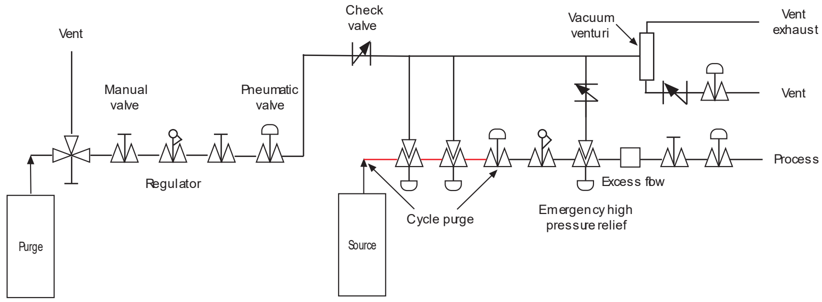


Figure 2

Gas cabinet with control panel specification

The gas cabinet is designed to provide an exhaust enclosure for gas cylinders, including:

- Auto-crossover functions, optional — the controller allows for a pressure input letting the system know when a cylinder needs to be changed. An alarm will sound for low cylinder pressure. The valve on the delivery panel will close, and the valve on the backup panel will open, ensuring the constant gas supply when the cylinder pressure falls to this set pressure. The newly replaced cylinder will serve as the backup for the current cylinder in use.
- Accept the output of hazardous gas monitors such that upon detection of a leak, the controller will enact a gas flow shut-off and indicate a local visual and audible alarm when required.
- An EMO must be hard-wired to the respective unit and can trigger a cylinder shutdown and indicate it via a visual and audible alarm.
- Constructed of 12-gauge steel.
- Downstream high-pressure sensor — when pressure exceeding safe levels is detected, the panel vents the system.
- Excess flow valve.
- Exhaust flow monitoring.
- Exhaust ventilation provides an average of 200 linear feet per minute with no reading less than 150 lfpm across any open access port.
- Fire detection for pyrophoric gases.
- Fire suppression and detection in the form of a wax-coated sprinkler head to be connected to the facility's automatic sprinkler system.
- Have a purge panel for evacuating and venting gases from process lines for corrosive, toxic, highly toxic and pyrophoric gases.
- Pneumatic cylinder isolation valve — cylinders can be ordered with a pneumatic cylinder valve in place of the standard manual valve. They are typically used with toxic, highly toxic and pyrophoric gases. A controller is configured with extra solenoid valves and programming and uses pneumatic pressure to open the cylinder. Should there be a fault condition requiring a cabinet shut down, such as leak detection, fire, power outage, EMO, etc., the activation air to this valve is shut, and the valve at the gas source closes.
- Provided with self-closing limited-access ports or windows for access to controls when feasible.
- Scales may be needed to quantify usage and monitor the cylinder liquid amount.
- Self-closing doors.
- Treated, coated or constructed of materials that are compatible with materials stored.
- Vacuum generator module: Creates the vacuum necessary for the safe operation of the gas system, including:
  - Check valve to prevent process gas back-flow into the house nitrogen system.
  - Isolation valve to control the house vacuum flow to the venturi.
  - Vacuum venturi capable of 100 torr.

Controller

A controller is needed to automatically monitor and control the gas cabinet operation. The controller is normally anchored to the cabinet top and comes with a standard set of inputs and outputs. Controllers must have an emergency shut-off button, a local audible alarm, a local visual alarm and pneumatic connections for input and output for emergency shut-off valve control.

Typical controller sensors and shutdowns include:

- Excess flow.
- Exhaust fails.
- Fire detection.
- Gas detector alarm.
- Gas detector warning.
- High delivery pressure.
- Low cylinder contents.
- Process line containment.
- Remote start.
- Remote shutdown.

Pneumatic gas: Panel operation of automatic valves typically requires 75 psi. Use inert gas in flammable and pyrophoric gas cabinets.

Appendix J

Pipe labeling requirements

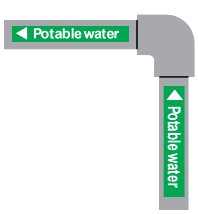
Refer to American National Standard Institute A13.1.

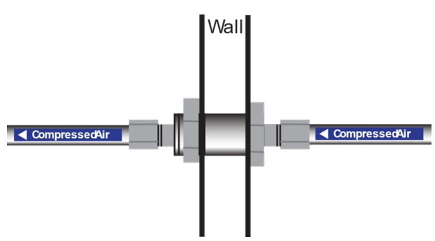
Pipe labels are required in the following places.

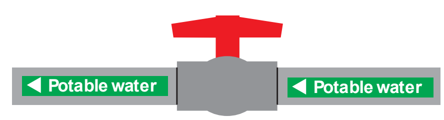
- At all changes in direction on both sides of the turn.
- At both entry point sides through floors and walls.
- Every 25–50 feet along the straight run of pipe.
- Next to all flanges and valves.

Note: See the MTW Semiconductor design guideline for specific line labeling at MTW.

Pipe labeling color guidelines		
Description	**Letter color**	**Background color**
Flammable	Black	Yellow
Oxidizing	Black	Yellow
Combustible	White	Brown
Toxic	Black	Orange
Corrosive	Black	Orange
Compressed air	White	Blue
Steam or water	White	Green
Fire suppression	White	Red







Gas cabinet worksheet

Name: ______________________________________ Date: ____________________

Email: _____________________________________ Phone: ____________________

Location: ___________________________________ Date required: _______________

Gas	Cylinder width	Cylinder height	DISS or CGA	Max flow	Outlet pressure	Excess flow range	Switchover setpoint, lbs.

Specifications

Location type	Indoors	Outdoors
Number of cylinders	Process	Purge
Automatic cycle purge	Yes	No
Gas cabinet controller	Yes If yes, what is the model? ____________________	No
Exhaust connection	Size: ____	
Tubing	Size: ____	
Process component materials i.e., 316 stainless		
Process regulator	Yes	No
Diaphragm valve	Yes	No
Cylinder scales	Yes	No
Excess flow switch	Yes	No
Venturi vacuum	Yes	No
Double-walled piping	Yes	No
Pneumatic cylinder valve	Yes	No
Exhaust sensor switch	Yes	No
Rate of rise temp sensor	Yes	No
UVIR flame detector	Yes	No
Gas detector needed	Yes	No
Gas detector installed	Yes	No
Sprinkler heads	Yes	No
EMO	Yes	No

Additional information