

M_002 Compressed Gas Safety Lecture



Milton J. Shoup III
Mechanical Safety Officer
University of Rochester
Laboratory for Laser Energetics

The Hindenburg disaster at Lakehurst, New Jersey on May 6, 1937 brought an abrupt end to the age of the rigid airship. After more than 30 years of passenger travel on German commercial zeppelins (during which tens of thousands of passengers flew over a million miles on more than 2,000 flights without a single injury) the era of the passenger zeppelin came to an end in a few fiery minutes.

Moral of the story?
One accident can end a successful program

Safety is everyone's business and compliance with safety procedures is **MANDATORY**



- **If an activity or practice seems unsafe, “Stop Work” and take the time to address concerns**
- **Situational Awareness – The best way to prevent an accident is to be aware of your surroundings**
- **All new gas systems must be inspected and approved by Mechanical Engineering (ME) prior to operation**
- **No unqualified pressure vessel systems may be deployed**
- **Only perform activities for which you are qualified**
- **Be familiar with the gases or cryogenic liquids that are being used**
- **Always use the proper Personal Protective Equipment (PPE)**

Pressurized gas systems at LLE are classified into three categories

- All gas system sources are classified as either Low (<150 psi), High pressure (>150 psi), or Flammable

 Low pressure systems that use “house” air or nitrogen and commercial air compressors designed for <150 psi and when used in accordance with manufacturer's recommendations require only ME Safety Training

 High pressure gas systems consist of either bottled gas sources or commercial equipment capable of developing >150psi

- Flammable gas systems require extra safety measures and will be evaluated on a case-by-case basis by the LLE safety officers and the gas products supplier
- All bottled gas systems must have operating procedures and be operated by personnel who have completed compressed gas training

All gas systems must be inspected and approved by ME prior to first use.

All operators of high pressure, flammable gas, or bottled gas systems must have compressed gas system training.

Personal Protective Equipment (PPE) is provided by LLE and usage is mandatory when required



- There are areas within LLE that require the usage of PPE. Most of these areas have signs indicating the type of required PPE.
- Types of PPE used when handling compressed gas and cryogenic liquid hazards include
 - Protective eyewear, face shields
 - Gloves – Latex, nitrile, heavy duty leather or other suitable material
 - Cryogenic Gloves and Aprons
 - Long sleeved clothing, trousers without cuffs
 - Closed toe footwear
 - Ear plugs or earmuffs

Review PPE requirements with the work area supervisor if you are unsure what the requirements are.

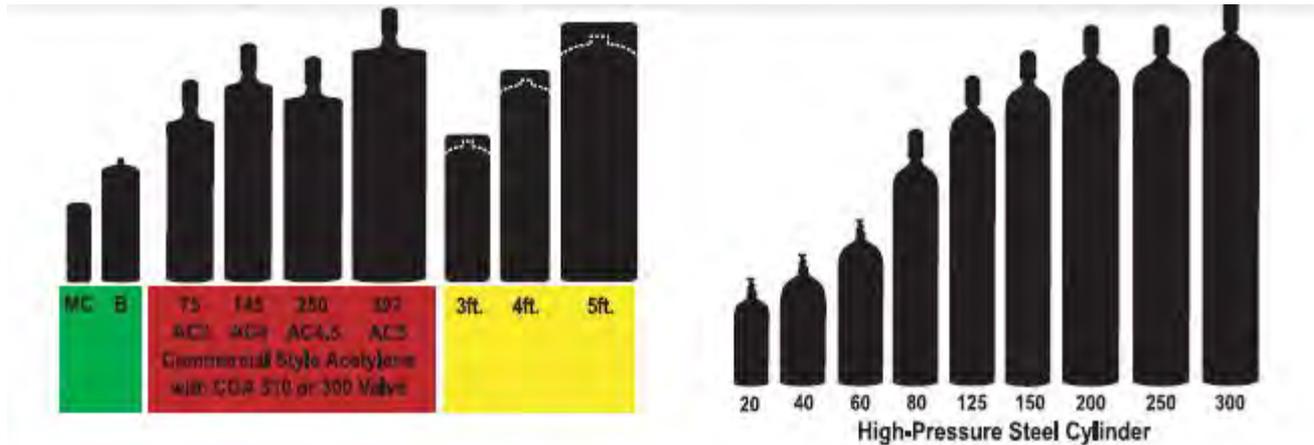
Contact a Safety Officer to conduct a job hazard analysis and help select PPE for new or altered activities and processes.

Maintenance (cleaning) and care of PPE is the responsibility of the employee



- **Keep PPE clean and in good working order**
- **Check the PPE before each use**
- **Wear the PPE correctly**
- **PPE that is provided in a work area that is damaged or is not functional must be taken out of service by returning it to the work area supervisor who will dispose of it, have it repaired, or replace it**
- **PPE that is provided in specific areas or for specific tasks must NOT be removed from that area**
 - **For example: do not “upgrade” your laser safety glasses from another lab, the wavelengths may not be compatible**

Compressed gases come in many cylinder sizes for low and high pressure applications



Specialty Gas Cylinder Size Comparison Chart							
Approximate Dimensions (inches)	Airgas	Linde	Air Liquide	Praxair	Matheson Trigas	MG	Scott Specialty Gases
High Pressure Steel							
9 x 55	300	049	49	T	1L	300	K
9 x 51	200	044	44	K	1A	200	A
7 x 33	80	016	16	Q	2	80	B
7 x 19	35	007	7	G	3	35	C
2 x 12	LB	LBR	LB	LB	LB	LB	LB
4 x 26	E	005	MEDE	ANE	3L	E	ER
10 x 51	3HP	485	44H	6K	1U	6K	—
9 x 51	2HP	—	44H	3K	1H	3K	—
Aluminum							
10 x 52	300A	—	AT	—	—	—	—
8 x 48	150A	A31	30AL	AS	1R	150AL	AL
7 x 33	80A	A16	22AL	AQ	2R	80AL	BL
7 x 16	33A	A07	7AL	AG	3R	33AL	CL
4.5 x 15	9A	—	9AL	—	—	9AL	—

Large compressed gas cylinders must be stored with a cylinder cap installed



- This is an example of a properly installed cylinder cap

Never lift a compressed gas cylinder by the cap

All gas cylinders must have a clearly visible and legible label



Cylinders that do not have a legible label must not be used and must be returned to the gas supplier

All gas cylinders must have a label indicating the usage status of the cylinder

- After placing a full cylinder in service rip off the “Full” tab to indicate that the cylinder is in service
- Put your name and date on the top of the label
- After the cylinder has discharged contents to a pressure that is no longer useful rip off the “In Service” tab to indicate that the cylinder is empty
 - Residual contents are permissible



A few basic steps must be executed before moving a gas cylinder

- **Before using any cylinder for any purpose check the label for proper contents (i.e. don't grab helium if you need nitrogen)**
- **If any cylinder is suspected of leaking, have the Shipping and Receiving staff contact the supplier immediately**
- **Always make sure a the cylinder cap is on tight before moving**
- **When cylinders are moved, they should not be subjected to abnormal mechanical shock which may cause damage to their valves, their safety devices or to the cylinder itself**

These rules must be followed when moving gas cylinders



- Cylinders should never be dragged
- **NEVER** lift a cylinder by the cap
- Move cylinders in an upright position by using a suitable cylinder cart or hand truck
- The cylinder must always be strapped to a cart
- Never move the cylinder without a cap installed
- Never move the cylinder with a regulator attached
- Small cylinders may be moved on a cart that has sides to prevent them from rolling off



FOLDABLE REAR ASSEMBLY WITH
LARGE 4" CASTERS

Airgas NO. 6114
HEIGHT: 46" DEPTH: 15" (O.D.)
WIDTH: 15" (O.D.) WEIGHT: 30 lbs.
WHEEL DIA: 10" x 1.75" SOLID RUBBER
CASTER: 4" x 1" SWIVEL / POST
SINGLE CYLINDER

This video demonstrates why it is important to protect the compressed gas cylinder valve

[\(YouTube link\)](#)



Additional rules pertaining to gas cylinders



- **Never permit cylinders to come in contact with electrical apparatus or circuits**
- **Never permit oil, grease, organic materials, or other combustible substances to come in contact with cylinders or their valves, particularly oxygen**
- **Never use oxygen as a substitute for compressed air**
- **Cylinders should never be used as rollers, supports, or for any other purpose than for which they were intended**
- **Wrenches should not be used on a cylinder valve that is equipped with a hand wheel**
- **If the valve is faulty, tag the cylinder and notify Shipping and Receiving personnel**

Gas cylinder storage at LLE consists of two separate areas in Shipping and Receiving (S&R) area

- Flammable gas storage



- Nonflammable gas storage



Gas cylinders must be stored in Shipping and Receiving until they are put into service

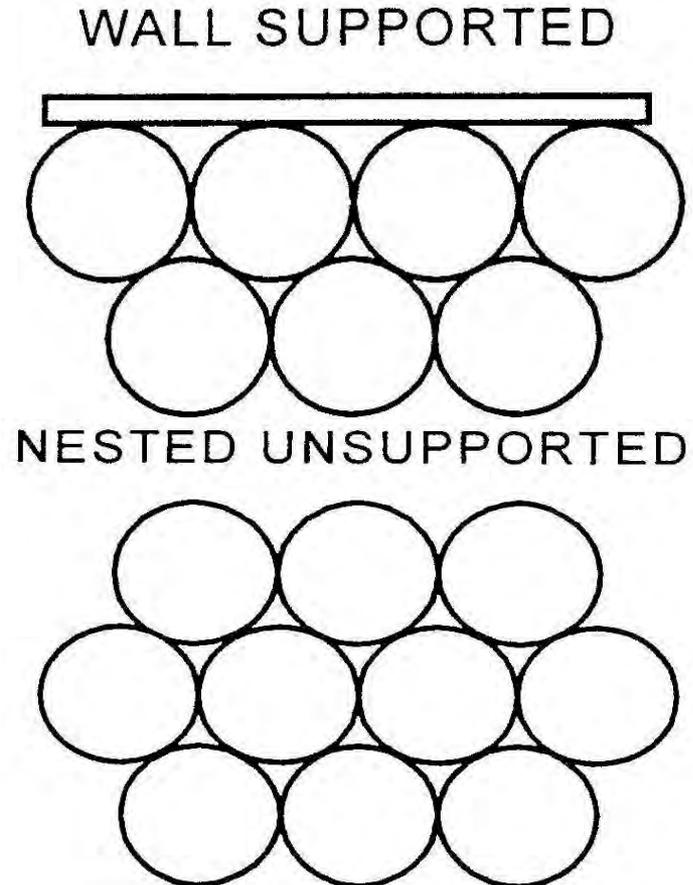


- Gas cylinders must be returned to Shipping and Receiving when they are removed from service
- Cylinders must be individually secured (strapped) to a wall bracket, bench clamp, or transport cart
- Cylinders must have a cap properly installed at all times except when in use
- Empty and full cylinders must be segregated and appropriately labeled

Do not store “extra” gas cylinders anywhere else

Nesting of compressed gas cylinders

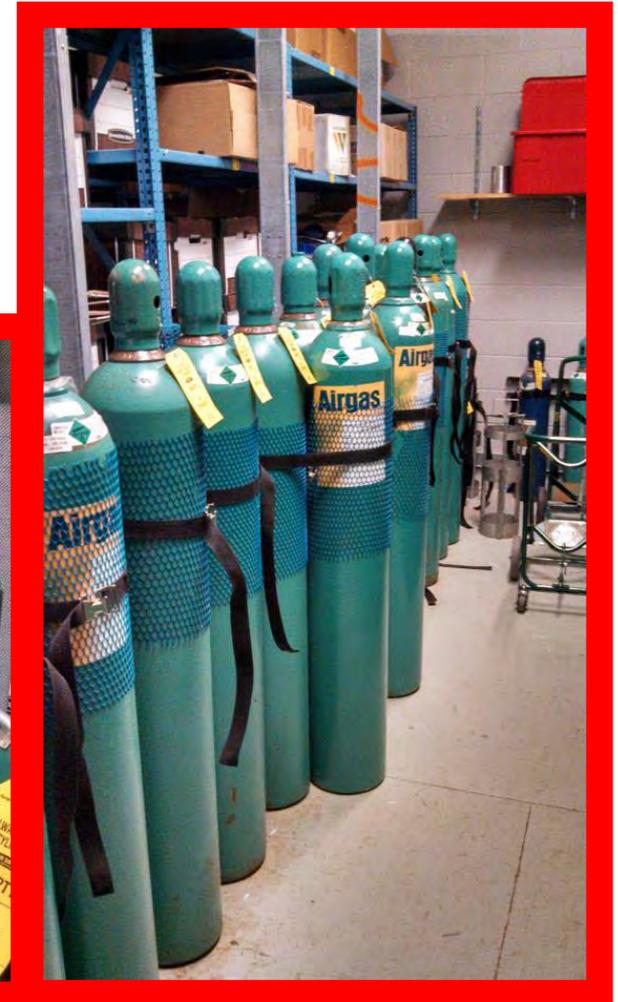
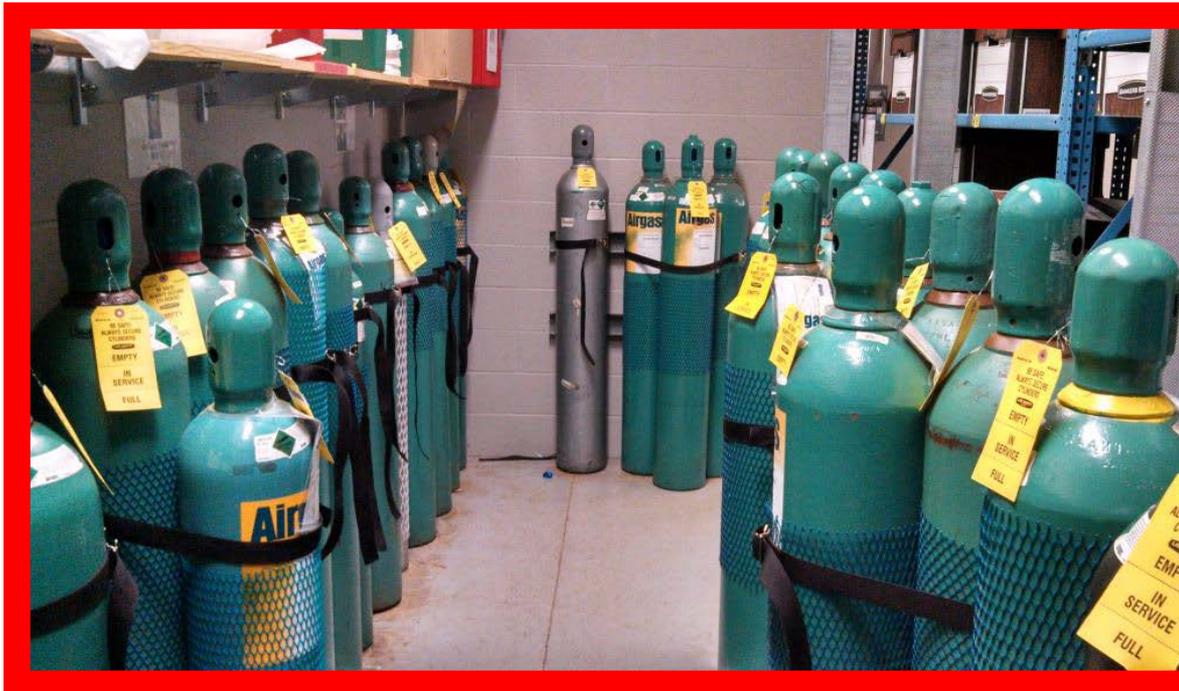
- Nesting is a method of securing cylinders in a tight mass using a contiguous three-point contact system where all cylinders in the group have at least three points of contact with other cylinders, walls, or bracing.
- When compressed gas cylinders are stored or handled at container filling or service facilities, the continuous handling makes the process of chaining the cylinders inconvenient and time-consuming for the employees. In those environments, the fire codes allow cylinders to be “nested.”



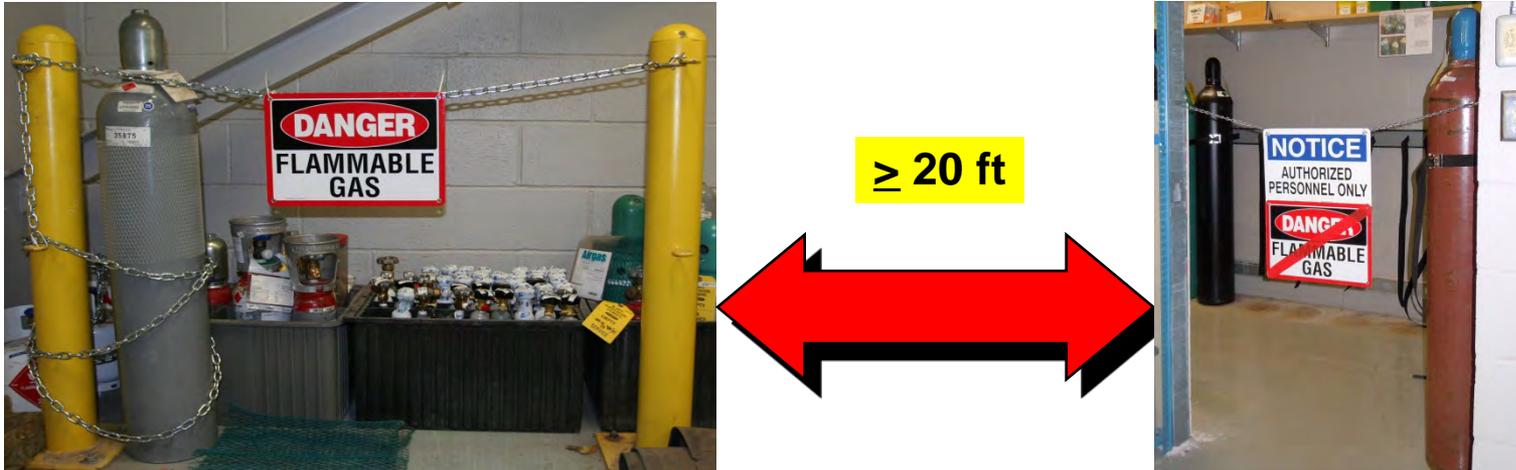
Nesting of compressed gas cylinders is not permitted at LLE

Nesting of compressed gas cylinders is not permitted at LLE and yet it is occasionally observed

- If nesting is observed in the gas storage area please report this to **Bill Byrne**



Flammable gases must be stored at least 20 ft away from any oxidizing gases or gas mixtures



- Flammable gases and gas mixtures must be:
 - Used and stored in a well-ventilated area that is readily accessible in case of emergency
 - Electrically grounded when in use to prevent sparks and static charge buildup. This is typically accomplished through the distribution system

For flammable gases, spark-proof tools must be used when changing regulators

Acetylene gas cylinder handling

- Because of acetylene's unstable nature, it must be stored under special conditions. This is accomplished by dissolving the acetylene in liquid acetone. The liquid acetone is then stored in the acetylene cylinder, which in turn, is filled with a porous (sponge-like) cementitious material.
- Acetone is used to stabilize the acetylene, but pockets of pure acetylene can develop at the valve stem if the cylinder is not kept in an upright position, or if the cylinder is dented or damaged.
- Acetylene cylinders are pressurized to 250 psig, but free acetylene is highly unstable over 15 psig.
- Acetylene gas regulators should not exceed a setting of 15 psig



Acetylene cylinders must always be stored upright. If a cylinder is lying on its side, it must be stored upright for at least 30 minutes prior to use.

Both full AND empty gas cylinders must be secured upright to an immovable object at all times



Gas system definitions

- **MOP – Maximum Operating Pressure**
 - The maximum nominal operating pressure of a gas system
- **MAWP – Maximum Allowed Working Pressure**
 - The maximum pressure that a gas system can be charged to
 - Pressure Relief Valves (PRV) are set to this pressure
 - **MAWP = 1.2 X MOP**
 - **MAWP is defined by the gas system component with the lowest pressure rating**

Never operate a gas system in excess of the Maximum Operating Pressure

Common components and safety features of a pressurized gas system

- Gas source (cylinder) with an integrated rupture disk
- Cylinder safety strap
- Regulator – single or two stage
- Fittings
- Manifolds
- Pressure Relief Valve (PRV) or Pressure Relief Device (PRD)



Vacuum fittings are not to be used on pressurized gas systems unless they are specifically rated for pressure applications

- Vacuum and pressure fittings are to be used in their rated operating ranges

Regulators are designed and constructed for use with specific gases and gas families



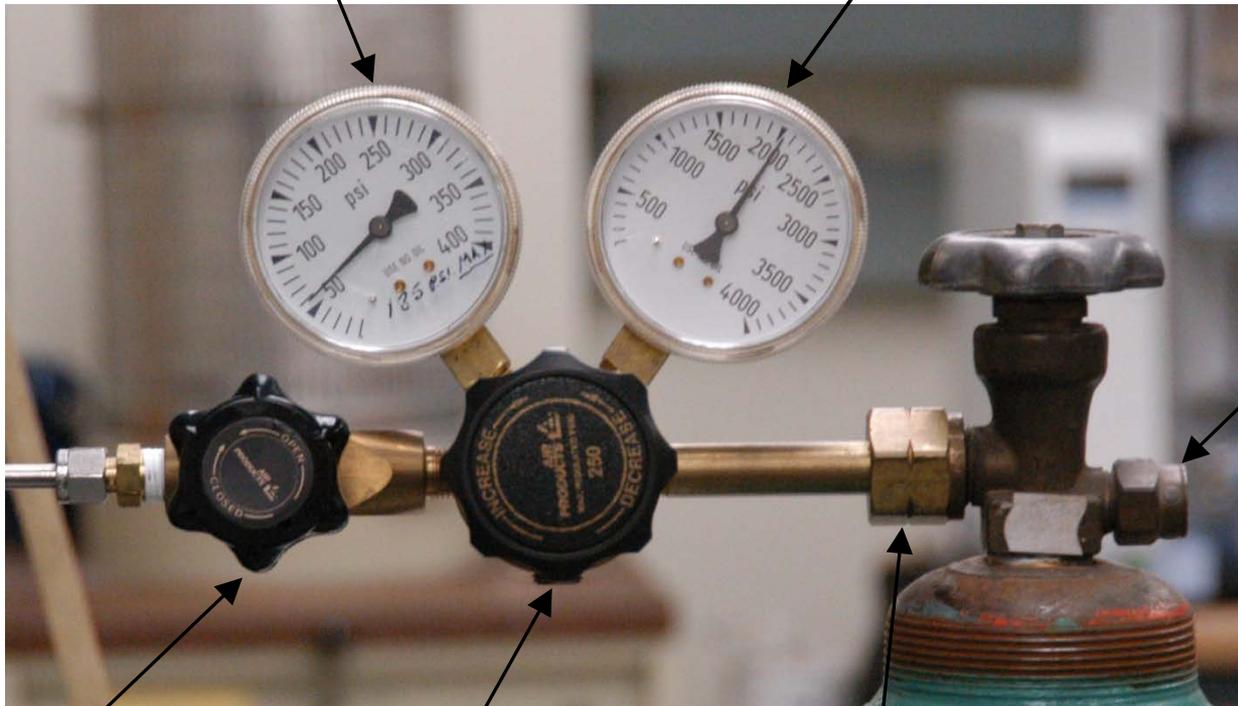
- Regulator selection is highly dependent upon the application
- Selection of a regulator is influenced by the following factors:
 - Type of gas being used (inert, flammable, oxidizer, corrosive etc.)
 - Grade of gas being used
 - Delivery pressure
 - Flow capacity
- Use care when installing regulators and valves on flammable gas cylinders. Many use left-handed threads to prevent them from being interchanged with oxidizing gasses.

Contact ME if you need help selecting a regulator suitable for your application

The key components of a two stage regulator and compressed gas cylinder

Outlet pressure gauge

Inlet pressure gauge



PRD

Valve

Regulator

Cylinder connection (CGA)

Never attempt to modify or repair any component of a regulator

Pressure gauges must be properly sized and suitable for the use conditions

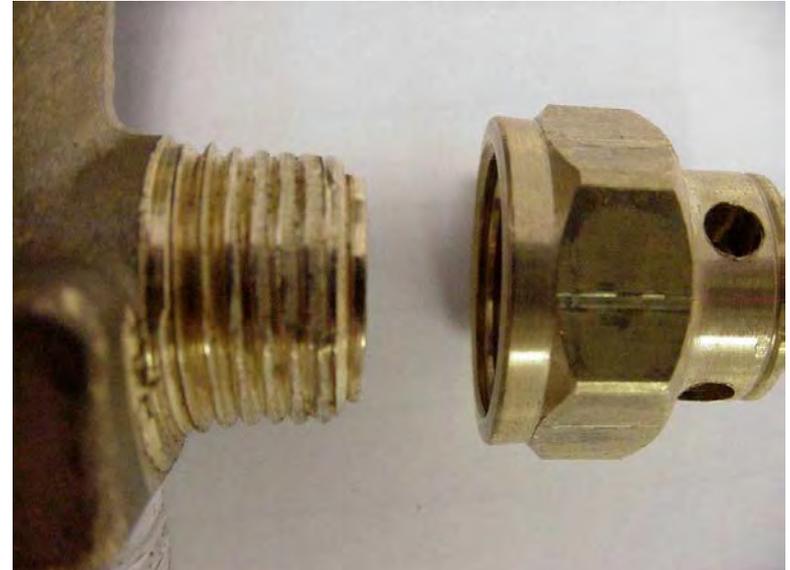


- **ASME B40.100 recommends that the normal operating pressure be confined to 25%-75% of the gauge scale**
- **If pulsation is present in the process, the maximum operating gauge pressure should not exceed 50% of the full-scale range**
 - **For example, a system operating at 100 psig the gauge scale should be graduated to 200 psig**
- **Safety gauges (a blow out back) must be used in high hazard situations. Gauges over 4" in diameter must use safety gauges**
 - **High hazard situations include fluids with the following properties that are hazardous to personnel: acids, bases, flammable, toxic, elevated temperatures, etc.**
- **Gauge materials must be compatible with the gas in service**

Contact ME if you need help selecting a gauge suitable for your application

All gas cylinders are equipped with a “frangible disk” Pressure Relief Device (PRD)

- If you discover a cylinder with a leaking PRD,
 - Evacuate the area
 - If it is a flammable gas, pull a fire alarm
 - Notify a supervisor or safety officer. Provide information about the gas
 - Do not return to the area until the area has been deemed safe (gas concentration is below flammability limits, safe O₂ levels)
- Notify Shipping and Receiving and have them contact the gas supplier



Nobody at LLE is permitted to repair a cylinder PRD

Compressed Gas Association (CGA) threaded connections on regulators and cylinders are NOT equivalent to pipe threads

The equipment shown in this photograph was found in service at LLE!

- **Make sure you use the correct regulator for your application (corrosive, flammable, oxidizer, pressure range, etc.)**
- **If you are unsure what regulator or fittings to use ask for help**



Never connect anything to a gas cylinder except the appropriate approved regulator

Organic residues on cylinder valve and regulator threads can be very dangerous



- **Always wear clean latex or similar gloves when handling cylinder stems, valves, and regulators (lotions, hand creams, make-up, hair products are organic based)**
- **Never use Teflon tape, pipe dope, or any similar product on the CGA threads of cylinder valves and regulators**
- **Teflon tape may be used on the regulator pressure gauges since they are pipe threads and not CGA threads**
- **Leak test with inert products such as SNOOP or use an electronic leak tester. Soaps and other products might leave organic residue**

Never use lubricants on compressed gas system components

- **This is an oxygen valve that had been contaminated with a common lubricant**
- **When the valve was opened, oxygen reacted with the lubricant, burning hot enough to ignite the metal. Flames shot up through the valve and burned the operator's hand**



Regulator – Installation



- 1. Wear leather work-gloves when handling gas cylinders that are not secured in-place, e.g. when loading, transporting and securing them**
- 2. Wear eye protection when handling gas cylinders and when using compressed gas**
- 3. Before removing the cylinder cap, move the cylinder to the work site**
- 4. Properly secure the cylinder to floor, wall or bench with appropriate chain or stand to prevent toppling**
- 5. Visually inspect all equipment used with the cylinder. Replace all defective equipment before proceeding**
- 6. Remove the cylinder cap**
- 7. Verify the cylinder valve is tightly closed**
- 8. Remove the cylinder valve plug, if any**

If a gas cylinder appears to be damaged or malfunctioning, including thread damage, notify LLE Shipping and Receiving immediately

Regulator – Installation



9. **Inspect the cylinder valve threads for damage or contamination**
10. **If necessary, clean all threaded connections using isopropyl alcohol and lint free wipes**
11. **Make sure all connections are dry**
12. **Attach the regulator and securely tighten**
13. **Make sure the regulator working pressure is as low as possible by turning the pressure control knob counter-clockwise**
14. **Position the cylinder between yourself and the regulator**
15. **Slowly open the cylinder valve and observe the high pressure gauge on the regulator as it climbs to full cylinder pressure**
16. **If no gross leaks (hissing sound) are readily observable, slowly open the valve to fully open (valves only seal properly when fully open or closed)**

All personnel who have not attached a regulator to a gas cylinder must first be shown and then demonstrate the process to an experienced user

Slowly open the cylinder valve and observe the high pressure gauge on the regulator

- This is especially important where oxygen is involved
- Opening a cylinder valve quickly causes rapid pressurization of down-stream equipment
- Pressurization generates heat by adiabatic compression
- Where oxidizing gases are involved, this can trigger a reaction that causes metals and elastomers to burn
- Once oxygen fires start, they will typically burn so long as there is sufficient pressure to feed the fire



Regulator – Leak check

- **Observe all connections for leaks**
- **Leak test with inert products such as SNOOP or use an electronic leak tester. Soaps and other products might leave organic residue or corrode regulator components**
- **To further check for leaks, if SNOOP cannot be used, close the cylinder valve for five minutes and watch for a drop in pressure**
- **Snoop is stocked in the Shipping and Receiving area**
- **Snoop is available from Swagelok**



Regulator – Set the working pressure

- Ensure that the cylinder valve is fully opened (remember to open slowly)
- Adjust to the desired working pressure by turning the pressure control knob clockwise, while observing the delivery pressure gauge for the desired setting
- Do not exceed the maximum delivery pressure indicated on the regulator
- With gas flowing through the system, some adjustment may be required to the regulator



Cryogenic liquids are also used at LLE

- **Liquid cylinders are similar to Thermos[®] bottles with a vacuum space and special insulation**
- **Even with all this, heat leaks in to the cylinder causing the cryogenic liquid to vaporize and build pressure**
- **The vaporization rate will depend on several factors including the product itself, ambient temperature, condition of the cylinder's vacuum, etc.**



Annular Space

Cryogenic liquid cylinders

- **The liquid-to-gas conversion rate is about 2.3% per day under perfect conditions, so the actual vaporization rate can vary**
- **If the gas product is not used, pressure will build until it is released by a control valve**
- **Hearing a slight hiss from a liquid cylinder may be the normal operation of its pressure relief device**
- **Never adjust, block, plug or attempt to repair anything on a liquid cylinder**
- **Liquid cylinders should always be stored and used in areas with appropriate natural or mechanical ventilation**



These rules must be followed when moving cryogenic liquid cylinders

- Always use an appropriate four-wheel hand truck when moving cryogenic liquid cylinders with a capacity greater than 20 gal (76 L)
- Be sure the cart height is adjusted properly for the cylinder being moved
- Containers and equipment assigned for a specific cryogenic liquefied gas service shall not be used for the storage or use of another cryogenic liquefied gas
- Store and handle cryogenic liquefied gas containers (dewar) in well-ventilated areas to prevent a hazardous concentration of gas



Cryogenic dewars with integrated casters are preferred

- Easier and safer to move
- Does not require a cart to be moved
- Dewars can be refilled at the LLE High Pressure Liquid Nitrogen Fill Station

- Filling of cryogenic dewars or the dispensing of liquid nitrogen requires additional training
 - C_004: High Pressure Liquid Nitrogen Fill Station



The personnel hazards associated with gases



- **The primary hazards associated with gases are**
 - **Asphyxiation:** the most common gas risk to personnel since nitrogen accounts for the majority of the gas used at LLE (others include helium, argon, CO₂, SF₆, ...)
 - **Flammability:** these gases must be used in specially designed systems to mitigate fire safety risks (e.g. Hydrogen, methane, isobutane, acetylene)
 - **Oxidizer:** can support and vigorously accelerate combustion in the presence of an ignition source and a fuel (e.g. oxygen)
 - **Pyrophoric:** gas with an autoignition temperature in air below 130°F (e.g. acetylene)
 - **Corrosive or Toxic:** these gases must be used in fume hoods to maintain personnel safety
- **Read and understand the Material Safety Data Sheets (MSDS) for each gas type used**

The personnel hazards associated with cryogenic liquids



- **Cryogenic liquids may pose Corrosive, Toxic, Flammability, Oxidizer, or Asphyxiation hazards**
- **The primary hazards associated with cryogenic liquids are**
 - **Skin or eye frostbite: from liquids or vapors**
 - **Boiling and splashing: from room temperature items coming into contact with cryogens**
 - **Flesh tearing: do not touch exposed cryogenic piping**
 - **Embrittlement: polymers and rubber can undergo brittle fracture at cryogenic temperatures**

Cryogenic liquids generate large volumes of gas when they are vaporized and can result in a potentially dangerous environment



- **Cryogenic liquids have large expansion ratios**
 - For example: 1 liter of liquid nitrogen expands to ~700 liters of gas at room temperature and pressure
- **Is a standard 20 gal. dewar a potential hazard in a 20'x20'x10' lab space?**
 - 1 gal. = 0.133 ft³
 - A nominal 20 gal. dewar can then yield 1872 ft³ of gas
 - The lab contains 4000 ft³ of air
 - Roughly 1/2 of the breathable air will be replaced by nitrogen leaving an oxygen concentration of ~11%
 - This is a dangerous scenario if the liquid nitrogen were to vaporize over a short period of time (i.e. a catastrophic event)

The amount of cryogenic liquids brought into lab spaces must be evaluated to ensure that hazardous conditions can not be developed

What is air?

- **The nominal make up of Air**
 - **20.9% Oxygen**
 - **78% Nitrogen**
 - **1.1% Other Gases**

- **Molecular Weight**
 - **Oxygen – 31.99**
 - **Nitrogen – 28.013**

- **Nominal acceptable OSHA limits for oxygen concentration by volume is in the range of 19.5% to 23.5%**

Hazards associated with oxygen deficiency



- **At room temperature and atmospheric pressure, oxygen is a colorless, odorless, and tasteless gas**
- **Oxygen Deficiency is any atmosphere less than 19.5% oxygen**
 - **15-19.5%: Decrease ability to work strenuously. May impair coordination and may induce symptoms in persons with coronary, pulmonary, or circulatory problems.**
 - **12%-15%: Respiration deeper, increased pulse rate, and impaired coordination, perception, and judgment**
 - **8%-10%: Mental failure, nausea, fainting**
 - **6% - 8%: in 8 minutes, may be fatal in 50-100% of exposures, in 6 minutes, may be fatal in 25-50% of exposures, in 4-5 minutes there is full recovery with treatment**
 - **4%-6%: Coma in 40 seconds and Respiration ceases**

Basic oxygen deficiency rules



- **Remember, oxygen-deficient atmospheres are an invisible danger**
 - They have no warning properties
 - Never enter a suspected O₂ deficient area without a source of supplied air
 - Exit the area immediately if an O₂-deficiency alarm is activated
- **The only way to detect an O₂ deficient atmosphere is with continuous monitoring with an O₂ sensor**
- **LLE personnel are not trained or permitted to work in an O₂ deficient atmosphere (A Self Contained Breathing Apparatus (SCBA) is required for this situation)**

Hazards associated with oxygen enrichment

- Principal hazard of oxygen is its ability to support combustion
- Oxygen enrichment is an atmosphere containing more than 23.5% oxygen
 - Sparks normally regarded as harmless may cause fires

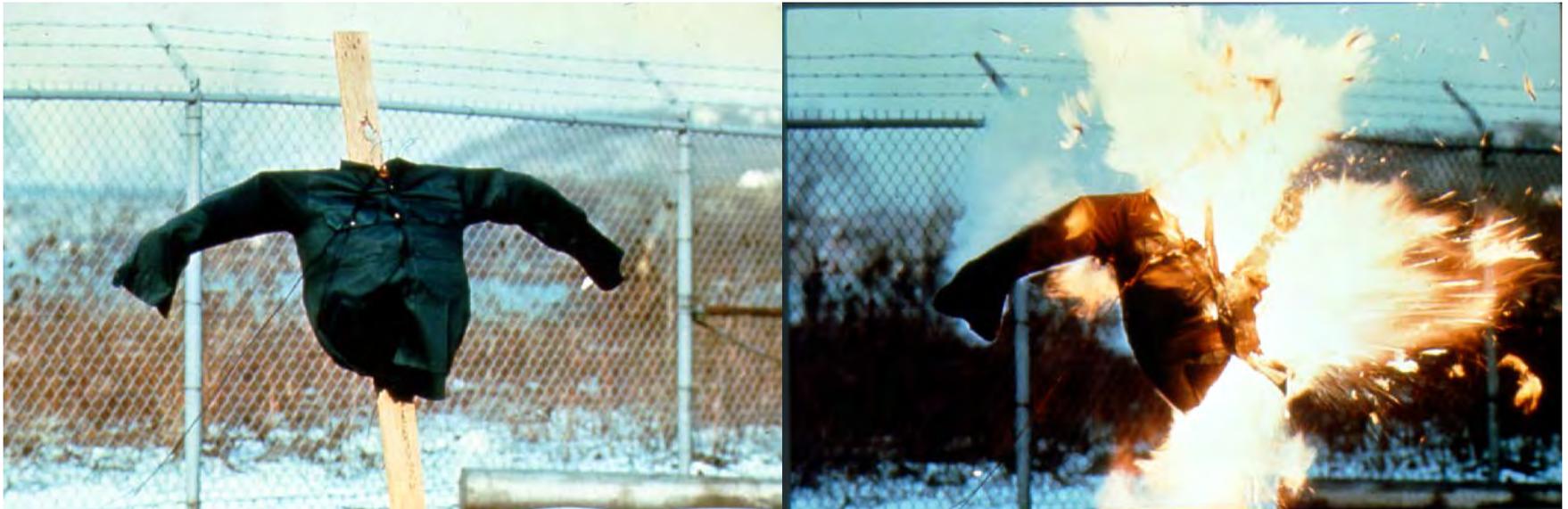
- Fire Chemistry starts to change

- Flammable ranges expand
- Autoignition temperatures start to drop
 - materials that typically would not burn in air will burn in enriched atmospheres
 - materials that readily burn in air will ignite much more easily and burn violently



CAUTION – Do not smoke and avoid other ignition sources for at least 30 minutes if your clothes become saturated with oxygen

- Oxygen enrichment of clothing is a serious hazard and can be readily mitigated by:
 - Isolating the clothing from ignition sources
 - Get to fresh air and air out the clothing for at least 30 minutes
 - Change your clothes



Additional safety practices for compressed gases



- **Use small cylinders in lieu of lecture bottles**
 - **Lecture bottles are costly to dispose of (~\$1,000) and should only be used as a last resort**
- **Never transport a gas cylinder in your car**

Compressed air/nitrogen safety



- **Compressed air used for cleaning shall be limited to a maximum pressure of 30 psig with appropriate chip protection and PPE**
- **Do not use compressed air to clean clothing; the air jet tends to drive particles into the fabric, where they can cause skin irritation. Keep a clothes brush handy or, preferably, wear a lab coat**
- **Be sure no one is in the path of the air stream when using compressed air to dry mechanical parts. Always wear goggles to protect your eyes.**
- **Never apply air pressure to the body**
- **Unless an automatic shut-off coupling is used, attach a short chain (or equivalent) between a hose and an air-operated tool to prevent whipping in the event the coupling separates**
- **Unless an automatic shut-off coupling is used, vent the pressure in an air line before changing the nozzles or fittings**
- **Do not substitute compressed oxygen for air. Clothing saturated with oxygen burns explosively**

Safety is everyone's business and compliance with safety procedures is **MANDATORY**



- **If an activity or practice seems unsafe, “Stop Work” and take the time to address concerns**
- **Situational Awareness – The best way to prevent an accident is to be aware of your surroundings**
- **All new gas systems must be inspected and approved by Mechanical Engineering (ME) prior to operation**
- **No unqualified pressure vessel systems may be deployed**
- **Only perform activities for which you are qualified**
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- **Always use the proper Personal Protective Equipment (PPE)**