COMPRESSED GAS SAFETY MANUAL FOR RESEARCH OPERATIONS

Columbia University

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Introduction

Columbia University is committed to maintaining a safe environment, in compliance with all local, state and federal regulations, for its laboratory personnel, neighbors and visitors. The Columbia University Compressed Gas Manual ("the Manual") has been prepared by Columbia University Environmental Health and Safety ("EH&S") for use by all laboratory personnel that use compressed gases in research laboratories ("laboratories") and other research settings at Columbia University, including the Irving Medical Center, Morningside, Manhattanville, Lamont-Doherty Earth Observatory and Nevis Laboratories' campuses.

This Manual contains information on all aspects of the use of compressed gases, from ordering and procurement, daily use and maintenance, through ultimate disposal. Emergency preparedness and response, as well as general safety and critical thinking, are also addressed to promote the safe use of compressed gases. It is important to note that the Manual is designed to complement the Compressed Gas Training Module TC5450. However, all laboratory personnel who use compressed gases shall be instructed by their Principal Investigator (PI), or their experienced designee regarding the specific hazard(s) of the gases used in their research, as well as the specific tasks and operations in which they will take part, such as changing regulators or replacing compressed gas cylinders from their laboratory equipment.

With preparation, training, thoughtful risk assessment, and an approach that respects the hazards of compressed gases, laboratory personnel can expect a productive and safe experience using these materials in their research. Please reach out to EH&S with any questions, comments, or concerns related to the use of compressed gases that are not otherwise covered in this Manual and the corresponding training module.

Abbreviations and Definitions

ANSI: American National Standards Institute

ASME: American Society of Mechanical Engineers

CERCLA: Comprehensive Environmental Response, Compensation, and Liability Act

CFR: Code of Federal Regulations

CGA: Compressed Gas Association

EH&S: Environmental Health and Safety Department

FDNY: Fire Department of New York

GHS: Global Harmonization System

IDLH: Immediately dangerous to life or health

IFC: International Fire Code

LDEO: Lamont-Doherty Earth Observatory

LION: Laboratory Information Online Network

NFPA: National Fire Protection Association

NIOSH: National Institute for Occupational Safety and Health

NYCRR: New York Codes, Rules and Regulations

NYSDEC: New York State Department of Environmental Conservation

OSHA: Occupational Safety and Health Administration

PEL: Permissible exposure limit (OSHA)

PI: Principal Investigator

PIH: Poison Inhalation Hazard (USDOT)

ppm: One part per million denotes one part per 1,000,000 parts (for gases 1 mL per 1 cubic meter, m^3)

PPE: Personal Protective Equipment

PSIA: Pounds Per Square Inch Absolute

RARAF: Radiological Research Accelerator Facility

RASCAL: Research Compliance and Administration System

REL: Recommended Exposure Limit (NIOSH)

RFO: Restrictive Flow Orifices

SDS: Safety Data Sheet

SOP: Standard Operating Procedure

TWA: Time-Weighted Average

USDOT: United States Department of Transportation

USEPA: United States Environmental Protection Agency

Asphyxiant: A gas possessing the primary or most acute health effect of asphyxiation; the unconsciousness or death resulting from lack of oxygen. There are two classes of asphyxiant: simple asphyxiants, such as nitrogen or methane, which act by replacing oxygen; and chemical asphyxiants, such as carbon monoxide, which cause asphyxiation by preventing oxygen uptake at the cellular level**.**

Ceiling Concentration: A concentration of a hazardous substance in the environment which is not to be exceeded at any time during the workday. Ceiling RELs or PELs are typically designated by "C" preceding the value in the NIOSH Pocket Guide.

ChemWatch: A web-based, subscription library of Safety Data Sheets accessible from any computer connected to Columbia University internet. https://research.columbia.edu/safety-data-sheets

Compressed Gas: Any gaseous element or compound or mixture which exerts in the packaging an absolute pressure of 280 kPa ((40.6 pounds per square inch absolute, psia) or greater at 20°C**.**

Compressed Gas Cylinder: A pressurized container designed to hold compressed gases at pressures greater than one atmosphere (101.3 kPa) at 20°C.

Corrosive Material: A material that causes full thickness destruction of human skin at the site of contact within a specified period of time and during transportation has exhibited a severe corrosion rate of aluminum or steel based on criteria specified in 49 CFR 173.137(c)(2).

Cryogenic Container: A pressurized container, low-pressure container or atmospheric container of any size designed or used for the transportation, handling or storage of a cryogenic fluid, and which utilizes venting, insulation, refrigeration or a combination thereof to maintain the pressure within design parameters for such container and to keep the contents in a liquid state.

Cryogenic Fluid: A fluid having a boiling point lower than -130^{o}F (-89.9^{o}C) at 14.7 pounds per square inch absolute (PSIA; an absolute pressure of 101.3 kPa). Per NYC Fire Code Section 3202.1, cryogenic fluids are gases that been transformed by refrigeration into extremely cold liquids, which are stored at temperatures below –130ºF (-90 º C). They are stored at low pressures in specially constructed, multi-walled, vacuum-insulated containers. Examples include oxygen, nitrogen, argon, neon, hydrogen, and helium.

Exhausted Enclosure: A device, typically consisting of a hood and fan, designed to capture gases, fumes, and mists generated at a workstation. Per the NFPA, it is an appliance or piece of equipment that consists of a top, a back, and two sides that provides a means of local exhaust for capturing gases, fumes, vapors, and mists. A fume hood is an example of an exhausted enclosure. In some regulatory references, an exhausted enclosure is referred to as a "ventilated enclosure." A generally ventilated room is not considered an exhausted enclosure.

Flammable Cryogenic Fluid: A cryogenic fluid that is flammable in its vapor state per NYC Fire Code Section 3202.1.

Flammable Gas: A material which is a gas at one atmosphere (101.3 kPa) and 20°C or less, and per USDOT it is ignitable at 101.3 kPa (14.7 PSIA) when in a mixture of 13% or less by volume with air and has a flammable range at 101.3 kPa with air of at least 12% regardless of the lower limit.

Gas Cabinet: A non-combustible fully enclosed isolated environment for the storage and use of compressed gases, including access ports for container exchange. Per the NFPA, a gas cabinet is a fully enclosed, noncombustible enclosure used to provide an isolated environment for compressed gas cylinders in storage and use.

Gas Room: A separately ventilated, fully enclosed room in which only compressed gases, cryogenic fluids, and associated equipment and supplies are stored or used. Per the International Mechanical Code, Chapter 5, a gas enclosure is a separate term from an exhausted enclosure or gas cabinet.

Handling: Any action or process that can affect a material, including the movement of the material in its container or removal of the material from its container.

Hazard Class: The USDOT category of hazard assigned to a material under the definitional criteria of 49 CFR 173, Subparts C, D, and I. Additionally, it includes the provisions of the Hazardous Materials Table in 49 CFR 172.101. A material may meet the defining criteria for more than one hazard class but is assigned to only one hazard class. Compressed gases are typically a USDOT Hazard Class 2 as defined in 49 CFR 173.115 and are assigned to one of three Divisions. Division 2.1: Flammable gas, Division 2.2: Non-flammable gas and Division 2.3: Poison gas. Each Poison gas is assigned one of four Zones, A through D, with A being the most hazardous and D being the least hazardous, as defined per 49 CFR 173.116. Materials referenced in the Manual and its related documents may also be assigned a subsidiary hazard or may belong to another hazard class or division. Other hazard classes referenced within the Manual or its related documents include: hazard class 3: Flammable Liquid, Division 4.2: Spontaneously Combustible (also referenced as pyrophoric), Division 4.3: Dangerous When Wet, Division 5.1: Oxidizer, Division 6.1: Poison (also referenced as toxic and defined differently than the NYC Fire Code). The USDOT definition of Division 6.1 materials may be found in 49 CFR 173.133. This Division may also include Hazard Zones A and B as defined in 49 CFR 173.133, and hazard class 8: Corrosive.

Hazardous Material: A substance or material that the Secretary of Transportation has determined capable of posing an unreasonable risk to health, safety and property when transported in commerce. It includes hazardous substances, hazardous wastes, marine pollutants, elevated temperature materials, materials designated as hazardous in the Hazardous Materials Table, 49 CFR 172.101 and materials that meet the defining criteria for hazard classes and divisions in 49 CFR 172, Subchapter C**.** This term includes the shipment of hazardous materials domestically by motor vehicle or rail. The synonymous international term when referencing multi-modal transport (air, water or internationally by motor vehicle or rail) is "Dangerous Goods".

Hazardous Substance: Any material listed in Appendix A to the Hazardous Materials Table in 49 CFR 172.101 are those identified in CERCLA as environmentally hazardous substances. A hazardous substance is a material, including its mixtures and solutions, that is packaged in a quantity greater or equal to the Reportable Quantity listed for it in the Appendix A to 49 CFR 172.101.

Hazardous Waste: The EPA defines a hazardous waste as solid waste that displays a hazardous characteristic (ignitability, corrosivity, reactivity, and toxicity) or a waste that is on one of the hazardous waste lists found in 40 CFR 261 Subpart D.

Highly Toxic Gas: As per NYC Fire Code Section 3702.1, a gas which has a median lethal dose (LD_{50}) of less than 200 parts per million when administered by continuous inhalation for 1 hour to albino rats weighing between 200 to 300 grams each; or a chemical that has a median LD50 of 200 mg or less per 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 2and 3 kg each; or a chemical that has a median LC_{50} in air of 200 ppm by volume or less of gas or vapor, or 2 mg/L of or less of mist, fume or dust, when administered by continuous inhalation for 1 hour (or less if death occurs within 1 hour) to albino rats weighing between 200 and 300 grams each.

Lecture Bottle: A small compressed gas cylinder up to a size of approximately 2" x 13".

Lethal Dose (LD): Typically expressed as a dose per kilogram of subject body weight, at which a given percentage of subjects will die (e.g. LD_{50}). The LD_{50} may be based on the standard person concept, a theoretical individual that has perfectly "normal" characteristics, and thus not apply to all sub-populations.

Lethal Concentration (LC): An LC_{50} value is the concentration of a material in air that will kill 50% of the test subjects (animals, typically mice or rats) when administered as a single exposure (typically 1 or 4 hours). Also called the median lethal concentration and lethal concentration 50, this value provides a relative acute toxicity of an inhalable material.

Non-Flammable Gas: Any gas that is not ignitable when in mixture of 13% or less by volume with air and has a flammable range narrower than 12 percentage points of concentration by volume when in mixture with air.

Oxidizing Gas: A gas that can support and accelerate the combustion of another material per NFPA. It is also defined as a material that is a gas at one atmosphere (101.3 kPa) and 20°C, and readily reacts to yield oxygen or other oxidizing agents to promote or cause the ignition of combustible materials. Additionally, per USDOT it includes pure gases or gas mixtures with an oxidizing power >23.5% per the CGA *Handbook of Compressed Gases*.

Poison Inhalation Hazard (PIH) per USDOT: A gas that at 20°C or lower and a pressure of 101.3 kPa and is known to be so toxic to humans as to pose a hazard to health during transportation and in the absence of adequate data on human toxicity, is presumed to be toxic to humans because when tested on laboratory animals it has a LC_{50} of not more than 5000 mL/m^3. The respective hazard zones are assigned Zones A-D based on inhalation toxicity as follows: PIH Zone A: $LC_{50} \leq 200$ ppm, PIH Zone B: $LC_{50} > 200$ ppm and ≤ 1000 ppm, PIH Zone C: $LC_{50} > 1000$ ppm and ≤ 3000 ppm, and PIH Zone D: $LC_{50} > 3000$ ppm or ≤ 5000 ppm.

Personal Protective Equipment (PPE): Personal Protective Equipment. Examples include at a minimum: laboratory coat, safety glasses, and gloves specifically rated for protection against the particular compound being used, laboratory attire covering the legs and arms and closed foot-shoes.

Pressure Relief Device: A device designed to prevent compressed gas cylinder rupture by releasing compressed gas from the valve at a specified pressure and/or temperature.

Pounds per square inch absolute (PSIA): Pounds per square inch absolute. Pounds per square inch absolute is used to make it clear that the pressure is relative to a vacuum rather than the ambient atmospheric pressure. Since atmospheric pressure at sea level is around 14.7 psi, this will be added to any pressure reading made in air at sea level.

Pyrophoric Gas: A material, which is a gas at one atmosphere (101.3 kPa), and 20°C, and can ignite spontaneously on contact with air at or below a temperature of 54°C.

RASCAL: The Columbia University Research Compliance and Administration System, a web-based application designed to help laboratory personnel and administrators manage ongoing research projects and related compliance activities at Columbia University. RASCAL is used for the submission of hazardous materials appendices, animal and human subjects' protocols, and for many training applications.

Standard Cubic Foot (SCF): A standard cubic foot corresponds to one cubic foot of gas at 60 °F (15.6 °C) and 14.73 PSIA.

Toxic Gas: A gas which has a median lethal dose (LC_{50}) of more than 200 parts per million, but not more than 2,000 parts per million when administered by continuous inhalation for one hour to albino rats weighing between 200 to 300 grams each per NYC Fire Code Section 3702.1.

Excpetion: Chlorine technically meets the definition of a toxic gas per NYC Fire Code, but for purposes of the NYC Fire Code it is classified as a highly toxic gas.

Time-Weighted Average Concentration (TWA): Concentrations for OSHA PELs shall not be exceeded during any 8-hour work shift of a 40-hour workweek. For NIOSH RELs TWA indicates time-weighted average concentrations for up to a 10-hour workday during a 40-hour workweek.

Note: The above definitions include partial or direct language from the vendor provided training manuals, federal, state or city regulations and/or the New York City Fire Code. In some cases, the author has paraphrased for brevity or expanded for clarity purposes.

Technical Summary:

- The safe use and handling of compressed gases in research laboratories is the responsibility of the Principal Investigator (PI) and their respective Department, while laboratory personnel have the responsibility of utilizing the appropriate administrative and engineering controls and assigned PPE.
- Compressed gas shall only be used after a review of the SDS and established SOPs, completion of safety training provided through RASCAL, as well as hands-on, function-specific training provided by a PI or an experienced designee. Equipment-specific or technical training, such as selection, installation and testing of compressed gas regulators or other associated compressed gas system equipment may be arranged directly with the equipment supplier.
- Per the requirements or recommendations of federal, state or city authorities, industry experts and EH&S, gas monitoring and leak detection equipment or specific engineering controls, such as ventilated cabinets or customized piping, may be required in laboratories where compressed gases are used or stored. Installation of such systems by a competent contractor is the responsibility of the PI and/or their associated Department. It is also the responsibility of a PI or Department to establish service contracts and provide financial resources for the maintenance of required and/or recommended engineering controls, gas monitoring and/or leak detection equipment.
- "All compressed gas cylinders are hazardous, understand those hazards completely and design systems accordingly. Never become complacent when using a compressed gas. Always respect the hazards and treat them accordingly." [1] NFPA 45 Annex F.21.

Chapter I: Responsibilities

Personnel at all levels of the research community play an active role in the safe use and management of compressed gases. The following personnel and groups, specifically, are required to participate in the University's safety programs in accordance with this Manual:

A. Environmental Health & Safety Department

Columbia University Environmental Health & Safety (EH&S) serves as the primary health and safety resource to assist laboratories in promoting best practices in safety and environmental performance in all education and research activities, while maintaining compliance with applicable federal, state and local regulatory requirements, agreements and permits. EH&S is available to assist with and consult on technical questions related to the use and management of compressed gases. EH&S is responsible for providing compressed gas cylinder safety training and reviewing and updating training content, as applicable. EH&S is responsible for evaluating safety and compliance conditions through field surveys and technical consultations with laboratory personnel.

B. Public Safety

In the event of an emergency involving a compressed gas, laboratory personnel are instructed to notify EH&S directly, and if after-hours, Public Safety. In turn, Public Safety will notify the on-call staff of EH&S. Based on instruction from EH&S, Public Safety will establish physical security measures and provide available information to other emergency responders, including the New York City Fire Department (FDNY) and hazardous materials response personnel.

C. Principal Investigators (PIs)

The PI has overall responsibility for safety and compliance in their laboratory, although the below responsibilities can be delegated to their designee(s) in the laboratory. The PI is responsible for:

a) Contacting EH&S and working with Capital Project Management (CPM) and departmental administration to notify and initiate consultation for monitoring, storage and handling needs, including equipment and infrastructure requirements specific to the gas being used.
b) Ensuring that laboratory personnel have read, understand and adhere to this Manual, its associated plans, including the Columbia University Chemical Hygiene Plan and the laboratory's Laboratory Assessment Tool and Chemical Hygiene Plan (LATCH), and all other University, school, departmental and laboratory policies and procedures.
c) Ensuring that new laboratory personnel attend Laboratory Safety, Chemical Hygiene and Hazardous Waste Management Training, and all other applicable safety training at the time of hire or before involvement in laboratory research activities involving compressed gases, and that refresher training is completed as required.
d) Verifying C-14 holders are present at any time that the laboratory is in operation, including while compressed gas cylinders are being used or exchanged from a manifold system. (Note – applicable to NYC campuses only)
e) Ensuring that current and new laboratory personnel receive process- and/or equipment-specific safety instruction from the PI, or their designee, before engaging in research activities involving compressed gases.
f) Ensuring that laboratory personnel are advised of applicable safety and emergency procedures when introducing new compressed gases, equipment, and procedures.
g) Ensuring that personal protective equipment (PPE) specific to the hazards of the gases is available and used.
h) Developing operating procedures to address a particular hazard or operation encountered in the laboratory. EH&S may be consulted to determine which operations warrant documentation of a standard operating procedure (SOP).
i) Ensuring that required signage is present inside and outside the laboratory to identify where hazards may exist, and that emergency contact information is accurately provided.
j) Providing installation and maintenance of all equipment in accordance with manufacturers' recommendations, including monitoring and distribution systems for high hazard operations (installation, extraction, etc.). Note: oxygen sensors are provided, maintained and replace periodically by EH&S.

D. Laboratory Personnel

All laboratory personnel are responsible for:

a) Reviewing and applying the information in this Manual and its associated plans including the LATCH, and all University, school, departmental and laboratory policies and procedures.
b) Knowing where SDS's are maintained and reviewing SDS's prior to use of compressed gases.
c) Attending Laboratory Safety, Chemical Hygiene and Hazardous Waste Management Training and other applicable trainings.
d) Holding a C-14 certification and observing relevant requirements. (Note – applicable to NYC campuses only)
e) Safely handling and disposing of compressed gases.
f) Using appropriate engineering controls (e.g., fume hoods, glove boxes) and PPE when working in the laboratory with compressed gases.
g) Reviewing and understanding emergency response procedures.

E. Department Administrators (DA)/Managers, Capital Project Management and ChemStores
For more information on the specific requirements for Department Administrators (DA)/Managers, Capital Project Management and ChemStores, see **Appendix 1**.

Chapter II: Training Requirements

All personnel working in a laboratory shall receive the initial, general Laboratory Safety Training, provided by EH&S, in person. The course needs to be refreshed on a biennial basis. The refresher courses can be taken though the University's online training portal at https://www.rascal.columbia.edu/ (Course Number TC0950).

Laboratory personnel who intend to use compressed gas cylinders or otherwise handle compressed gases shall complete the Compressed Gas Safety training, available through RASCAL TC5450, prior to starting any relevant work. TC5450 is not a substitute for task and operational specific instruction, to be provided by the PI, but rather a precursor training.

The PI or their designee shall provide task and specific operational instructions to laboratory personnel. PIs, or their designee(s), are responsible for providing instruction to new laboratory personnel or before they working with compressed gases for the first time. This instruction may include the following operations:

- Safe use of hazardous compressed gases material
- Attachment and detachment of regulators and/or ancillary equipment
- Connection of supply lines or operation/attachment of specialty apparatus.
- Emergency management

Training may also be available, by special arrangement, through a compressed gas supplier. These training sessions may include how to safely use the material, attach and detach regulators connect supply lines or operate, or attach specialty apparatus and/or ancillary equipment. The session can also include what to do in the event of an emergency that may arise during routine use of the compressed gas.

Chapter III: Prevention and Critical Thinking

Prior to handling a hazardous material – including any compressed gas cylinder, regardless of contents – laboratory personnel should carefully consider the hazards that the material poses, actively plan for prevention of accidents and incidents, and generate a strategy should an accident or incident occur. A risk assessment can take many forms and be a formal or informal exercise depending on the severity of the hazard, the frequency of the operation, and other contributing factors. Refer to **Appendix 2** for detailed information on preventing accidents and conducting risk assessments.

Chapter IV: Hazards of Compressed Gas Cylinders

A. General Hazard Information

Hazards associated with compressed gases can be attributed to the physical or chemical characteristics of the gases. Importantly, all compressed gas cylinders also pose physical hazards due to the potential energy of the compressed contents. If the pressure in a compressed gas cylinder is released very quickly due to improper storage, handling, fire or valve damage, it may cause a compressed gas cylinder to become a projectile capable of penetrating a cinder block wall, or metal storage cabinet and severely injuring people or property. Some compressed gases are flammable, cryogenic, reactive, toxic, corrosive, or asphyxiants, and some possess all or a combination of these hazardous properties as well as others. Some corrosive gases including chlorine may form valve plugs if stored improperly, such as in areas of high moisture. As a result, laboratory personnel may believe the compressed gas cylinder to be empty when it is not, presenting a pressurization hazard when attempting to operate the valve. This example illustrates the importance of understanding all of the hazardous properties of a compressed gas, including conditions that may be unique to a particular compound.

Since many compressed gases can be flammable, smoking must never occur in or around flammable, cryogenic, oxidizing liquids or reactive gases where they are stored, handled, loaded/unloaded or near their associated monitoring equipment or in any research laboratory. Additionally, flammable gases must always be stored away from oxidizing gases.

Flammable, cryogenic, corrosive, pyrophoric, reactive, toxic, and asphyxiation hazards of compressed gases are summarized in Attachment 1: *Summary Hazards Table of Compressed Gases*. This table includes information such as the physical properties, characteristic hazards, or other special hazards unique to select gases commonly found in the laboratory setting.

As a general reference, additional information may be found in Attachment 2: Matheson *Materials Compatibility Guide*.

B. Types of Compressed Gas Cylinders

In order to safely transport, store, and manipulate chemicals with highly reactive properties – such as spontaneous ignition or the release of toxic gases upon contact with air - specialized containers that may not look like a traditional compressed gas cylinder are often utilized. This section illustrates some of the different types of physical containers that may contain highly hazardous gases. These include the following types of compressed gas containers, including their USDOT packaging type codes:

- Calibration compressed gas cylinders (DOT 39) typically contain compressed air, isobutylene and nitrogen (Figure 1[2]).
- Lecture bottles (DOT3E1800) typically contain a wide variety of gases that can be flammable, toxic or corrosive at high pressure (Figure 2).
- Aldrich Surepac cylinders (DOT 4B240) typically contain highly flammable, pyrophoric or otherwise reactive gases or liquefied gases at low pressure (Figure 3).
- Sample compressed gas cylinders (DOT3E1800) are typically used for testing or product sample purposes (Figure 4).
- Stainless steel bubblers typically contain reactive or highly toxic liquids, are not rated for gases, and are often confused with compressed gas cylinders. They can contain methyl mercury, butyl lithium, diethyl zinc and trimethyl aluminum (Figure 5).
- Gas purifiers and scrubbers used to purify gases typically can contain solids such as lithium hydride or magnesium hydride, or residual amounts of arsine and phosphine (Figure 6[2]).

Figure 1: Calibration compressed gas cylinders.[2]

Figure 2: Lecture bottles.[2]

Figure 3: Aldrich SurePac® cylinders.[2]

Figure 4: Sample compressed gas cylinders.[2]

Figure 5: Stainless steel bubblers.[2]

Figure 6: Gas purifiers and scrubbers.[2]

Laboratory personnel should never attempt to operate a compressed gas cylinder if unfamiliar with its operation until they are instructed by either their PI, or their designee. If assistance is required for the disassembly of a piece of equipment with a compressed gas cylinder attached to or contained within it, please contact EH&S at labsafety@columbia.edu.

Chapter V: Hierarchy of Controls

In research spaces, the implementation of a combination of hazard controls can reduce the risk of exposure or accident occurrence when working with compressed gases. Once the hazards associated with the specific compressed gases are identified, control methods can be applied. Laboratory personnel are responsible for implementing and utilizing appropriate controls, and should follow the hierarchy of controls to reduce the risk of unsafe conditions in the laboratory. EH&S is available to consult on questions related to hazard controls. The graph below lists the categories of controls, in order of effectiveness (Figure 7[3]).

A. Elimination

When possible, laboratory personnel should eliminate the risk of exposure by completely removing compressed gases from their working environment, if not needed. All compressed gases of unknown ownership or content should be returned to the original supply vendors or disposed of through EH&S.

B. Substitution

Flammable, toxic and reactive gases should be substituted with non-hazardous alternatives whenever permitted by the specific research activity being performed. Laboratory personnel can request guidance in examining possible substitution options by contacting EH&S at labsafety@columbia.edu.

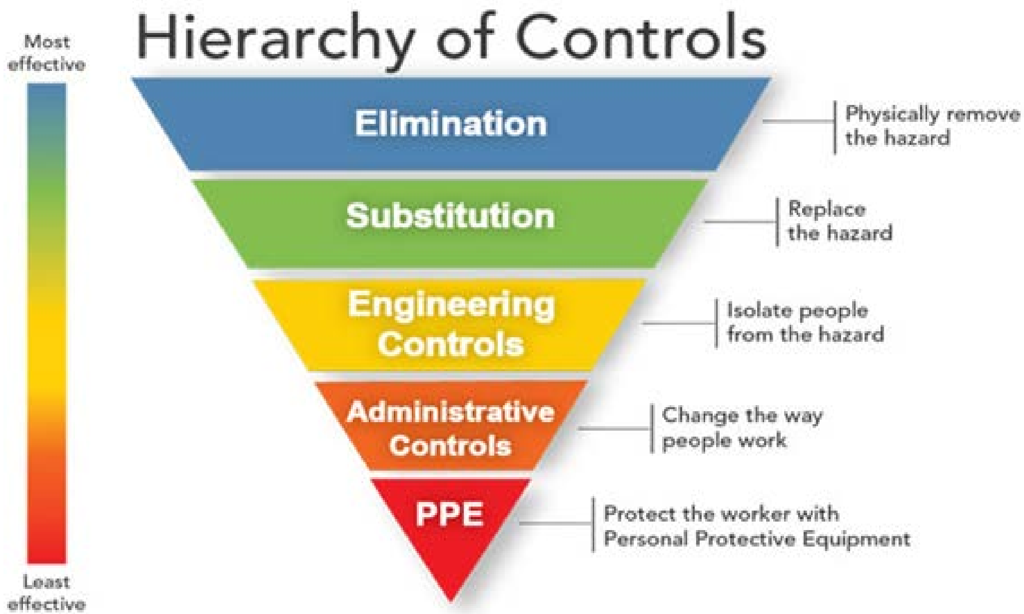


Figure 7. Hierarchy of Controls[3]

Substitution can also apply to equipment and gas-related infrastructure. For example, the use of fixed or plumbed gas lines is considered safer than handling flammable compressed gas cylinders. When available, the use of flammable compressed gas cylinders should be substituted by the gas from a central gas supply line. The temperature and pressure at which the gas is dispensed can also play a crucial part in the choice of the tubing/piping, since the tubing/piping should be compatible to all the experimental conditions. Another example of substitution includes using a hydrogen generator. They are available in a wide range of sizes and can potentially result in savings based on usage.

It is advisable to consult the vendor regarding appropriate tubing to be used, prior to setting up the experiments, since there is a variety of tubing/piping available dependent on the gas cylinder constituents, as well as physical conditions.

C. Engineering Controls

Engineering controls, including the standard laboratory certified chemical fume hood, can be employed in areas where compressed gas cylinders are stored or used.

Specialized equipment such as regulators, flow restrictors, pressure relief devices, flash arrestors, rupture discs, fusible plugs, leak monitors, and ventilation systems can also be applied and may be required for the use of specific types of gases. For more information, refer to Section C. 1 Cylinder-specific Hazard Control Devices.

These recommendations are provided by expert industry resources, including Air Products Safety Gram and the CGA *Handbook of Compressed Gases,* which contains valuable information regarding engineering controls. Please refer to
http://www.airproducts.com/~/media/files/pdf/company/safetygram-15.pdf

Compressed gas cylinders shall be always used in ventilated spaces such as the laboratory. Inert, non-hazardous gases such as nitrogen or argon can be used inside the laboratory space without any additional ventilation systems. However, for gases that exhibit hazardous properties such as toxicity, the corresponding cylinders shall always be used in a certified chemical fume hood. Highly reactive gases shall be used under inert atmosphere systems such as gloveboxes. A vented gas cabinet shall be used for storage of compressed gas cylinders with hazardous components such as flammables and toxic gases.

Compatibility of said gases with the ducts, vents and other parts of the ventilation equipment shall be ensured by discussion with the vendor prior to use. Gases with corrosive or oxidizing properties may attack metals damaging piping, ducts and other metallic surfaces. Where exhausted enclosures are used for flammable gases or toxic gases, the exhausted enclosure shall be protected by a fire extinguishing system (unless it is in a laboratory hood or exhaust system or that exhausted enclosure duct is only used for nonflammable and non-combustible gases under all conditions and concentrations). Additionally, the installation of gas-absorbing or treatment scrubbers may be necessary depending on the specific toxic or highly toxic gas being used. Laboratory personnel should consult with the compressed gas vendor for further details and recommendations.

For proper storage of compressed gas cylinders, stands or chain mounts shall be used. Ventilated cabinets or exhausted enclosures may also be used for storage. Additional information in Chapter VII: Storage requirements of this Manual.

1. Cylinder-specific Hazard Control Devices

A. **Valves**

Compressed gas cylinder valves are mechanical devices attached to compressed gas cylinders that permit flow into or out of the cylinder when the device is in the open position and prevent flow when in the closed position. Standardized compressed gas cylinder valve outlet and inlet connections have been established and must always be used for applicable compressed gases. The function and longevity of valves is dependent on multiple variables such as materials of construction, gas service, environmental exposure of the valve, use and abuse of the valves, number of times the valve has been cycled, and the care and maintenance it has received.

Valve protection is necessary during the transport and handling of compressed gases due to the potential risk of damage from being dropped or involved in an accident. Some methods of valve protection include (but are not limited) to the use of valve caps or guards. The use of over-pack protection or specialized containers may be necessary in certain scenarios.

The following are some guidelines for safe handling of valves:

- Choose the correct type of valve. "The valve used on a compressed gas cylinder for a gas mixture shall be selected so the materials of construction are compatible with all mixture components. The type of valve, packed or diaphragm, is chosen based on the integrity and regulatory requirements of the mixture. The outlet connection is selected based on the physical and chemical characteristics of the components,"[4] per *CGA Handbook of Compressed Gases*.
- In North America, outlet connections are usually designated by a three-digit number preceded by the letters CGA, for example, CGA 350. The CGA systems employ a large number of connections to minimize the ability to inadvertently connect a cylinder to a system that may not be compatible with the gas or cylinder pressure, or that may contain a gas that would be unsafe (i.e., inert gas to a medical oxygen system).
- Valve outlet connections are generally of two types: bullet-nose or a gasketed connection. A bullet-nose connection consists of a valve outlet, a nut, and a nipple, whereas the gasketed connection also has a washer.
- Sometimes an ultra-high integrity connection is preceded by a "DISS" designation rather than the more common CGA designation. DISS is the acronym for Diameter Index Safety System. These are designed for applications where the requirements for system leak integrity are very high, primarily in the semiconductor industry. A DISS connection is a washered type connection that consists of the valve outlet, nut, nipple, and washer.
- Inspect valves regularly. Regular inspections must be performed to ensure the threads on a compressed gas cylinder valve outlet are intact and clean, and with no signs of damage. As indicated in CGA *Handbook of Compressed* Gases, "The operator should examine the valve before each compressed gas cylinder filling for evidence of leakage, damage, wear, looseness of parts, corrosion, tampering, unsatisfactory operation of the valve closure mechanism etc. Indication of any of these conditions require corrective actions."[5]
- Force fitting valve connections that are ill fitting is unsafe and strictly prohibited.

- Close valves when not in use. Compressed gas cylinder valves must be kept closed at all times (even when empty), except when the compressed gas cylinder is in use. When flowing gas, make sure to open the valve slowly and carefully as to not release pressure too quickly, avoiding potential injury to laboratory personnel or damage to equipment.
- Always close the cylinder valve before making any adjustments to downstream valves which can prevent accidentally loosening and leaking of the gas outside of the system.
- Always point the valve outlet away from any personnel when opening, to avoid causing injury.
- Use the correct tools, when necessary. If the compressed gas cylinder valve does not have a hand wheel, the use of wrenches as recommended by gas suppliers shall be used to operate the valve. Any other wrench, hammer or tools should not be used.
- Continued use of damaged valves or valves that do not function is unsafe and strictly prohibited.
- Lubrication of internal valve surfaces within the pressure boundary is not allowed, unless recommended by the manufacturer.
- The use of the valve hand wheel as a handle to move or lift the compressed gas cylinder is strictly prohibited.
- Do not use the valve hand wheel as a brace to counterbalance the force of a wrench being used to tighten or remove a connection.
- Never attempt to remove a valve. Devalving is a high-risk operation due to the possible uncontrolled release of gas(es) to the environment that can result in catastrophic risk to laboratory personnel health and safety. Never devalve compressed gas cylinders in the lab.
- Protect valves when not in use. Per NFPA 45 Annex F.14, shut off compressed gas cylinders that are not in use. Always cap any compressed gas cylinder that is being stored or is not in use.

B. **Regulators**

"Often safe delivery of product from compressed gas cylinders and other containers requires some type of pressure control. This is usually provided by the use of a pressure regulator,"[6] per CGA *Handbook of Compressed Gases*.

The use of regulators is recommended to safely reduce the pressure of the discharged gas. The two common types of pressure regulators are single-stage and two-stage regulators (Figures 8 and 9[7]). A single-stage regulator provides pressure reduction in a single step, whereas a two-stage regulator provides pressure reduction in two steps. Two-stage regulators are generally better at maintaining a constant pressure under different experimental conditions. Technical training on how to change regulators can be arranged through the gas vendor with advanced notification.

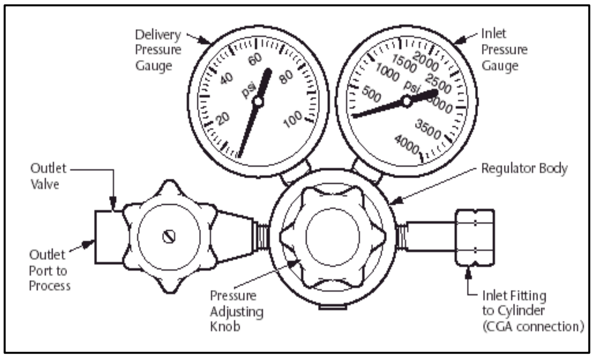


Figure 8. Front View - Typical Pressure Regulator.[7]

Figure 9. Regulators, Hoses, Tanks & Torch Connections[7]

Guidelines regarding regulators:

- Regulators may only be installed and used by laboratory personnel who have received the Laboratory Safety Training provided by EH&S and the RASCAL based compressed gas safety training, TC5450. Hands-on instructions from PI's, or their designee, shall include instructions on how to safely attach, open, close, and detach a regulator.
- Before installing a regulator, laboratory personnel shall ensure that it has been approved by the manufacturer for use with the specific gas. Different types of regulators may be required for different types of gases.
- Regulators should not be confused with gauges, which are used to monitor the pressure within a gas delivery system. Always refer to the manufacturer and/or gas supplier's reference for the selection of gas regulators. Consult with the gas supplier for assistance in choosing the correct CGA connections, gauges and regulators.
- Cross threading or force fitting regulators on tubing, or lubricating connections to facilitate attachment to a compressed gas cylinder is unsafe and strictly prohibited.
- Teflon tape should never be used when fitting a regulator onto a cylinder.
- Regulators shall not be tampered with, altered or manually repaired by laboratory personnel.
- Regulators shall be inspected regularly by laboratory personnel to ensure the absence of cracks or evidence of damage. In case of damage such as worn threading or worn outlet/inlet fittings, gas vendors shall be contacted for further guidance and to aid in replacement or correction.
- Per NFPA 45 Annex F.6, never use a compressed gas cylinder without a pressure-reducing regulator or device that will safely reduce the cylinder pressure to the pressure desired in the system. Only use regulators that have both a high- and a low–pressure gauge (unless it is a direct read, low-pressure calibration gas cylinder, Figure 10[8]). This permits the laboratory personnel to monitor both the pressure in the compressed gas cylinder and the pressure in the system.

Figure 10: *Compressed gas cylinder*[8]

- Generally, the regulator hand knob turns in the reverse direction of what is expected (counterclockwise to "stop" flow and clockwise to "open" flow).
- The regulator outlet valve can be closed by rotating the valve knob in a clockwise direction (Figure 11[9]).

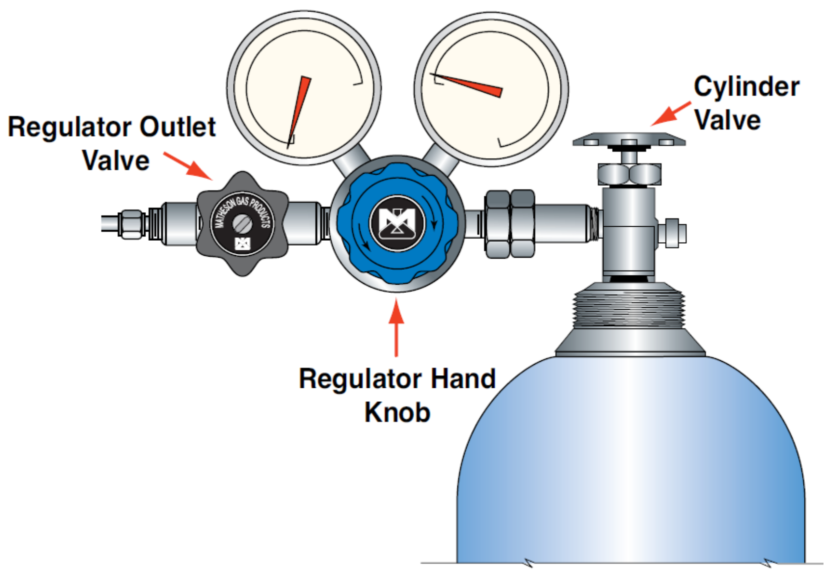


Figure 11: Upright schematic view of cylinder with valve placements, Matheson Guide to Regulators[9]

- In case of cylinders containing toxic, corrosive or flammable compressed gases, regulator fitting shall be done in a ventilated area such as a certified chemical fume hood.
- After a regulator fitting, the compressed gas cylinder valve should be opened slowly to prevent any damage to the regulator's internal parts.
- All regulators shall be removed before moving or relocating compressed gas cylinders. The valve should be protected by the compressed gas cylinder valve cap provided by the supplier or other suitable means depending on the size and type of compressed gas cylinder.
- PPE such as safety goggles/glasses shall be worn while replacing regulators.
- Laboratory personnel should be mindful of certain indications that denote regulator malfunction. These can include gauges not reading zero when all gas is drained from the regulator and/or leaking gas from the outlet when the regulator is in closed position.
- Per NFPA 45 Annex F.8, ensure that the valve on the compressed gas cylinder and the pressure-reducing regulator in use have the correct CGA connection for the gas in use. Never use an adapter between a cylinder and a pressure-reducing regulator. The CGA serial numbers can be found on the cylinder valve and on the gas regulators inlets (Figures 12 and 13).
- For detailed information on regulator fittings see [Attachment 13 Matheson Guide to Regulators]

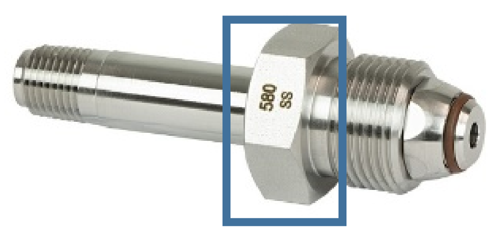


Figure 13: CGA serial number on compressed gas cylinder regulator inlet[26]

Figure 12: CGA serial number on compressed gas cylinder valves[26]

- The regulator connection to the cylinder should not be overtightened.

- The connection for a cylinder containing toxic, poisonous or flammable gases (pure gas or mixtures) will be reverse-threaded in an LH (left-hand) manner. A left-hand nut has a cut mark on the hex of the nut, and can be differentiated from the regular ones with right-hand (RH) threading.
- Exercise caution while using tanks without regulators, for example with liquefied carbon dioxide. Cylinders without regulators pose immediate danger of potential high pressure release, which can cause physical injury.
- Refer to Attachment 11: TechAir Regulator Change Out Procedure and Operating Instructions for further technical guidance on the safe change out and operation of compressed gas cylinder regulators.

C. **Gauges**

Factors while choosing pressure gauges include usual range of pressure encountered, corrosivity, and the opening temperature. Always make sure pressure gauges are reading pressure measurements in the same unit. Also, the pressure gauges are the weakest link in the system in regards to bursting due to over pressurization. Risk of such over-pressurization by the installation of a Bourdon tube gauge.

- Per NFPA 45 Annex F.7, never use a gauge above 75% of its maximum face reading. For example, a 20,700 kPa system should use at least 27,600 kPa gauges. If the system can achieve a maximum pressure of 517 kPa, the gauge monitoring the system should be at least 690 kPa. Immediately replace any gauge whose indicator pointer does not go back to its zero point when pressure is released.
- Material of construction for Bourdon tube gauges must be compatible with the gas in use. They are generally made out of beryllium-copper alloy with silver or brazed connections. For special applications stainless steel or monel tubes can be used, and specially cleaned gauges are used for oxygen or other strong oxidizers. Bourdon tube gauges are usually available with blowout back-pressure relief so that an over-pressurization condition does not result in throwing gauge parts toward the front of the gauge.

2. Safety Devices

a. Backflow Prevention Devices

- Backflow of moist air and incompatible substances from the atmosphere into an empty non-liquefied gas cylinder can cause cylinder damage by corrosion, fire, or explosion from mixing of incompatible substances. To prevent the backflow from higher-pressure systems into partially empty, lower pressure cylinders, a backflow prevention device shall be implemented.
- Where flammable and oxidizing gases are connected to a common piece of equipment or where low- and high-pressure gases are connected to a common

set of piping, backflow check valves shall be used. Do not rely on a closed valve to prevent backflow, per NFPA 45 Annex F.15.

- As indicated in CGA *Handbook of Compressed Gases*, "unless provided with a backflow prevention system, compressed gas cylinders shall not be connected to process piping where the container can be contaminated by the backflow of other process materials."[10] If need be, certain design considerations can be included such as check valves or traps. All cylinder systems must be evaluated for the potential of backflow contamination, and where this potential exists, preventers or controllers must be installed.

b. Restrictive Flow Orifices

Restrictive flow orifices (RFO) are used to "limit the potential danger of an uncontrolled flow from a compressed gas cylinder. Unchecked the instantaneous flow from a 44 L compressed gas cylinder filled to 2,000 psig can be as much as 20,000 L per minute. By inserting an RFO into the outlet of the CGA connection the flow rate could be reduced by a factor of 100 to approximately 200 L per minute."[11] This device typically threads into the outlet of most CGA connections that have external male threads. If a laboratory's research involves high purity compressed gas applications such as the above, please consult with the gas vendor for additional information regarding the appropriate RFO connection and refer to Attachment 4: Matheson Restrictive Flow Orifices Guide

c. Pressure Relief Devices

Pressure relief devices are typically installed on most compressed gas cylinders to prevent a potential catastrophic rupture of the cylinder if accidentally exposed to extreme heat, such as during a fire condition (Figure 14). In the event of activation, the pressure relief device is designed to allow a small amount of gas to escape, and then reseal the cylinder upon re-pressurization, resulting in a limited (as opposed to complete) release, and thus a significant safety enhancement. Pressure relief devices are installed by the manufacturer, and gas cylinders will be delivered with the pressure relief devices attached. Never tamper with or attempt to remove these devices.

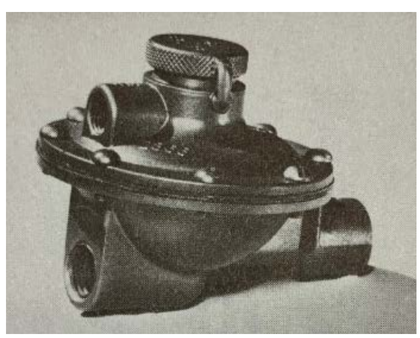


Figure14: An adjustable spring loaded relief valve opens at a preset pressure to relieve system over pressurization and closes again when a safe pressure is reached.[12]

Pressure relief devices are of four types: Type (1) CG-1, (2) CG-2 and CG-3, (3) CG-4, CG-5 or combination device, and (4) Type-7 devices. Type CG-1, or pressure relief rupture disk, provides protection against the development of excessive pressure in compressed gas cylinders, and is designed to rupture when the compressed gas cylinder pressure exceeds the minimum test pressure, thus venting the entire contents of the compressed gas cylinder**.** Type CG-2 and CG-3 or fusible devices, are thermally activated plugs or caps, that can provide protection when the compressed gas cylinder is exposed to high heat conditions. Type CG-4, CG-5 or combination rupture disk/fusible device that requires both temperature and pressure to operate. Higher heat conditions can melt the fusible metal and then the device acts like a CG-1 disk. Type-7 or pressure relief valves, are spring-loaded, pressure-activated devices that can act to vent excess cylinder pressure, reclose and reseal once the normal pressure is restored.

Guidelines for proper care and use of pressure relief devices includes the following:

- Pressure relief devices shall meet strict regulatory standards as part of their design and function. However, not all compressed gas cylinders are equipped with a pressure relief device as the danger of exposure to the contents may be considered more hazardous than that of a potential compressed gas cylinder failure. For example, USDOT Hazard Class 2.3, gases such as arsine, chlorine, phosphine, and phosgene are not equipped with pressure relief devices.
- Per NFPA 45 Chapter 11.3.5.1, pressurized equipment (equipment used at pressures above 103 kPa [15 psi]) shall be designed and constructed by qualified individuals for use at the expected temperature, pressure and other operating conditions affecting safety. Equipment such as piping or regulators shall be fitted with a pressure relief device, such as a rupture disc or a relief valve. The pressure relief device shall be vented to a safe location such as inside a certified chemical fume hood.
- The type and design of pressure relief devices are determined based on several factors including the type of gas, rating of the compressed gas cylinder, test pressure and the size of the compressed gas cylinder.
- Laboratory personnel should never attempt to fill or refill compressed gas cylinders, since the functioning of pressure relief devices depends largely on the proper filling of the cylinder.
- Tampering with pressure relief devices is strictly forbidden as it may cause a sudden release of high pressure from the compressed gas cylinder resulting in an accident and/or injury.[5] For additional information, including an illustration of where to locate a pressure relief device on a compressed gas cylinder, see Attachment 5: Matheson Safety Guide.
- Do not contaminate pressure relief devices with lubricants, dirt, or other materials as these may corrode or otherwise prevent the pressure relief device from functioning.
- Never obstruct a pressure relief device, for example, by hanging a coat on the top of the compressed gas cylinder, as this may prevent it from functioning correctly if warranted by high temperature or fire conditions.

- Immediately report any changes to or problems regarding the pressure relief device laboratory personnel, the PI and the gas vendor, for immediate service.

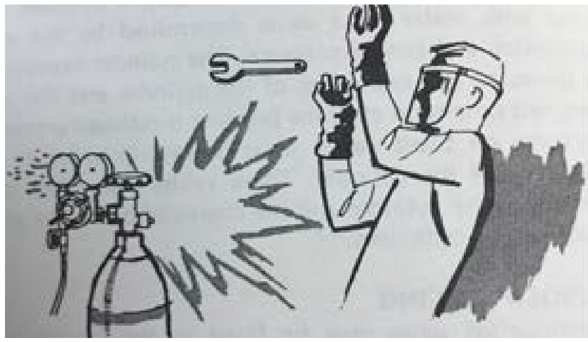


Figure 15: Never Tamper with Safety Devices in Cylinders or Valves[13]

- For more information on the different types of pressure relief devices found on compressed gas cylinders and how they function, consult the Air Products, Safety Gram 15: *Cylinder pressure-relief devices* or the CGA *Handbook of Compressed Gases.*

In general, just because a compressed gas cylinder is equipped with a pressure relief device does not mean that the compressed gas cylinder should be handled any less safely; all safety practices should always be followed. It is the responsibility of laboratory personnel to ensure that the pressurized system (piping, manifolds, and associated vessels or containers) can be isolated or closed off and each component has their own pressure-relief devices installed. Do not solely rely on the pressure relief device on the compressed gas cylinder's regulator; it is not designed to protect the downstream system. This is particularly important for cryogenic systems.

d. Flash Arrestors and Check Valves

Flash arrestors and check valves are used with flammable gases, and are typically installed on the hose lines carrying the gas. As explained in CGA *Handbook of Compressed Gases* "check valves can be used in various piping and hose line systems and are designed to allow gas flow in one direction only to minimize potential for reverse flow [...]. Check valves can help reduce the possibility of high pressure back up, which can overpressure any upstream lower pressure equipment such as a flowmeter or gas mixing system apparatus." [14]

The arrestor and the check valve are typically in the fully open position and are designed to close instantly if a reverse flow were to start. The arrestor thereby prevents the mixing of gases, which, if ignited or subject to a source of ignition, would cause a fire – for example, acetylene and oxygen. If reverse flow could potentially cause a fire during research operations (e.g. welding), contact the gas vendor for recommended flash arrestors and check valves; the gas vendor can also provide services like installation and safety training to operate the device under the laboratory's specific operation. Any laboratory using a combination of flammable gases or those mixed with another gas must protect those systems with flash arrestors (Figure 16) and check valves.

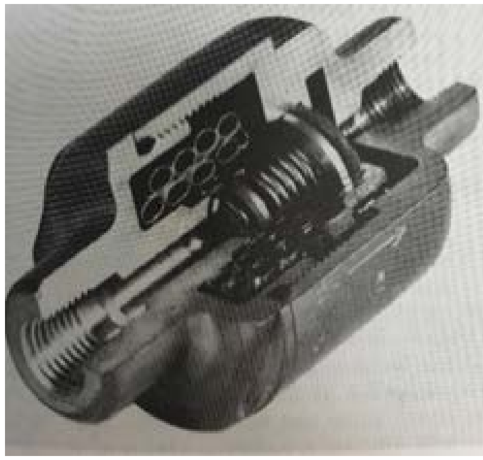


Figure 16: Flash arrestor safety device.[15]

3. Piping

Some important information to be mindful of while choosing piping for compressed gas cylinders are as follows:

- Consult PurityPlus "Gas Safety and Material Compatibility Data Chart" to ensure proper selection of piping and connections with materials compatible with the gas being used. See Attachment 14, Section 5, page 312 of this reference for this information.
- Copper piping shall not be used for acetylene.
- Plastic piping shall not be used for any portion of a high-pressure system.
- Cast iron pipe shall not be used for chlorine.
- Distribution lines shall not be concealed where a high concentration of a leaking hazardous gas can build up and cause an accident.
- Distribution lines and their outlets should be clearly labeled as to the type of gas contained.
- Piping systems should be inspected for leaks on a regular basis.
- Special attention should be given to fittings as well as possible cracks that may have developed.
- Double walled piping can be used to provide containment of product leaks. This can be important when working with highly toxic gases. Please consult EH&S, Facilities and a vendor if handling highly toxic gases to understand the need and application for double walled piping.

- Orbital tube welding is another process that can be implemented to eliminate mechanical seals and joints, and can be a safer option when handling highly hazardous gases.

4. Threading

A mis-threaded connection can result in an unsafe release of pressure or potentially dangerous leak. Hazards related to monitoring the pressure and flow and turning the flow on/off can be avoided by using the correct regulator fitted with the correct CGA connection for the gas in use. CGA fittings are designed specifically to the gas or group of gases to prevent the inadvertent mixing of gases, which could be reactive, and to avoid other possible misuse hazards of incompatible gases.

- Threading on regulators or other equipment that is intended to be connected to a compressed gas cylinder must fit the threading on the valve outlet. Some fittings may have right-hand threads whereas others may have left-hand threads. Incompatible threading is intended to prevent certain unsafe connections such as ones that would result in mixing oxygen with a flammable compressed gas (e.g. hydrogen).
- Laboratory personnel shall not attempt to alter the threading, cross thread, or force-fit equipment on a compressed gas cylinder if the threading of the equipment is not identical to the threading on the outlet. Refer to the CGA connection number that may be stamped on the neck of the compressed gas cylinder where it connects to the handle.

5. Manifold Systems

A cylinder manifold system is a high-pressure structure that is specially fabricated for interconnecting two or more cylinders of the same gas to a common supply line when consumption requirements are high. Manifold systems should not be used for mixing gases but only to extend the supply of a single gas. Do not connect more than one type of gas to the same manifold.

Gas manifolds increase safety by eliminating gas cylinder and pressure regulator handling during cylinder change out. It is advisable to consult with the vendor for appropriate choice of manifold systems. Installation of manifold system should be done by experienced personnel including vendors.

- Laboratory personnel shall not connect chemically incompatible gases on the same manifold. For example, by utilizing engineering controls, flammable and oxidizing gases must not come in contact through mixing or backflow.
- Check valves and careful design of manifold systems should be used. A single valve shall not be relied upon to prevent mixing, since valves can leak and fail.
- Connecting empty compressed gas cylinders along with full compressed gas cylinders on the same manifold shall be avoided, in order to prevent reverse flow of gas.

- If manifold systems are used, they shall be compatible with the gas being used, as well as the operating temperatures, pressures and flow rates.
- All manifold systems and custom set-ups shall be reviewed by the gas vendor prior to initial use.

Figure 17: Gas Cylinder Manifold and Pipeline.[16]

D. Administrative Controls

Administrative controls are the policies, procedures, effective communication and best work practices designed to ensure the safety of personnel. Training is a cornerstone of a safe laboratory environment, and a fundamental administrative control. In laboratories where compressed gases are handled, provision of required safety training shall be documented. As indicated in the CGA *Handbook of Compressed Gases,* "transfer of compressed gases from one container to another should only be performed by the gas supplier or laboratory personnel who are trained in both the transfill equipment and written operating procedures."[17]

Safety instruction shall be provided by the PI or their designee as a competent person. Compressed gas cylinders may only be used by laboratory personnel who have received all the recommended safety training. For more information, refer to Chapter II: Training Requirement of this Manual. In addition, access to compressed gas cylinders shall be limited to those who are authorized and instructed by their PI or their designee, and are also trained in accordance with University requirements in their use. Additional administrative controls are discussed below.

- **Emergency Equipment -** Emergency equipment shall be present in locations where compressed gases are being used or stored. Emergency eyewash units shall be installed in all laboratories, and laboratory personnel are responsible for regular (weekly) testing of the units to ensure functionality. Fire extinguishing equipment is required, such as Class ABC dry chemical, Class D, water or CO_2 fire extinguishers, depending on the chemicals and the specific compressed gas(es) in use in the laboratory . Please consult with EH&S at labsafety@columbia.edu for guidance in selecting the correct fire extinguishing media.

  Where corrosive gases are filled or used, an emergency shower and eyewash shall be located nearby in the event of an exposure. Seek medical assistance for exposure to corrosive gases. For additional details, refer to, Chapter XI: Emergency Procedures of this Manual.

  Per NYC Fire Code Section 3805.3.10 and 14, liquefied petroleum gases shall not be stored, handled or used for a stationary installation in any area where access to piped natural gas from a public utility is available, except as authorized by the commissioner. The use of nonmetallic pipe, tubing and components for any installation, appliance or equipment using liquefied petroleum gases is prohibited except as authorized by the commissioner.

- **Emergency Shut-off Systems -** Per NYC Fire Code Sections 4103.1, 4003.1.2, 3503.1.3 and 3704.2.10.2 compressed gas cylinder systems conveying pyrophoric, oxidizing, flammable and highly toxic and toxic gases shall be provided with approved manual or automatic emergency shutoff valves that can be activated at each point of use and each source. A manual or automatic fail-safe emergency shutoff valve shall be installed on supply piping at the container or other source of supply or at the point of use, which is connected to the supply system. Manual or automatic container valves on the containers supplying the pyrophoric, oxidizing or flammable material may serve as the emergency shutoff valve when the compressed gas cylinders are the sole source of supply and are not manifolded.

- **Basic Storage Requirements -** Compressed gas cylinders shall be secured when in use or storage. Storing specific gases in a non-upright position can be unsafe (e.g. acetylene compressed gas cylinders shall never be stored horizontally). Straps, chains, clasps, or cylinder bases specifically designed to fit cylinder(s) shall be used to ensure that the cylinder remains in place in the event of accidental release of gas. (OSHA 1926.350(a) (9), CGA *Safe handling of compressed gases*.

For other safe storage and segregation practices and requirements see Chapter VIII: Storage Requirements of this Manual.

1. Training

Training is an essential administrative control. For detailed information on training requirements, please see Chapter II.

2. Standard Operating Procedures (SOPs)

Lab personnel shall consider developing operating procedures to address a particular hazard or operation encountered in the laboratory while working with compressed gas cylinders. EH&S can be consulted to determine which operation warrant documentation through standard operating procedures (SOPs). All procedures involving toxic, reactive, corrosive or flammable gases shall follow a written SOP. Other SOPs for compressed gas usage can include the following:

- Safe handling, use and storage of specific compressed gas cylinders being used in the laboratory.
- Changing and safe movement of compressed gas cylinders on manifold systems
- Changing regulators.
- Quenching the experimental setup atmosphere for safe handling of reactive gases.

3. SDS/ChemWatch

- Laboratory personnel are responsible for ensuring that SDSs are accessible to all laboratory personnel via ChemWatch, by maintaining paper binders with hard copies, or by providing access to a computer where all SDS files are saved in a specified folder.
- Laboratory personnel must not start working with a compressed gas before reviewing the SDS for the specific product.
- Laboratory personnel should review SDS and be familiar with the hazards, components, first-aid measures, emergency measures, handling, physical/chemical/toxicological properties and other safety information associated with all compressed gases cylinders present in their research laboratory.
- SDS can be obtained through any Columbia University computer via the online ChemWatch subscription, available through the EH&S website at: https://research.columbia.edu/content/safety-data-sheets
- All compressed gases shall be accompanied by their respective SDSs, whether provided by the vendor, or downloaded from ChemWatch or an online source.
- If unable to obtain a SDS for any chemical, laboratory personnel can contact labsafety@columbia.edu.

4. LATCH and LION

The Laboratory Information Online Network, LION, is Columbia University's online system for management of personnel, spaces, assets, standard operating procedures, emergency equipment and training data. It also serves as the communication platform for EH&S survey information and applicable corrective actions. The Laboratory Assessment Tool and Chemical Hygiene Plan (LATCH) is the laboratory-specific complement to the Columbia University Chemical Hygiene Plan. LATCH is a tool in LION that helps laboratory personnel maintain records, identify tasks, identify the corresponding administrative, engineering controls and PPE needed to reduce potential exposures for those activities, as well as track safety training. Laboratory personnel who use compressed gas cylinders shall select the corresponding activity categories in the LATCH to ensure that hazards are assigned correctly, and to ensure that laboratories have been identified for future engagement regarding corrective actions during survey findings and other programming. Refer to **Appendix 3** for instructions on how to use LATCH and LION.

5. Labeling and Signage

The use of signage, labeling, and other means of communicating the hazards associated with the specific gases and with compressed gases, in general, are considered essential administrative controls and are required by relevant regulations such as OSHA Hazard Communication Standard 29 CFR 1910.1200, GHS, and NYC Community Right-to-Know Law.

Laboratory personnel are responsible for ensuring that all compressed gases used in their laboratory are accurately labeled. Details regarding labeling include:

- Compressed gas cylinders shall be legibly marked to identify contents with either the chemical or the trade name of the gas. Such marking shall be by means of stenciling, stamping, or labeling, and shall not be readily removable. Whenever practical, the marking shall be located on the shoulder of the cylinder per 29 CFR 1910.253(b) (1) (ii).
- Laboratory personnel should always confirm the identity of the compressed gas by consulting the compressed gas cylinder label before using the gas or otherwise handling the cylinder. Accurate labeling on compressed gas cylinders shall be verified prior to taking delivery; secondary labels may be necessary if originals are not visible due to cylinder position/orientation. All cylinders shall have legible, affixed labels that clearly identify their contents in accordance with GHS, CGA, OSHA and USDOT requirements. This can be in the form of a manufacture's stencil, tag or paper/plastic label affixed to the cylinder. If a cylinder is found in a laboratory without a label or it has fallen off and assistance affixing a new label is needed, please contact EH&S at labsafety@columia.edu
- Labels on compressed gas cylinder should at a minimum contain the following information:
    - Name and Contact Information of Manufacturer
    - Chemical name and identifier
    - Signal Word (such as WARNING or DANGER)
    - Hazard Statements (indicating hazards associated with the specific product)
    - Precautionary Statements
    - OSHA hazard pictograms used for communicating potential hazards

- The color, shape or size of the compressed gas cylinder may not be indicative of the cylinder's contents. Unlabeled compressed gas cylinders, or ones with illegible or damaged labels should not be used, handled or stored in laboratories. If unsure of the contents of a compressed gases, laboratory personnel shall avoid using or handling the cylinder and should contact their gas supplier and/or EH&S.

- Laboratory personnel should not accept incoming compressed gas cylinders if the manufacturer's label is missing, damaged, illegible or incomplete.
- Laboratory personnel should not deface manufacturer's labels from the compressed gas cylinder or remove or alter any tags, stencil marks or other markings used by the supplier for identification of the cylinder contents.
- Empty compressed gas cylinders shall be marked as "EMPTY" and stored separately from in-use compressed gas cylinders.
- Per NYC Fire Code Section 3203.4.4, cryogenic container connections, fluid level indicating devices, pressure gauges, regulators and safety devices shall be marked with a permanent tag or label identifying their function or identified by a schematic drawing designating their function and whether they are connected to the vapor or liquid space of the cryogenic container. Where an emergency shutoff valves are present, it shall be identified by posting a durable sign at a conspicuous location at or near the valve.
- Per NYC Fire Code Section 2703.5 and NFPA 704, hazard identification signs (NFPA diamonds) for the specific material contained must be affixed to stationary containers and at the entrances to locations where hazardous material are stored, handled or used. Individual containers shall be conspicuously marked or labeled. Signs reading "COMPRESSED GAS" shall be conspicuously posted at the entrance to rooms and on cabinets containing compressed gases.
- Signs should indicate the presence of compressed-gas-associated hazards by including the relevant pictogram(s).
- Specific signage may be needed regarding specific gases and emergency procedures.
- Laboratory door signs for Columbia University can be downloaded and printed from the EH&S website at the following link: https://research.columbia.edu/content/laboratory-door-signs

6. Inspections - Cylinders, Installations and Connections

Inspections are an important aspect of compressed gas safety and help ensure safe operating conditions in the laboratory. Laboratory personnel should periodically inspect compressed gas cylinder conditions, regulators, manifolds and applicable monitoring equipment, and contact the appropriate vendor when service may be needed. Please see Attachment 12: NIOSH Self-Inspection Checklist for further guidance regarding cylinder inspections. This is also available on the EH&S "Compressed Gas Safety Program" webpage. Additionally, gas distribution systems and monitoring equipment may require service contracts for maintenance. These contracts are the responsibility of the individual laboratory and/or department.

Inspection, maintenance, and reconditioning shall only be performed by laboratory personnel who are trained and experienced in the use, hazards and handling of the specific compressed gases used in the laboratory. A designated vendor shall perform major repairs and reconditioning.

Compressed gas cylinders should be inspected by laboratory personnel upon receipt from vendor. If the integrity of the compressed gas cylinder appears to be compromised in any way, it should be rejected and immediately returned to the vendor without being used. Indications of a compromised compressed gas cylinder include, but are not limited to, dents, gouges, cuts, bulging, burns, and any evidence of having been exposed to fire, excessive rust, corrosion with pitting, or any other condition that appears aberrant. Compressed gas cylinders should be rejected and returned to the vendor if there is no clear label or marking as to the contents of the cylinder.

Laboratory personnel should visually inspect their compressed gas cylinder and installations, refer to Attachment 12: NIOSH Self-Inspection Checklist for details, before every use and at least once a day to confirm the following:

- The compressed gas cylinder is undamaged, not misshaped or displaying any signs of mechanical stress.
- The compressed gas cylinder is properly secured with straps, chains, holders or otherwise secured to a wall, an unmovable object or on a specialized stand or cart.
- The compressed gas cylinder is in an upright position.
- The label is legible and not damaged.
- The valve, regulator, and all connections appear to be in place, in their proper position, and are not damaged, or the compressed gas cylinder is capped, with the regulator removed, if not in use.

Additionally, compressed gas cylinders shall be equipped with connections complying with the American National Standard Compressed Gas Cylinder Valve Outlet and Inlet Connections, ANSI B57.1-1965, which is incorporated by reference as specified in Sec. 1910.6 per 29 CFR 1910.253(b)(1)(iii).

Hazards associated with incompatible reactions between gases and a cylinder's components, connections, and associated devices can be avoided by using compatible materials as part of the setup. These issues should be addressed during the planning and execution phases of the experiment. For example, acetylene gas should not be piped through copper lines as it may form copper acetylide (II), which is a friction-sensitive compound (sensitive to impact and heat) when dry. An explosion occurred during maintenance work on a copper condenser in a methanol plant that was attributed to copper acetylide deposits in the heat exchanger. For additional information on whether a gas is compatible with material recommended, consult with the gas supplier.

7. Checking for Leaks

Compressed gas cylinders should be checked for potential leaks as part of a regular safety inspection. Every time a new connection is made, additional equipment is attached to the valve, a regulator is added or replaced, or any alteration to the installation takes place, a leak check should be performed. Additionally, leak testing should be performed before using the compressed gas cylinder for the first time or whenever a user suspects a leak (e.g. low pressure may be an indication of a leak). Leak testing should also be done on special occasions as dictated by the SOP or for reasons related to specific hazards associated with the properties of the compressed gas.

"Operators should always be on alert for leaks. Some leaks can be smelled, heard, or seen depending upon the type of gas in the cylinder. Certain gases may not be detectable by human senses, and other leak detection methods will be required,"[18] per CGA *Handbook of Compressed Gases*. To check for leaks, laboratory personnel may use a manufacturer or supplier's recommendation for a leak testing solution or a dilute soap solution. However, soap can render the surface of the cylinder slippery and make handling and/or use difficult or unsafe. EH&S recommends the use of specialized leak detection products (e.g. Snoop). General guidance on leak testing includes the following:

- Inspect compressed gas cylinders for any visible signs of damage or leaks, when receiving deliveries from vendors. This is to ensure the cylinders were not compromised in any way during transportation.
- Valves must be visually inspected at each refill for any signs of damage or leakage.
- Both inlet and outlet threads should be examined before insertion of equipment into a compressed gas cylinder CGA connection to ensure that the threads are not damaged.
- Flammable or corrosive products may not be used to detect leaks. Oils and petroleum-based lubricants shall be avoided.
- The leak detecting solution should be applied on the area where the valve connects to the body of the cylinder and around all thread connections.
- If a leak is suspected or confirmed, laboratory personnel should immediately follow emergency procedures as described in Chapter XI. Emergency Procedures of this Manual.
- If using toxic gases, the use of additional leak detection methods is recommended (e.g. monitor devices or gas detectors).
- Caution is recommended while inspecting any valve that is attached to a cylinder that could be pressurized.

A good method to quantitatively assess any potential leaks in compressed gas cylinders is to **partly** open the cylinder to fill the line with gas (releasing only a few hundred psi of the tank pressure to the first gauge on the regulator), and then close the cylinder valve to trap the gas in the line (including the regulator). Note the pressure on the first valve representing the tank pressure. Wait 5-10 min and note whether the valve decreases. If so, there is a leak. The regulator valves and system valves can be opened and closed systematically to determine the origin of the leak.

8. Lockout/Tagout Systems

The OSHA standard for The Control of Hazardous Energy (Lockout/Tagout), Title 29 Code of Federal Regulations (CFR) Part 1910.147, addresses the practices and procedures necessary to disable machinery or equipment, thereby preventing the release of hazardous energy while employees perform servicing and maintenance activities. The requirements stated apply to the contents of a compressed gas cylinder as they represent both pneumatic and, in the case of flammable gases, potential thermal energy. Lockout is the placement of a locking device on an apparatus such as the valves on a manifold system, thus isolating the device, and preventing operation until the locking device is removed. Tagout is the placement of a tag or other warning devices to alert laboratory personnel of faulty and malfunctioning equipment.

Figure 18: Standard examples of Lockout/Tag out systems[27]

9. Gas Detection Systems

There are several regulatory requirements for gas detection systems. For example, gas detection systems shall be equipped with a visual and audible alarm. Alarm and shutoff threshold information is provided by the manufacturer of the detection system. Detection systems should be placed close to the gas cylinder in question, for quick detection in case of a leak. The monitors for the detection system need to be calibrated often, generally about every 6 months or per the manufacturer's recommendations. Please contact vendors to learn about the calibration process, or request calibration. Always ensure that soft wired devices are plugged in; confirm calibration intervals, lifespans, and responsibility of end user for maintenance with the vendors directly. Additional requirements cited per regulatory requirement include the following:

- Flammable gas detection and alarm systems are required in areas where flammable gas distribution piping operates at levels above 15 pounds per square inch per NYC Fire Code Section 908.9.1.
- Gas detection and alarm systems are required for toxic and highly toxic gas storage and use per NYC Fire Code Section 908.3 and Section 3704.2.2.10. Per this requirement, a gas

detection system shall be provided to detect the presence of gas at or below the permissible exposure limit (PEL) or ceiling limit of the gas for which detection is provided.

- Gas detection systems are required in laboratories using 20 SCF/4 lbs. or more of “highly toxic” gas or 810 SCF/150 lbs. or more of “toxic” gas according to NFPA 55.
- The detection system shall alarm when the presence of gas reaches or exceeds 25% of the LEL or at one-half of the IDLH concentration per IFC 5303.16.10. Note: a gas detection system is not required for toxic gases when the physiological warning properties for the gas are at a level below the accepted PEL for the gas.
- Per NFPA 72 Chapter 17.10.2.4, the selection and placement of gas detectors shall be based on an engineering evaluation. There are multiple detection device options available for gas cabinets (eg, UVIR, FTIR, exhaust detection, and decay rate alarms). Please consult with associated vendors to learn more about detection device requirements.
- Characteristics to consider when selecting a gas monitoring and detection system include the following:
    - Compatibility of the material to the atmosphere being monitored (Ex. when monitoring for a flammable gas be sure the instrument is intrinsically safe and non-sparking),
    - Flow rate of the gas vs. the capability of the instrument to receive that flow rate,
    - Temperature and pressure of the gas vs. capability of the instrument to receive those pressures and temperatures and operate safely and accurately under them, and
    - Any atmospheric interferences that may influence the ability of the instrument to detect the gas (ex. humidity or nearby chemical experiments).

10. Oxygen and Hydrogen Sensors

a) **Oxygen Sensors:** NYC Fire Code Section 32 outlines the requirements for storage and handling of cryogenic liquids including alarm requirements under Section 3205.4.1.1.1, in areas where cryogenic liquids are in use. Oxygen sensors (Figure 19[19]) equipped with an audible alarm shall be provided in dispensing areas to continuously monitor the level of oxygen in the area. The alarm shall actuate when oxygen concentration drops below 19.5 percent. In case of activation, evacuate all workers in the room, close the door, and immediately call Public Safety. If alarm activation is noticed prior to entering a laboratory space, do not enter, and call Public Safety. When the need for an O_2 sensor is identified during the design of a new laboratory or a substantial renovation, installation of an oxygen monitor is the responsibility of the PI in conjunction with Capital Project Management; ongoing maintenance is the responsibility of the PI. EH&S is responsible for the installation of O_2 sensors when needed in existing laboratories.

Figure 19: Commonly used oxygen sensors from Gas Clip and PureAire.[19]

b) **Hydrogen Sensors:** Hydrogen sensors are used to detect any leakage of gas from a nearby hydrogen cylinder. Due to the broad range of flammability of hydrogen gas (NFPA 704 rating of 4 on flammability scale) when in contact with air, it is very important to detect leaks of even trace amounts of hydrogen immediately. The use of hydrogen sensors is not mandated by any regulatory agency. However, laboratory personnel are strongly advised to utilize a hydrogen sensor to ensure safe operations.

11. Low-level Gas Alarms

Low-level gas alarm systems that are designed to alert laboratory personnel when the gas in a cylinder drops below a predefined limit are available on the market, and can be useful for limiting the risk of running out of gas in the middle of experiments. The use of low-level cylinder alarms is not mandated by any regulatory agency. However, laboratory personnel are encouraged to utilize them if the experimental set up would directly benefit from their installation. To avoid confusion between low-level gas alarms and actual gas leaks, laboratories must add signage in relevant areas to differentiate between low level alarms and alarms pertaining to leaks and releases.

Per NYC Fire Code Section 3203.1.1.2, cryogenic containers shall be provided with a liquid level-indicating device. It shall be unlawful to use cryogenic containers with glass liquid level gauges in direct contact with the contents of such containers. Note: cryogenic containers are defined in the Definitions section of this Manual for further information.

12. Cylinder Maintenance and Hydrostatic Testing

Hydrostatic tests are performed on a compressed cylinder gas at intervals specified by the USDOT, typically every 5 years or more frequently, if necessary. Per USDOT, 49 CFR 173.301(a)(7) "a cylinder with an authorized service life may not be offered for transportation after its authorized service life has expired. However, a cylinder in transportation or a cylinder filled prior to the expiration of its authorized service life may be transported for reprocessing or disposal of the cylinder's contents." [20] Table 1 below illustrates the minimum test pressure and requalification period for different rated USDOT cylinder types. If a compressed gas cylinder is past its hydrostatic test date, please contact the vendor for immediate replacement.

Table 1: Retest and Inspection of Cylinders Table. Available at http://www.tymsinc.com/hydrostatic-faq.html

Specification under which cylinder was made	Minimum test pressure (psig) [2]	Requalification period (years)
DOT 3	3000 psig	5.
DOT 3A, 3AA	5/3 times service pressure, except noncorrosive service (see § 180.209(g))	5, 10, or 12 (see § 180.209(b) , (e), (f), (h), and (j).
DOT 3AL	5/3 times service pressure	5, 10 or 12 (see § 180.209(e) , (j) and § 180.209(m) [3]).
DOT 3AX, 3AAX	5/3 times service pressure	5, 10 (see § 180.209(e) .
3B, 3BN	2 times service pressure (see § 180.209(g))	5 or 10 (see § 180.209(e) , (f)).
3E	Test not required.	
3HT	5/3 times service pressure	3 (see §§ 180.209(k) and 180.213(c)).
3T	5/3 times service pressure	5.
4AA480	2 times service pressure (see § 180.209(g))	5 or 10 (see § 180.209(e) or (h)).
4B, 4BA, 4BW, 4B-240ET	2 times service pressure, except non-corrosive service (see § 180.209(g))	5, 10, or 12 (see § 180.209(e) , (f), and (j)).
4D, 4DA, 4DS	2 times service	5.
DOT 4E	2 times service pressure, except non-corrosive (see § 180.209(g))	5 or 10 (see § 180.209(e)).
4L	Test not required.	
8, 8AL		10 or 20 (see § 180.209(i)).
Exemption or special permit cylinder	See current exemption or special permit	See current exemption or special permit.
Foreign cylinder (see § 173.301(j) of this subchapter for restrictions on use)	As marked on cylinder, but not less than 5/3 of any service or working pressure marking	5 (see §§ 180.209(l) and 180.213(d)(2)).

Table Notes: [1] Any cylinder not exceeding 2" outside diameter and less than 2' in length is excepted from volumetric expansion test. [2] For cylinders not marked with a service pressure, see 49 CFR 173.301a (b) of this subchapter. [3] This provision does not apply to cylinders used for carbon dioxide, fire extinguisher or other industrial gas service.

13. Additional Technical Information and Resources

Additional information often delineated by specific gas or family of gases, regarding the safe handling or operation of compressed gas cylinders can be found in Attachment 7: CGA *Electronic Library Contents*. This technical collection of 316 documents includes:

- Information regarding standards for visual inspection for a variety of cylinder types;
- Information on gas flowmeters;
- Standards for compressed gas check valves for pressures up to 3000 psi;
- Guidance on the use of fluorine and fluorine mixtures with inert gases;

- Standards for compressed gas cylinder valve outlet, inlet connections;
- Selection of PPE;
- Hazard ratings for compressed gases;
- Safe handling of cryogenic liquids

A comprehensive overview of compressed gas cylinder safety and handling in laboratory settings, which highlights many of the important points in this Manual, can be reviewed in Attachment 3: Matheson *Safe Handling of Compressed Gases in the Laboratory and Plant*.

The CGA *Handbook of Compressed Gases* and the Matheson *Gas Data Book* are also excellent resources for technical information regarding compressed gas safety. Additionally, specialized guidance is contained within these referenced books and they may be independently purchased as downloadable files such as Position Statements or Technical Bulletins, including the CGA P-12, *Safe Handling of Cryogenic Liquids.*

E. Personal Protective Equipment

Personal Protective Equipment (PPE) represents the "last line of defense" and the lowest level on the hierarchy of controls. Nonetheless, it is a critical component of working safely with hazardous materials, including compressed gases.

PIs shall ensure that PPE is available to laboratory personnel who use compressed gases in laboratories. As indicated in the CGA *Handbook of Compressed Gases*, "Gas venting from the cylinder valve outlet or other points of leakage is a hazard to personnel using the cylinder. A high-pressure gas stream can penetrate the skin causing serious injury; the eyes and face are extremely vulnerable. Valve outlets should be directed away from the body when being opened. The use of goggles or a face shield is also recommended."[21]

At a minimum, eye protective equipment and lab coats shall be worn when handling any type of compressed gas cylinder. A face shield or safety goggles, rubber gloves (or other suitable chemically resistant gloves specifically tested for the gas in use), a chemical resistant apron specifically tested for the gas in use and safety shoes may be required, in particular, when using corrosive gases to avoid skin and eye contact. Laboratory personnel should reach out to EH&S to request assistance to assess the level of PPE needed. Respiratory protection may be needed as emergency PPE in locations where toxic gases are being used or stored. Training and medical clearance is required for the use of respiratory protection equipment.

Laboratory personnel working in laboratories shall always be dressed in appropriate laboratory attire, which includes clothing that covers the upper torso, arms, lower body and legs to the ankles. Shoes shall completely cover the foot. Shorts, short skirts, sandals or other types of open-toed shoes are not considered appropriate laboratory attire.

PPE recommendations for the handling and transfer of cryogenic liquids include the use of heavy leather protective gloves (or other cryogenic-specific gloves), safety shoes, aprons and eye protection (including a face shield).

Chapter VI: Regulations, Consensus Standards and Permits

Federal, state, and local regulations regarding the use of compressed gases are to be followed at all times at all Columbia University campuses. Refer to Attachment 8: Lab Requirements for Hazardous Gases for more details regarding regulatory requirements.

At the University's NYC campuses, for example, NYC Fire Code shall be followed. Accordingly, PIs shall ensure that a Certificate of Fitness holder is present during the handling, use, filling of containers/transfer of nonflammable compressed gases between containers and storage of compressed gas in quantities requiring a permit per NYC Fire Code Section 3001.4.1 through 3001.4.4. Compressed gas quantities requiring FDNY permits as per NYC Fire Code Section 105.6(1) are indicated below in Table 2.

Table 2: FC105.6 of the 2014 Fire Code: *Permit quantities for compressed gases*. Available at: http://www.nyc.gov/html/fdny/pdf/firecode/2014_02_05/website_permit_requirements_2_5_14.pdf

PERMIT QUANTITIES FOR COMPRESSED GASES

TYPE OF GAS	QUANTITY (SCF)
Corrosive	400
Flammable	400
Highly toxic	Any Quantity
Nonflammable and nonoxidizing, except carbon dioxide	3,000
Carbon dioxide	4,500
Oxidizing	504
Pyrophoric	Any Quantity
Toxic	Any Quantity
Unstable (reactive)	Any Quantity
Water reactive	Any Quantity

For SI: 1 cubic foot = 0.02832 m^3.

Chapter VII: Handling of Compressed Gas Cylinders

Compressed gas cylinders should only be accepted for handling and use after the contents have been identified and verified to the SOP in use. Manufacturer's labels or tags must be clearly visible when in use and shall not be removed or defaced. Compressed gas cylinders of an unknown origin shall not be used. Please consult EH&S to arrange disposal of such compressed gas cylinders. All compressed cylinders shall be inspected and verified as in safe condition prior to use. SDSs shall be readily available to laboratory personnel for the compressed gas cylinder in use in the event of an emergency such as a release or exposure. All compressed gas cylinder valves shall be protected by a cap while the cylinder is being secured to its place of use, when it is not in active use or while being moved within the laboratory or building. Since small compressed gas cylinders are lightweight, easy to mishandle and do not have protective valves, the original manufacture's packaging should be used to protect the valve while in storage or when moving it throughout the laboratory.

- Do not drop compressed gas cylinder when in use by securing them to a work area.
- Do not lift compressed gas cylinder by their valve, cap or regulator.
- Immediately cap the cylinder valve when the cylinder has been disconnected from a regulator, and is no longer being actively used (e.g. it is common to leave the old cylinder

uncapped while fitting the new cylinder onto the regulator, during which laboratory personnel may slip and knock over the uncapped cylinder).

- Aluminum-based compressed gas cylinders are easily damaged during handling due to the soft nature of the metal and thus making them easily susceptible to damage by heat. Therefore, carefully inspect these cylinder types for signs of excessive heat, burn marks or bulges that may affect the integrity of the cylinder.
- Care should be taken to ensure that the metal walls of compressed gas cylinders are not weakened or compromised in any way (such as by an intense flame impinging on the sidewall).
- The "buddy system" should be implemented by the laboratory for installations and other hazardous gas operations.
- Per the CGA *Handbook of Compressed Gases*, "the use of pyrophoric gases shall be done in a closed system that is capable of withstanding the pressure of the gas being utilized. All equipment shall be purged with an inert gas prior to use and opening the cylinder valve. A check valve or back-flow protection device should be utilized in the lines containing the gas to the container to prevent reverse flow and potential reaction, which could cause a container failure."[22]
- Spark-resistant tools shall be used when attaching components to compressed gas cylinders of flammable and pyrophoric materials. Laboratory personnel shall use spark-proof tools, and incorporate grounding techniques to prevent the accidental ignition of flammable gases.
- When handling oxidizing gases, never lubricate valves, regulators, gauges or other connections with combustible materials such as oil or handle these parts with oily hands or gloves.
- According to the CGA, *Handbook of Compressed Gases*, flammable compressed gas systems (ex. piping, tubing, fittings, gaskets, and thread sealants) shall be suitable for the applicable flammable compressed gas service, the pressure and temperatures involved to the material specifications, and thickness requirements for piping and tubing shall conform to the American Society of Mechanical Engineers Code (ASME) B31.1, *Process Piping*.

Chapter VIII: Storage Requirements

According to OSHA 29 CFR 1910.101(c), cylinders must be chained to a fixed object to prevent inadvertent tipping and should be kept in ventilated enclosures such as a laboratory or certified chemical fume hood.

According to CGA position statement PS-6-2011, an accepted safe method for securing compressed gas cylinders in storage is as follows:

- Nesting of compressed gas cylinder by positioning them in a tight mass using a contiguous three-point contact system with other cylinders or using a solid support structure such as a wall or railing.

- Providing a substantial chain, (noncombustible) rope, or (noncombustible) strap that is positioned in front of or around the compressed gas cylinder, and secured to a solid structure or rigid support.

For additional information and illustrations, refer to the CGA Position Statement PS-6-2011, *Securing compressed gas cylinders from falling at gas manufacturers', distributors' facilities and users' sites* available through EH&S.

There are general storage requirements for compressed gas cylinders of all hazard classes under federal, state and city requirements including 29 CFR 1910.253(b)(2)(i and ii), 29 CFR 1910.101(c) and NYC Fire Code Section 30. NFPA 45 Chapter 10 also references storage limits in laboratories depending on the class of laboratory and may be applicable to the LDEO and Nevis campuses. Refer to Attachment 8: Lab Requirements for Hazardous Gases for additional specific details regarding hazardous gases. In summary, storage guidance includes the following:

- NFPA 45 Chapter 10.1.6.4 states, "cylinders not 'in use' shall not be stored in the laboratory unit." They define 'in use' in 10.1.6.3 as "connected through a regulator to deliver gas to a laboratory operation, connected to manifold being used to deliver gas to a lab operation, a single cylinder secured alongside the cylinder to use to as a reserve cylinder."
- Empty compressed gas cylinders shall be stored separately from full ones.
- When compressed gas cylinders are stored inside of buildings, they are to be stored in well-protected, well-ventilated, dry locations, at least 20' (6.1m) from highly combustible materials such as oil or excelsior.
- Compressed gas cylinders shall not be kept in unventilated enclosures such as lockers and cupboards.
- Compressed gas cylinders should always be stored in an upright position, secured to prevent falling, not be stored where they may be damaged by falling objects, and must not restrict a safe exit.
- Per NYC Fire Code Section 3003.3.3, to prevent movement from contact, vibration or seismic activity, compressed gas cylinders shall be secured to one of the following:
  - A fixed object with one or more noncombustible restraints (not to electrical or plumbing conduits),
  - A cart or other mobile device signed for the movement of cylinders,
  - A nest of compressed gas cylinders at a filling or servicing facility, that is not accessible to the public and if dislodged, does not obstruct egress,
  - Within a rack, frame work, cabinet or similar assembly designed for use, except when being inspected, serviced filled or transported,
  - A foundation designed for such use in accordance with the construction codes, including the Building Code.
- While in storage, do not expose compressed gas cylinders to direct heat, flame, or temperature extremes such as temperatures over 125° F (51.7 °C). Gas mixtures should

be maintained at a temperature that would prevent one or more of the components from condensing.

- Per NYC Fire Code Section 3003.5.7 and 8, compressed gas cylinders and systems shall not be exposed to sources of ignition that could create a hazardous condition or exposed to corrosive chemicals or fumes that could damage compressed gas cylinders, valves or valve-protective caps.
- Compressed gas cylinders shall not be stored or used in such a way that they can become part of electric circuits and to make sure they are not damaged by electric arcs.
- Assigned storage spaces shall be located where compressed gas cylinder will not be knocked over or damaged by passing or subject to tampering by unauthorized persons. These storage areas shall be clearly marked (refer to signage section) and secured against unauthorized access.
- Per NYC Fire Code Section 3003.5 and NFPA 45, compressed gas cylinders shall be stored in clearly defined areas away from elevators, unprotected platform ledges, stairs, or gangways where the cylinder could drop a distance exceed one-half the height of the compressed gas cylinder.
- Signage shall be used to identify storage locations of compressed gas cylinders and/or cryogenic liquids per NFPA and NYC Fire Code.
- Gas rooms, gas cabinets and exhausted enclosures shall be equipped with a sprinkler system and ventilated per NYC Fire Code Section 3704 and the International Mechanical Equipment Code Chapter 5, Section 510. For additional information about when to use these spaces refer to Section B: Ventilation Systems of this Chapter. Additional details on gas cabinets and exhausted enclosures includes:

  a) To understand gas cabinet requirements for flammable, corrosive, toxic, highly toxic and pyrophoric gases as stipulated by National Codes such as NFPA and International codes such as International Fire Codes (IFC), International Building Code (IBC) and International Mechanical Code (IMC), consult Attachment 15: Airgas Guide to Gas Cabinet Safety and Code Conformance.
  b) Gas cabinets per NYC Fire Code Section 3704.1.2:
     - May not exceed three compressed gas cylinders per cabinet unless they are <1 lb. in net content and then up to 100 compressed gas cylinders is permitted.
     - Shall be ventilated in accordance with the International Mechanical Equipment Code Chapter 5, see Attachment 6 International Mechanical Code, 2018, Chapter 5: Exhaust Systems.
     - Shall be protected by a sprinkler system. Alternative fire extinguishing systems shall not be used in lieu of a sprinkler system.

  c) Exhausted enclosures per NYC Fire Code Section 3704.1.3:
     - Shall be ventilated in accordance with the International Mechanical Equipment Code Chapter 5, see Attachment 6.
     - Shall be protected by a sprinkler system. Alternative fire extinguishing systems shall not be used in lieu of a sprinkler system.

- While in storage, per NYC Fire Code Section 3003.4.1, compressed gas cylinder valves shall be protected from physical damage by use of a protective cap, collar or similar devices. Those caps or devices shall be in place except when compressed gas cylinders are in use or being serviced of filled.
- Per NYC Fire Code Section 3003.5.1 and 2703.9.8, incompatible materials shall be separated based on hazard class of their contents while in storage or use in accordance with 2703.9.8, except for compressed gas cylinders having a capacity of ≤5 lbs. (2 kg) or 12 gallon (2L). Separation shall be accomplished by:

    - Segregation incompatible materials in storage by a distance of >20’
    - Isolating by a noncombustible partition extending >18” above and to the sides of the stored material
    - Storing compressed gases in gas cabinets or exhausted enclosures. Incompatible, including gases, liquid and solid materials shall not be stored within the same cabinet or exhausted enclosure.

A. Storage Requirements for Specific Gases

The following sections outline specific storage requirements for a variety of specific hazards classes of compressed gas cylinders.

1. Pyrophoric gases 

Pyrophoric gases are spontaneously flammable and may ignite immediately upon contact with ambient air. Therefore, handling pyrophoric materials alone is a dangerous practice and shall be avoided. The use of gloveboxes is highly advised for storage and handling of pyrophoric gases. These gases are harmful if inhaled.

- Lecture bottles shall be stored in a ventilated storage cabinet or fume hood and away from other combustible or flammable materials. Cylinders larger than a lecture bottle containing pyrophoric gases shall be stored in a gas cabinet equipped with a sprinkler system per NFPA 45 Chapter 10.1.4.3.
- Compressed gas systems conveying pyrophoric gases where automatic shut off devices are required per NYC Fire Code Section 4103.1.1.1, the shutoff valve shall be operated by a remotely located manually activated shutdown control located not less than 15’ from the source of supply. (NOTE – pyrophoric gases such as Aldrich SurePac® DOT 4B240 compressed gas cylinder applications and use are EXCLUDED from this requirement).

2. Flammable Gases

- Per NYC Fire Code Section 2706.5, any flammable gas is prohibited for storage, handling or use below grade.

- Acetylene cylinders should be stored valve end up (as opposed to on their side) per OSHA 29 CFR 1910.253(b)(3)(ii).
- Per NYC Fire Code Section 3504.1.3, for storage of ≤3,500 SCF of gas, flammable gas cylinders shall be stored and used:

    - 20’ from all classes of flammable and combustible liquids, oxidizing gases and readily combustible materials, such as paper and combustible fiber,
    - 25’ from open flames, ordinary electrical equipment or other sources of ignition,
    - 50’ from air-conditioning equipment, air compressors and intakes of ventilation, and
    - 50’ from other flammable compressed gas cylinder storage.

Note: The minimum required distances shall be reduced to 5’ when protective structures having a minimum fire-resistance rating of 2 hours interrupt the line of sight between the compressed gas cylinder and the exposure. The protective structure shall be at least 5’ from the exposure. The configuration of the protective structure shall be designed to allow natural ventilation to prevent the accumulation of hazards gas concentrations.

- According to the CGA, *Handbook of Compressed Gases*:
    - Specified exposures such as incompatible materials can be separated using a 1-hour fire resistive noncombustible partition. The construction of walls, partitions, ceilings, openings, and rooms with other building occupancy shall be in accordance with the building code.
    - Liquefied flammable compressed gases shall be stored and used with the pressure relief device in direct contact with the vapor phase.

3. Liquefied Petroleum Gases

Per the NYC Fire Code Section 38, liquefied petroleum gases are limited to compressed gas cylinders less than 16.4 ounces (0.465 kb). These containers shall not be used in classrooms or areas below grade with the exception of self-contained torch assemblies or as authorized by the commissioner. Where more than one liquefied petroleum gas cylinder is present in the same area, each compressed gas cylinder shall be separated from others by a distance of not less than 20’. The compressed gas cylinders shall be kept a minimum of 10’ from combustible waste and materials.

More information on the storage of compressed gas cylinders, piping systems and installation of liquefied petroleum gases is available in the NFPA 58 and the associated *Liquefied Petroleum Gases Handbook*.

4. Toxic Gases

Laboratory personnel shall only store toxic gases in an exhausted enclosure (e.g., a certified chemical fume hood), gas cabinet or gas room per NYC Fire Code Section 3704.2.2.1 and NFPA 55 Chapter 7.9.2.1. Additionally, per NFPA 55 Chapter 7.9.2.2, outdoor storage shall not be within

75’ of lot lines, streets, alleys, public ways or means of egress, or buildings not associated with such storage or use. Per NYC Fire Code Section 2706.6.10, it shall be unlawful to store, handle or use in any education and instructional laboratory unit any combination of highly toxic and toxic gases in quantities that exceed 220 SCF (0.566m^3).

Per NYC Fire Code Section 3704.2.2.10.2, there shall be a gas detection shut-off valve at the source of the gas supply piping and tubing. However, the automatic shutdown is not required for reactors utilized for the production of highly toxic or toxic compressed gases, where such reactors are operated at pressures less than 15 psig (103.4 kPa), continuously attended and provided with readily accessible emergency shutoff valves.

- Per NYC Fire Code Section 3704.2.2.10, a gas detection system, capable of detecting the presence of toxic or highly toxic gases at or below the permissible exposure limit, or ceiling limit of the gas shall be provided. The system shall be capable of monitoring the discharge from the treatment system at or below one-half the IDLH limit. However, a gas detection system is not required for toxic gases when the physiological warning properties for the gas are at a level below the accepted PEL for the gas.
- Per NYC Fire Code Section 3704.2.2.10.1, the gas detection system shall initiate a local alarm and transmit a signal to a continuously attended control station on the premises whenever it detects the presence of the gas in the atmosphere. The alarm shall be both visual and audible and shall provide warning both inside and outside the area where gas is detected. However, signal transmission to a continuously tended control station is not required where not more than one container of highly toxic or toxic gas is stored.
- Per the International Mechanical Equipment Code Chapter 5, Section 502.9.8, where the highly toxic and toxic compressed gases exceed the maximum allowable quantity per control area (refer to Attachment 10 for details regarding NYC Fire Code control areas), local exhaust shall be provided to capture leakage from indoor and outdoor compressed gas cylinders. The local exhaust shall consist of portable ducts or collection systems designed to be applied to the site of a leak in a valve or fitting on the compressed gas cylinder. The local exhaust system shall be located in a gas room. Exhaust shall be directed to a treatment system where required by the *International Fire Code*.
- Per NYC Fire Code Section 2703.2.2.2, where those toxic gases exceed the maximum allowable quantity per control areas (Refer to Attachment 10 for details) supply piping and tubing shall be in accordance with ASME B31.3.
- Piping and tubing utilized for the transmission of highly toxic or toxic gases shall have welded, threaded or flanged connections throughout, except where connections are located within a ventilated enclosure if the material is a gas.

5. Corrosive gases

Per NYC Fire Code Section 3105.1, indoor handling and use of corrosive materials in amounts exceeding the maximum allowable quantity per control areas (refer to Attachment 10 for details) shall be provided with mechanical exhaust ventilation in accordance with NYC Fire Code Section 2705.2.1.1 when dispensed or used.

- Per NYC Fire Code Section Table 2703.1.1(2), available in Attachment 10: NYC Fire Code Table 2703.1.1(1) Maximum Allowable Quantity per Control Area of Hazardous Material Posing a Physical Hazard and NYC Fire Code Table 2703.1.1(2) Maximum Allowable Quantity per Control Area of Hazardous Material Posing a Health Hazard, quantities of corrosive compressed gases that are permitted to be stored in a control area increases significantly when they are stored in approved gas cabinets or exhausted enclosures.
- Per NYC Fire Code Section 2703.2.2.2, where those corrosive gases exceed the maximum allowable quantity per control areas supply piping and tubing shall be in accordance with ASME B31.3. For more details refer to Attachment 10: NYC Fire Code Table 2703.1.1(1) Maximum Allowable Quantity per Control Area of Hazardous Material Posing a Physical Hazard and NYC Fire Code Table 2703.1.1(2) Maximum Allowable Quantity per Control Area of Hazardous Material Posing a Health Hazard
- Piping and tubing utilized for the transmission of highly volatile corrosive gases shall have welded, threaded or flanged connections throughout, except where connections are located within a ventilated enclosure if the material is a gas.

6. Oxidizing gases

Oxygen and gas mixtures containing high percentages of oxygen and other oxidizers can react violently with organic materials to produce heat and a potential fire or explosion.

- Per OSHA 29 CFR 1910.253(b)(4)(iii), all oxidizing gases shall be stored 20' away from ignitable and combustible materials and sources of ignition or by a noncombustible barrier at least 5' (1.5 m) high having a fire-resistance rating of at least one-half hour.
- Greasy and oily materials should never be stored near oxygen cylinders.

7. Cryogenic Fluids

Numerous NYC Fire Codes apply to cryogenic fluids. Below are the sections relevant to research operations in laboratories. Specific quantities of cryogenic fluids require a permit in NYC. Refer to Table 3 below from NYC Fire Code Section 1 Table 105.6(2) for reference:

Table 3: FC105.6 of the 2014 Fire Code: P*ermit quantities for cryogenic fluids.*[23]

FC TABLE 105.6(2)
PERMIT QUANTITIES FOR CRYOGENIC FLUIDS

TYPE OF CRYOGENIC FLUID	INDOORS (gallons)	OUTDOORS (gallons)
Flammable	More than 1	10
Nonflammable	60	100
Oxidizing (includes oxygen)	10	50
Physical or health hazard not indicated above	Any Quantity	Any Quantity

For SI: 1 gallon = 3.785 L.

- Per NYC Fire Code Section 3203.2.1, cryogenic compressed gas cylinders shall be provided with pressure relief devices. Precautions shall be taken to prevent over-pressurization of atmospheric tanks. Such pressure relief devices shall communicate with the vapor space of the container, not the cryogenic fluid.

- Per NYC Fire Code Section 3203.2:

    - The pressure relief devices, vent piping and drains in vent lines shall be arranged to discharge unobstructed at rated capacity to the outdoors, in such a manner, as to prevent escaping gas from impinging on personnel, cryogenic compressed gas cylinders, equipment and adjacent structures or from entering enclosed spaces, with the exception of USDOT specification cryogenic compressed gas cylinders with an internal volume of 2 ft3 (0.057 m3) or less.
    - Pressure relief device vent lines shall be installed in such a manner to exclude or remove moisture and condensation and prevent malfunction of the pressure relief device because of freezing or ice accumulation or other types of obstruction.

- Per NYC Fire Code Section 3203.2.6, shutoff valves shall not be installed between pressure relief devices and cryogenic compressed gas cylinders. As an exception, a shutoff valve is allowed on cryogenic compressed gas cylinders equipped with multiple pressure-relief device installations where the design and arrangement of the valves provide sufficient relief capacity for the pressure relief device to prevent the cryogenic container or system from being exceeded at all times.
- Per NYC Fire Code Section 3205.1.2.3.1, shutoff valves shall be provided on all cryogenic container connections except for pressure relief devices. Shutoff valves shall be readily accessible and located as close as practical to the cryogenic container. Manually operated shutoff valves shall be designed and installed to minimize accidental opening and closing. Exception, valves before pressure relief device shall be installed in accordance with NY Fire Code Section 3203.2.6.
- Best practice notes:
    - Make sure that the liquid release valve is closed tightly when the tank arrives, since valves are sometimes partially open and cryogenic liquid can spew out of the tanks.
    - Use caution when walking near the outlet of the pressure relief valve or, if possible, direct the relief outlet away from personnel, since cold contents can spew out at a high velocity near face-level.

B. Ventilation Systems

In rooms where hazardous compressed gases are stored (note: this is distinct from a gas room, defined per regulation), ventilation systems shall operate continuously and provide air movement across all portions of the floor at one cubic foot per minute for each square foot of floor space. The ventilation system for gas rooms, gas cabinets and exhausted enclosures shall be noncombustible in design and designed to operate at negative pressure to the surrounding area.

The International Mechanical Code Chapter 5 (Attachment 6: International Mechanical Code, 2018, Chapter 5: Exhaust Systems) may be referenced regarding infrastructure requirements and gas ventilation system requirements. Additional details, specific to hazardous gas classes is also referenced in Attachment 8: Lab Requirements for Hazardous Gases

The exhaust ventilation from gas cabinets, exhausted enclosures and gas rooms, and local exhaust systems required by Section NYC Fire Code Section 3704.2.2.4 and 3704.2.2.5 shall be directed to a treatment system to handle the accidental release of a gas and to process exhaust ventilation. It shall be designed in accordance with this Section and the International Mechanical Equipment Code. The exception includes highly toxic and toxic gases-storage. Exhaust to a treatment system is not required when the following controls are provided:

- Valve outlets are equipped with gas tight outlet lugs or caps,
- Hand wheel-operated valves have handles secured to prevent movement, and
- When approved containment vessels or containment systems are provided in accordance with NYC Fire Code Section 3704.2.2.3.

1. Cryogenic Fluids

- Indoor areas where cryogenic fluids are dispensed shall be ventilated in accordance with the International Mechanical Code (see detail below) in a manner that captures any vapor at the point of generation per NYC Fire Code Section 3205.4.1.1.
- Oxygen sensors must be installed to continuously monitor the level of oxygen in areas where cryogenic fluids are used or dispensed in quantities $\geq$60 gallons per NYC Fire Code requirements. The alarm shall actuate when oxygen concentrations drop below 19.5% per NYC Fire Code Section 3205.4.1.1.1. Contact EH&S at labsafety@columbia.edu for more information about installation requirements in new or renovated laboratories and in existing laboratories.
- Per NYC Fire Code Section 3204.2.1.3, storage areas for cryogenic compressed gas cylinders shall be ventilated (at the vapor's point of generation per NYC Fire Code Section 3205.4.1.1) in accordance with the International Mechanical Code Chapter 5, Section 502.8.1.1 which states the following requirements:

  - Ventilation must occur at a rate of not less than one cfm per square foot of floor area over the storage area.
  - Ventilation must operate continuously unless alternate designs are approved.
  - A manual shutoff control shall be provided outside of the room in a position adjacent to the access door to the room or in another approved location. The switch shall be a break-glass or other approved type and shall be labeled: VENTILATION SYSTEM EMERGENCY SHUTOFF.
  - The exhaust ventilation shall be designed to consider the density of the potential fumes or vapors released. For fumes or vapors that are heavier than air, exhaust shall be taken from a point within 12” of the flor. For fumes or vapors that are

lighter than air, exhaust shall be taken form a point within 12” of the highest point of the room.

- The location of both the exhaust and inlet air openings shall be designed to provide air movement across all portions of the floor or room to prevent the accumulation of vapors.
- The exhaust air shall not be recirculated to occupied areas if the materials stored are capable of emitting hazardous vapors and the contaminants have not been removed. Contaminated air shall not be recirculated.
- Cryogenic compressed gas cylinders shall be positioned such that the pressure relief valve discharge is directed away from any building exit per NYC Fire Code Section 3204.3.1.2.5.

2. Toxic Gases

Additional requirements from NYC Fire Code regulations and the International Mechanical Equipment Code Chapter 5 regarding ventilation of toxic or highly reactive gases include the following:

- Portable compressed gas cylinders of toxic, highly toxic or reactive gases shall be stored in a separately ventilated gas cabinet, gas room or exhausted enclosure which shall be connected to an exhaust system per the International Mechanical Code.
- Per NYC Fire Code Section 2703.1.1(4), 20 SCF of gaseous or 4 lbs. of liquefied highly toxic materials are allowed only when used in approved exhausted gas cabinets, exhausted enclosures or fume hoods.
- Gas cabinets and exhausted enclosures shall not be the only source of ventilation in a room where toxic, highly toxic or reactive gases are stored.
- Local exhaust shall be provided at the point of use for portable compressed gas cylinders of toxic and highly toxic gases.

3. Inert Gases/ Asphyxiants

Any gas that can displace oxygen can cause asphyxiation. Laboratories shall provide ventilation for inert gases in storage. According to the CGA *Handbook of Compressed Gases*, “nonflammable liquefied gases such as carbon dioxide, sulfur hexafluoride and nitrous oxide also pose asphyxiation hazards by reducing the oxygen content in air if large quantities are spilled or released. When the materials are also heavier than air, such as sulfur hexafluoride, it can accumulate in low lying areas creating an asphyxiation hazard.”[24]

4. Corrosive Gases

Where corrosive compressed gas cylinders, having a NFPA hazards ranking of three or four as defined in NFPA 704, are used, mechanical exhaust ventilation shall be provided to capture gases, fumes, mists or vapors at the point of generation, except where those gases do not generate harmful fumes, mists or vapors.

C. **Storage and Handling of Small Compressed Gas Cylinders**

Some special considerations should be made while storing and handling small compressed gas cylinders. Refer to Chapter IV. Hazards of Compressed Gas Cylinders, Section B. Types of Compressed Gas Cylinders for photos of such types of compressed gas cylinders such as lecture bottles DOT3E1800, calibration compressed gas cylinders DOT39 and Aldrich SurePac® DOT4B240 cylinders. These small compressed gas cylinders should not be stored in laboratory bench drawers or under sinks or under certified chemical fume hoods (unless the underside of the certified chemical fume hood is ventilated. Additionally, toxic gases having a NFPA health hazard rating of 3 or 4, NFPA health hazard rating of 2 with no physiological warning properties and pyrophoric compressed gas cylinders shall be stored in a ventilated cabinet or enclosure (such as a certified chemical fume hood).

For small compressed gas cylinders that do not fit the above classification, they may be stored in the laboratory on specifically designed racks for the storage of such compressed gas cylinders (Figure 20), for example lecture bottles, where they may be stored on their side with the exception of acetylene, which cannot be stored on its side.

Figure 20. Small compressed gas cylinders - style racks[28]

The CGA Safety Bulletin SB-27-2013, *Safe use and handling of small cylinders* available through EH&S states the following:

- Excessive force should not be used while connecting small cylinders to the piece of equipment.
- Small cylinder valves can be damaged by over tightening.
- The length of wrench used with the valve shall be the shortest to open and close the valve leak-tight without causing damage to the stem or valve body seat.
- Wrenches supplied by valve manufacturers for particular applications should be used where available.
- Adjustable wrenches or pliers are not recommended for attaching connections to lecture bottles.

D. Signage

Laboratories using compressed gas cylinders must post required signage on all laboratory entrances. Laboratory door signs for Columbia University can be downloaded and printed from the EH&S website at:
https://research.columbia.edu/content/laboratory-door-signs

- The signs must indicate the presence of compressed gas associated hazards by including the relevant GHS pictogram(s). For example, use the GHS flammable pictogram if working with flammable gases.

Flammable

- Specific signage may be needed regarding specific gases and emergency call procedures. Please refer to the laboratory SOP regarding the specific gases in use, PI guidance and consultation with EH&S.
- Per NYC Fire Code Section 2703.5, hazard identification signs, unless otherwise exempted by the commissioner, as set forth in NFPA 704 for specific materials shall be conspicuously affixed on stationary containers…and at entrances to locations where hazardous materials are stored, handled or used, including dispensing, in quantities requiring a permit (…).
- Per NYC Fire Code Section 2703.5.1, signs reading "COMPRESSED GAS" shall be conspicuously posted at the entrance to rooms or on cabinets containing compressed gases.
- Locations where there are specific alarms/monitors must include detailed information regarding what to do and who should be contacted if the alarm sounds (e.g. in areas where cryogenic compressed gas cylinders are used).
- Per NYC Fire Code Section 2703.2.2.1, where emergency shutoff valves are present, a durable sign shall be conspicuously posted immediately adjacent to such valves that identifies their location. The emergency shut off valves shall be clearly visible and shall be readily accessible.
- Per NYC Fire Code Section 3503.1.4.2, "NO SMOKING" signs shall be posted at entrance to and in areas containing flammable compressed gas cylinders, piping and equipment.
- Per NFPA 55 Chapter 7.6.3.2, signs shall be posted in areas containing flammable gases communicating that smoking or the use of open flame, or both, is prohibited within 7.6 m (25') of the storage or use area perimeter.

Chapter IX: Gas Vendors and Procurement Overview

When laboratory personnel are planning to use compressed gas cylinders that require specialty ventilation and/or storage, detection and monitoring equipment, or implementation of engineering controls and/or administrative controls or specialty PPE, please consult with EH&S at labsafety@columbia.edu prior to purchase.

A variety of vendors provides compressed gases to meet a laboratory's needs and requirements. Any service issues related to the vendor interactions onsite, such as the supply and delivery of compressed gas cylinders, should be managed by laboratory personnel directly with the vendor.

In many instances, such as at the Morningside and Irving Medical Center campuses, the University has negotiated approved vendors to minimize costs and maximize available time for delivery to campus; laboratories should contact their Departmental Administrator for details. In general, if a laboratory needs to set up a new account, first contact the vendor to obtain a quote, then proceed with ordering through the department or campus specific protocol.

If a laboratory already has an account with a vendor from one Columbia University campus, this account can typically be transferred to an additional University address, such as the Zuckerman Institute. For example, at the Zuckerman Institute, an exclusive vendors' page is available: https://internal.zi.columbia.edu/content/exclusive-vendors-greene-science-center.

At LDEO, laboratory personnel can order compressed gas cylinders through University approved vendors. However, the order must be approved by the Safety Department in order to ensure adequate escort availability during delivery. Additionally, the Safety Department reviews all orders on a weekly basis to ensure the safety, compliance and security of the compressed gases cylinders purchased in alignment with LDEO and University policy.

At Nevis, laboratory personnel in RARAF order compressed gas cylinders through University preferred vendors via telephone or online vendor systems specific to the ordering department's protocol. However, laboratory personnel shall be present during delivery to perform a check to match the order to the received item and then later to cross check invoices with the orders and delivery slips.

Chapter X: Movement of Compressed Gas Cylinders

Compressed gas cylinders and cryogenic fluids pose potential hazards while being moved, such as damage to the valve or a potential leak that may occur if the cylinder is dropped. Accordingly, compressed gas cylinders may not be transported on mass transit or in a public, private, or rented vehicle. All movement of compressed gas cylinders between campuses shall be done using a University approved vendor and by a trained professional. Please contact EH&S for additional assistance to Hazmat@columbia.edu.

Guideline when moving a compressed gas cylinder larger than a lecture bottle within a laboratory or research building:

- Laboratory personnel shall wear the PPE specified in their SOP for the hazards involved in working with that cylinder.
- Ensure that a cap is installed with the correct thread.
- Always use freight elevators, when available, when transporting compressed gas cylinders from one floor to another.

- The transportation of cryogenic liquids in elevators can pose potential asphyxiation and fire/explosion risk if personnel become trapped in an elevator with a container of cryogen. Do not ride in the elevator with a cryogen Dewar, but use the buddy system to collect it from the elevator on the intended floor.
- Never roll, drag, drop or slide compressed gas cylinders, as this can cause damage to the cylinder walls.
- Caps shall not be used for any other purpose (ex. scooping or breaking of dry ice) besides protecting the compressed gas cylinder valve when in storage or during their movement.
- Valve outlet caps or plugs shall be used on compressed gas cylinders while moving within the laboratory or building.
- Never lift a cylinder by its cap. When moving compressed gas cylinders, use a handcart designed and designated for cylinder transport (Figure 21), to minimize the risk of dropping, falling or striking a cylinder against other cylinders or objects. It is safest for laboratory personnel to transport one compressed gas cylinder at a time, unless the cart is designed for more.
- Never use ropes, chains or slings to lift or suspend compressed gas cylinders, unless provisions were made at the time of manufacture, to include attachments such as lugs.

Figure 21: Compressed gas cylinder and handcart[28]

- Always be mindful of the physical hazards associated with the use of pushing, pulling, and maneuvering handcarts. Some common hazards involve the following:
    - Fingers and hands being caught in, on, or between the cart and other objects.
    - Toes, feet and lower legs being bumped or crushed by the cart.
    - Slips, trips, and falls.
    - Strain injuries predominantly for the lower back, shoulder, and arm muscles and joints.
    - Carpets being bunched up under weight of cylinder cart causing trip hazards.

Chapter XI: Disposal

Compressed gas cylinders are designed to be used and recycled many times over and are generally returned to the supplier at the end of the laboratory's use of the cylinder. Accordingly, in most cases, disposal of compressed gas cylinders should be coordinated by laboratory personnel via return to the cylinder's supplier.

When it is not feasible to return a cylinder to its supplier, laboratories must submit a chemical waste pickup request through EH&S using the following link: https://cumc.co1.qualtrics.com/jfe/form/SV_6gqSpJrYyxX5lul.

Disposal of cylinder contents by venting, neutralization, scrubbing, incineration or other treatment methods is subject to permitting by government agencies and is strictly forbidden by laboratories. Further, devalving of compressed gas cylinders shall not be conducted by laboratory personnel.

Disposal and Characterization

- "U.S. Environmental Protection Agency (EPA) determined that compressed gas cylinders that are returned by customers for re-use, refilling, and re-issue are not considered wastes. The decision of when a cylinder or the contents of the cylinder is waste shall made by the owner of the compressed gas cylinder. Once a decision has been made to discard any remaining contents of it, and/or the compressed gas cylinder itself, then it may need to be managed as a hazardous waste."[25]
- For cylinders that are not returned to their supply vendor, a hazardous waste determination is required per 40 CFR 262.11 to establish the appropriate method for treatment and disposal. Please refer to the EH&S website regarding hazardous waste management at https://research.columbia.edu/hazardous-waste-management and then refer to non-hazardous waste and hazardous waste links for additional details.
- Prior to disposal or return, regulators and piping shall be disconnected and valves on the compressed gas cylinders should be checked and tightened according to the closure instructions provided by the manufacturer or supplier.
- Per NFPA 45 Annex A.10.1.2, compressed gas cylinders of hydrogen fluoride and hydrogen bromide should be returned to the supplier within 2 years of the shipping date. Cylinders of corrosive or unstable gases should be returned to the supplier when the expiration date of the maximum recommended retention period has been reached.

Chapter XII: Emergency Procedures

Always maintain updated emergency contact information for the laboratory on the door signage sheets, so that the designated laboratory personnel can be contacted in the event of an after hours emergency. In the event of an emergency involving compressed gases, such as an injury, fire, release or suspected release, contact EH&S immediately at the applicable telephone number listed below. If the emergency occurs after normal business hours, contact Public Safety, who will contact EH&S. Any service issues related to compressed gas cylinders should be managed by laboratory personnel directly with the vendor.

In the case of a release or suspected release of a hazardous compressed gas, evacuate the laboratory if the compressed gas cylinder is outside of a fume hood or other ventilated containment. If it can be done safely, close the main compressed gas cylinder valve, as it is the single most effective life safety and firefighting method, and/or move the compressed gas cylinder to an area of containment or a well-ventilated area. Ensure all laboratory personnel are aware of the location and function of emergency equipment, including monitors and alarms that may signal a release, prior to working in the laboratory. If the compressed gas cylinder is inside of a fume hood, close the hood sash, evacuate the lab, and contact EH&S and/or Public Safety, according to the contact information below:

Columbia University Irving Medical Center
- EH&S (212) 305-6780
- Public Safety (212) 305-7979

Morningside Campus
- EH&S (212) 854-8749
- Public Safety (212) 854-5555

Manhattanville Campus
- EH&S (212) 854-8749
- Public Safety (212) 853-3333

Lamont-Doherty Campus
- Safety Department (845) 359-2900

Nevis Campus
- 911
- EH&S (212) 854-8749 (contact after the active emergency has been addressed)

Some general emergency guidelines recommended by the CGA *Handbook of Compressed Gases*, include the following:
- In the event of a fire involving a compressed gas leak, do not attempt to extinguish burning materials if the flow cannot be shut off safely and immediately.

    - There is a table of recommended fire extinguishing agents for cryogenic fluids available in the CGA *Handbook of Compressed Gases* and available upon request through EH&S at labsafety@columbia.edu

- Fires involving fuel supported by liquid or gaseous oxygen cannot be effectively blanketed by such agents as carbon dioxide, dry chemical or foam. Instead, the combustible materials shall be cooled below their ignition temperature to stop the fire (e.g. by utilizing a large volume of water)

- If a gas that is not inert is inhaled, remove the person to fresh air and request immediate medical attention.
- All laboratory personnel working in the immediate area of toxic and highly toxic gases shall be trained regarding the toxicity of the gases being used and appropriate methods of protection against harmful exposure, emergency procedures and first aid treatment in case of exposure, including reviewing PELs as outlined in 29 CFR 1910 Subpart Z.
- If liquid oxygen is spilled on clothing or other combustible materials, it can pose a serious fire or explosion hazard due to rapid chemical reaction. If liquid oxygen is spilled on clothing, immediately remove it and air it out before re-use.

Attachments and Appendices

Attachment 1: Summary Hazards Table of Compressed Gases

Attachment 2: Matheson Materials Compatibility Guide

Attachment 3: Matheson Safe Handling of Compressed Gases in the Laboratory and Plant

Attachment 4: Matheson Restrictive Flow Orifices Guide

Attachment 5: Matheson Safety Guide

Attachment 6: International Mechanical Code, 2018, *Chapter 5: Exhaust Systems*

Attachment 7: CGA Electronic Library Contents

Attachment 8: Lab Requirements for Hazardous Gases

Attachment 9: Vendor Questionnaire for Gas Detection Systems

Attachment 10: NYC Fire Code Table 2703.1.1(1) Maximum Allowable Quantity per Control Area of Hazardous Material Posing a Physical Hazard and NYC Fire Code Table 2703.1.1(2) Maximum Allowable Quantity per Control Area of Hazardous Material Posing a Health Hazard

Attachment 11: TechAir Regulator Change out Procedure and Operating Instructions

Attachment 12: NIOSH Self-Inspection Checklist

Attachment 13: Matheson Guide to Regulators

Attachment 14: PurityPlus Gas Safety and Material Compatibility Data Chart see Section 5, page 312

Attachment 15: Airgas Guide to Gas Cabinet Safety and Code Conformance

Appendix 1: Department Administrators/Managers, ChemStores and Capital Project Management Responsibilities

Appendix 2: Prevention, Critical Thinking and Conducting Risk Assessments

Appendix 3: LATCH and LION user instructions

Appendix 1: Department Administrators (DA)/Managers, ChemStores and Capital Project Management Responsibilities.

- Department Administrators (DA)/Managers are responsible for working with Principal Investigators and other University stakeholders such as Facilities Operations and Capital Project Management to ensure that laboratory and research facilities meet the needs of their department's occupants. DAs may be asked to arrange contracts for installation and maintenance of systems, laboratory design and other aspects of safe facility function related to the use of compressed gases.
- ChemStores – In the Department of Chemistry, ChemStores staff and management are responsible for the receipt and storage of compressed gases at the designated location in the Chandler Building. ChemStores staff shall also ensure that all Chemistry Department laboratory personnel are equipped to move and transport compressed gas cylinders from ChemStores to their laboratory. ChemStores personnel may notify Public Safety and EH&S in the event of an emergency involving compressed gas.
- Capital Project Management – Project Managers are responsible for ensuring architects and engineers design compressed gas cylinder storage and use areas and distribute systems in compliance with all federal, state and city regulations. Please consult with EH&S for further guidance before beginning any projects involving compressed gases.

Appendix 2: Prevention, Critical Thinking and Risk Assessment

Laboratory personnel using compressed gas cylinders should perform a risk assessment to evaluate risk factors, and to determine when to apply specific control methods. In addition to the detailed handling and storage guidance elsewhere in this Manual, laboratory personnel should take a generally cautious approach at all times and actively plan for a variety of scenarios, including injuries, releases, damage to compressed gas cylinders or components, and other outcomes. Actively planning for these situations is an effective means of preventing or limiting exposure and mitigating potential harm to people and the environment. Prudent planning and critical thinking can begin with the simple approach of asking, "What would happen if…" and then brainstorming potential conditions or factors that could result in an unexpected event.

Two techniques in conducting risk assessments that may prove useful for risk assessment of compressed gas cylinder activities are Job Hazard Analysis and Control Banding.

Job Hazard Analysis (JHA) – Job Hazard Analysis involves the step-by-step breakdown of a particular job or task into its component activities, identifying the associated risks for each activity, and applying appropriate controls and/or personal protective equipment to each. JHA's have the added benefit of serving as a useful training tool for new or existing laboratory personnel competing a task for the first time. An example of a partial JHA for a compressed gas cylinder-based task is below:

Laboratory procedure to be analyzed: **Connection of hydrogen gas to manifold**

Department:

Hazard Severity Rating (please circle): MAJOR* MODERATE MINOR

List each individual task within the procedure and analyze its hazards	Potential Hazards	Hazard Control and Detection Method(s)	Required Training
1. Remove compressed gas cylinder from wall bracket.	Compressed gas cylinder may fall over and injure laboratory personnel or sustain damage.	1. Confirm compressed gas cylinder is not leaking prior to removal from restraint. 2. Use two-person system to ensure compressed gas cylinder is stable once un-restrained.	Compressed Gas Safety Training. Task-specific instruction from experienced person.
2. Place compressed gas cylinder on transport cart.	Compressed gas cylinder may fall over and injure laboratory	1. Use only compressed gas cylinder-specific cart for transport.	Compressed Gas Safety Training

	personnel or sustain damage.	2. Use two-person system to safely maneuver compressed gas cylinder onto cart.	Task-specific instruction from experienced person.

To complete the JHA, additional steps or tasks would be added and listed in sequence until the overall job is complete. Once complete, the JHA should be discussed with all laboratory personnel who are involved in the procedure to ensure that no steps are missed and that all users are in agreement with the identified control methods. If the laboratory conducts many tasks involving compressed gases, JHAs should be prioritized for those that involve the highest hazard materials or those that are performed most frequently (and therefore contribute to the greatest risk).

Control Banding – Control Banding is an alternative method of hazard and risk evaluation that applies relative ranks and corresponding to the various hazards inherent in an operation. Ratings, for example 1-4, are applied to the various hazards involved, and then when compared to a relative rank of exposure potential, are used to assign a pre-determined set of controls.

		Exposure Potential			
		1	2	3	4
Hazard Level	1	CL1	CL1	CL2	CL2
	2	CL1	CL1	CL2	CL2
	3	CL2	CL2	CL3	CL4
	4	CL3	CL4	CL4	CL4

In the table above, examples of hazard level might be assigned as follows: Inert Gas = 1, Toxic Gas with strong warning properties and high LD50 = 2, Flammable gas = 3, Pyrophoric gas = 4. Exposure potential is based on factors that include handling frequency, operator competency, container size and other factors that should be determined by the stakeholders participating in the risk assessment.

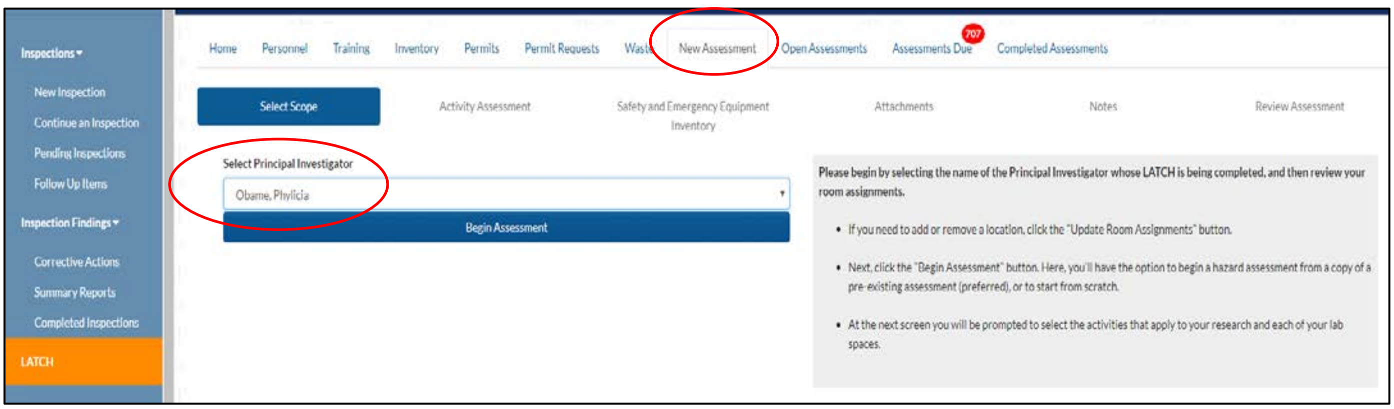
Once the hazard level and exposure potential are agreed upon, the control level is assigned by the corresponding cell at which the two factors intersect. So if a flammable gas (Hazard Level 3) were used in an open bench setting (perhaps Exposure Potential 3), laboratory personnel would apply controls that correspond to the pre-determined CL3, or Control Level 3. These may include enhanced detection methods, substantially upgraded PPE and other strict limitations on user qualifications, in order for the experiment to proceed as planned.

Laboratories are strongly encouraged to conduct a risk assessment using a methodology consistent with their use of hazardous compressed gases, and to document the outcome.

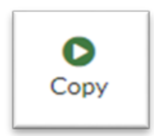
Appendix 3: LATCH and LION User Instructions

Laboratory personnel shall select the appropriate options when completing the activity assessment in LATCH. To do so, please follow the steps below:

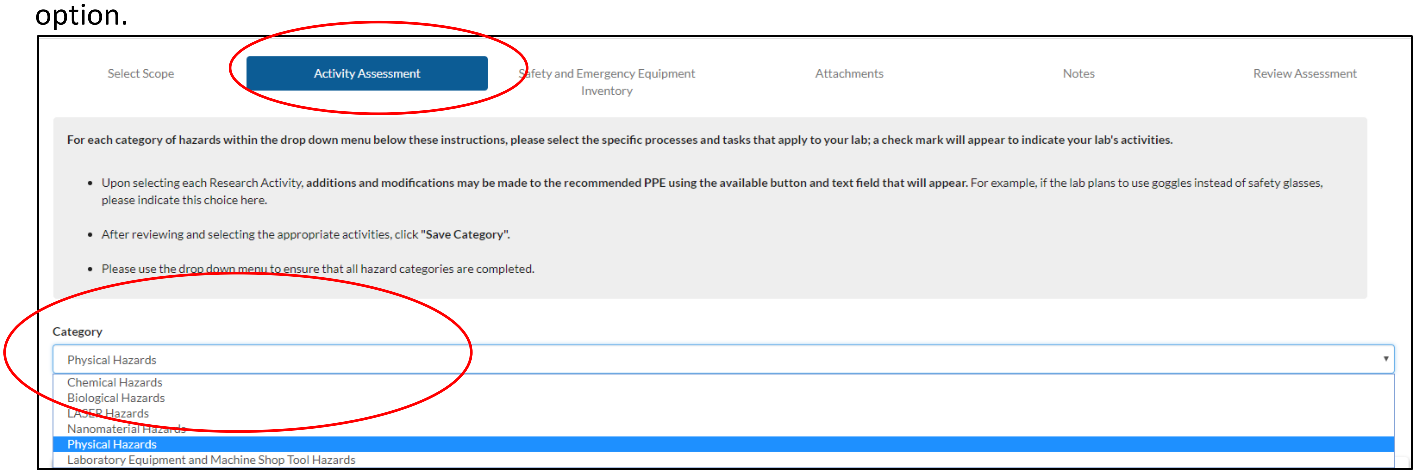
1. Log in to LION. Link: https://labcliq.com/home.cfm
2. Select LATCH, on the left side column.
3. Select "New Assessment", and select the Principal Investigator's name using the drop down option.



4. Start a new assessment or update it using the copy button



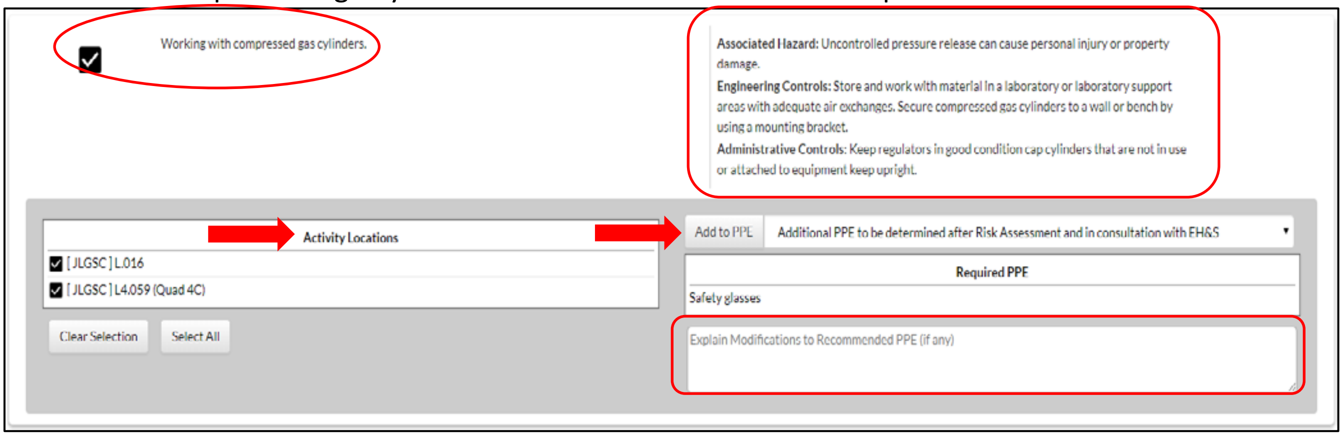
5. Select "Activity Assessment", and select "physical hazards" from the drop down category option.



6. Under physical hazards, there are two options to choose from if there are compressed gas cylinders in the laboratory. Choose the option: "**Working with compressed gas cylinders**" if the lab uses inert gas (argon, helium, neon, nitrogen, etc.).

The system will then assign the associated hazards, engineering controls and administrative controls associated with using inert compressed gas cylinders.

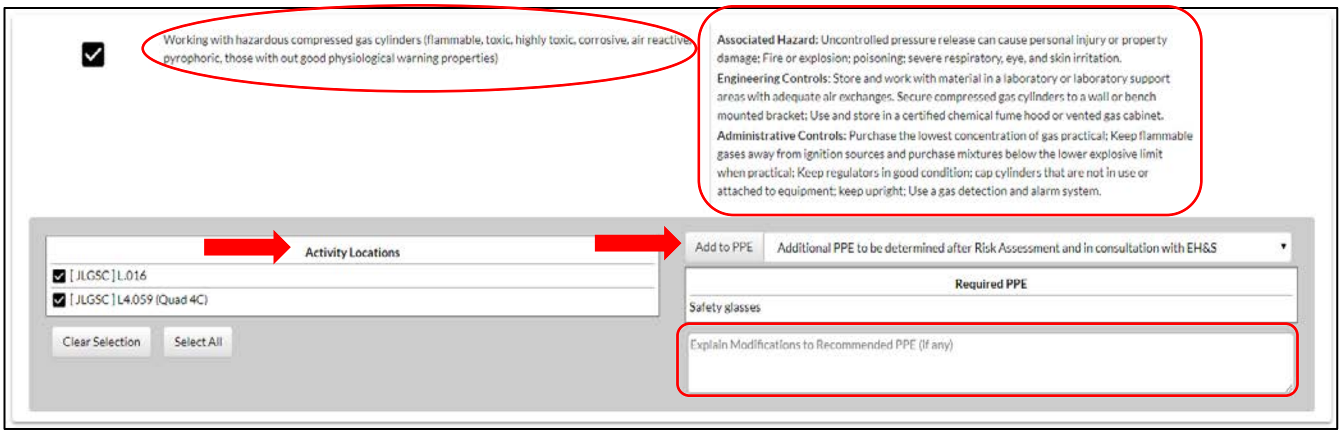
- Choose the location where the compressed gas cylinders are stored and used under the “Activity Location” tab.
- Select the drop-down menu for the “Add to PPE” (personal protective equipment) tab to choose required PPE that shall be used while working with compressed gas cylinders.
- Safety glasses are required while working with compresses gas cylinders and will already be present under the “Required PPE” tab.
- Select “Explain Modification to Recommended PPE (if any)” to make necessary changes, for example adding any PPE that is not mentioned in the drop-down menu.



7. Choose the option: “Working with hazardous compressed gas cylinders (flammable, toxic, highly toxic, corrosive, air reactive, pyrophoric, those without good physiological warning properties)” if the lab uses hazardous compressed gases, including flammable, toxic, corrosive or reactive gases.

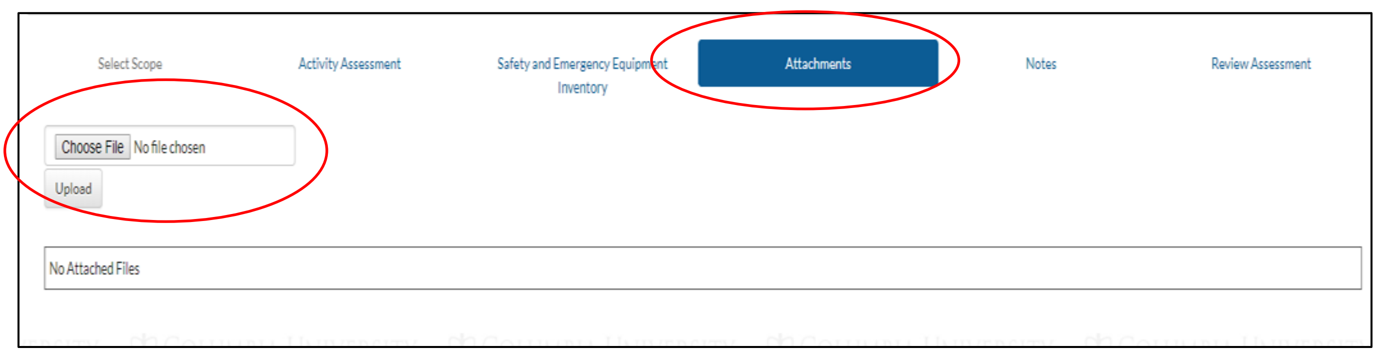
The system will then assign the associated hazards, engineering controls and administrative controls associated with using hazardous compressed gas cylinders.

- Choose the location where the compressed gas cylinders are stored and used under the “Activity location” tab.
- Use the drop-down menu for the “Add to PPE” (personal protective equipment) tab to choose appropriate PPE that should be used while working with compressed gas cylinders.
- Safety glasses are required while working with compresses gas cylinders and will already be present under the “Require PPE” tab.
- Use the “Explain Modification to Recommended PPE (if any)” to make necessary changes, for example adding any PPE that is not mentioned in the drop-down menu.



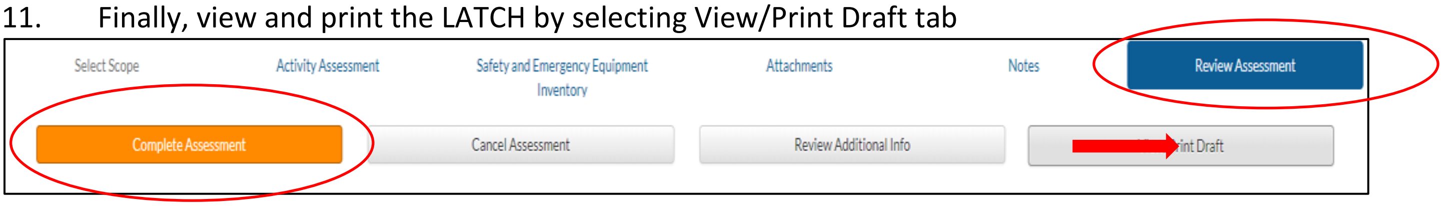
8. Use the “Save All Categories” tab to save the changes that have been made to the LATCH.

9. Attach the laboratory’s compressed gas inventory and other documents (chemical inventory, etc.), as necessary, by clicking “Attachments” and upload the file(s).



10. Review the LATCH by selecting the “Review Assessment” tab and select the appropriate option for completing, canceling or further reviewing the LATCH.

11. Finally, view and print the LATCH by selecting View/Print Draft tab



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