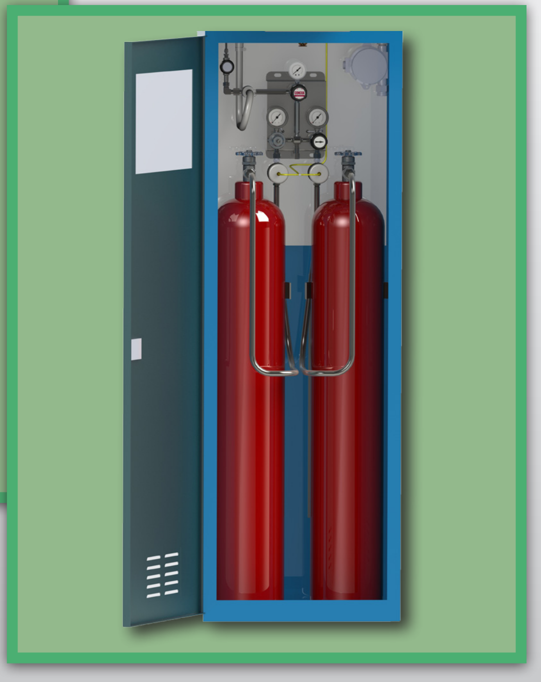
CYCLOTRON

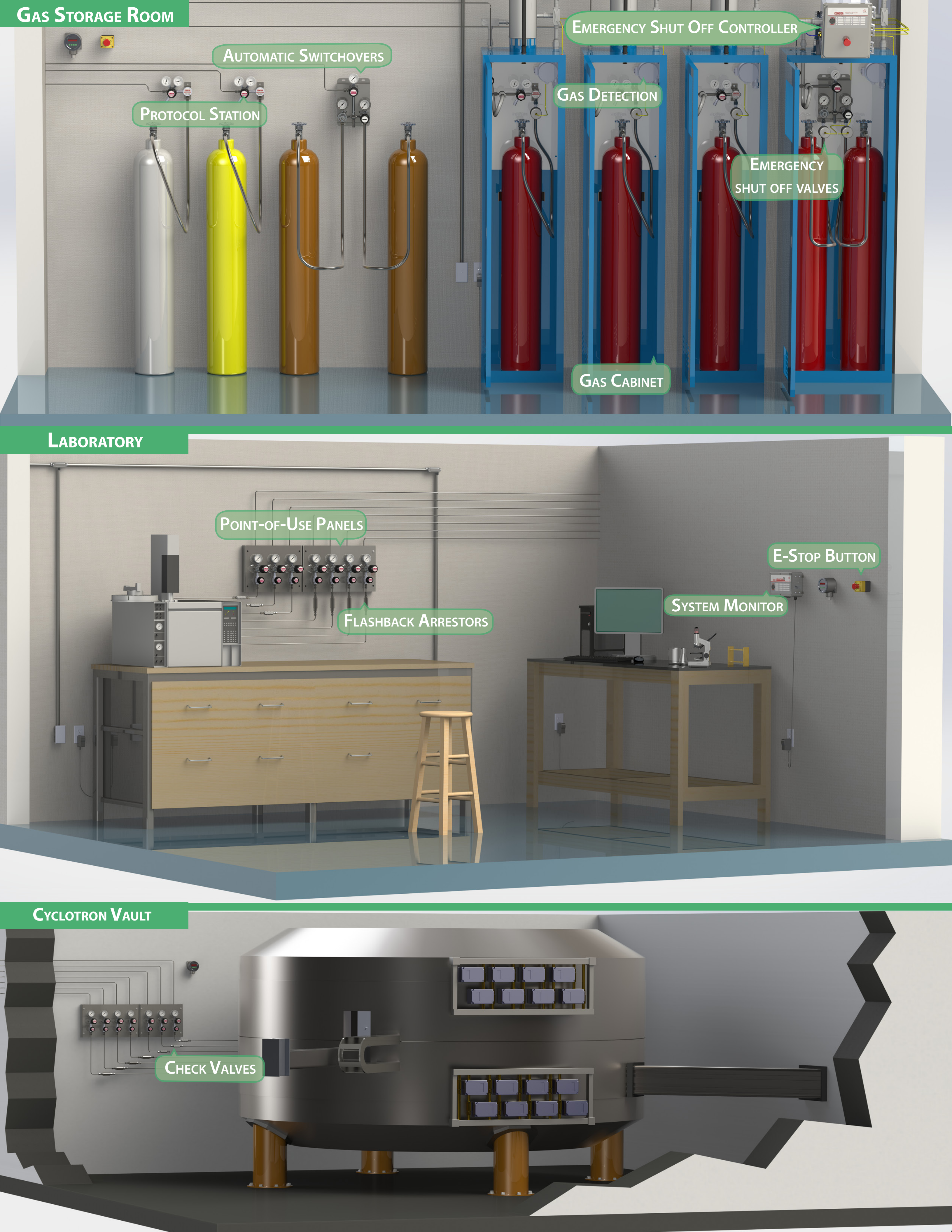
GAS DELIVERY SYSTEMS

As proton therapy continues to expand into traditional medical care facilities, cyclotrons have created new requirements for gas delivery systems beyond typical medical pipelines. Cyclotrons use highly flammable gases such as hydrogen, deuterium, methane, and propane in addition to highly toxic and reactive gases such as fluorine. Ultra-high purity gases are used in beam analysis while safeguards against radioactive contamination are required. CONCOA provides the high purity equipment necessary for the safe and compliant design, installation, and operation of cyclotron gas delivery systems.



CONCOA®

PRECISION GAS CONTROLS



Gas Storage Room
Automatic Switchovers
Emergency Shut Off Controller
Protocol Station
Gas Detection
Emergency
shut off valves
Gas Cabinet
Laboratory
Point-of-Use Panels
E-Stop Button
System Monitor
Flashback Arrestors
Cyclotron Vault
Check Valves

Cyclotron Gas Systems

Using highly charged particles to deliver a targeted dose of radiation to the patient, proton therapy has emerged as a primary means of effectively eradicating cancer cells. Producing these highly charged particles requires the use of a cyclotron, a particle accelerator that circulates particles outward from the center of the equipment using flammable, hazardous, and inert gases to transport, contain, and analyze the particles. To avoid cross contamination of radioactive material, these gases are supplied in separate delivery systems from the gas storage room to the cyclotron vault or the laboratory. The cyclotron vault houses the cyclotron that produces the particles and delivers them to an adjacent room directly to the patient, while the laboratory analyzes the gas composition to ensure optimal process conditions. Storing and transporting flammable, high purity, and hazardous gases necessitate the use of equipment in the gas system to ensure safety and the highest possible leak integrity.

Gas Storage Room

Common Cyclotron Gases		
Flammable	**Hazardous**	**Inert**
Hydrogen	Fluorine	Nitrogen
Methane	Ammonia	Argon
Propane		Helium
Deuterium		Air
		Neon

The gas storage room contains identical delivery systems individually supplying the cyclotron vault and laboratory using flammable, hazardous, and inert gases. Flammable gases such as hydrogen and deuterium must be contained in gas cabinets with excess flow switches on the downstream side and integral leak detectors in the cabinet. Gases requiring continuous delivery are supplied by 316L stainless steel automatic switchovers whereas those not requiring uninterrupted supply are delivered using dual-stage 316L stainless steel regulators with isolation valve on the outlet side. Flashback arrestors installed on the downstream side of all flammable gases are required to prevent the transmission of flame and possible reverse flow of radioactive material in the supply line.

Hazardous gases such as ammonia and fluorine, not typically requiring continuous delivery, must likewise be contained in gas cabinets. Gas delivery systems for fluorine, a highly reactive gas, require components that have been passivated to eliminate reaction with system components. Leak detection inside the cabinet is advisable; however, check valves installed on the downstream side of all hazardous gases are required. This will prevent possible backflow of radioactive material to the gas source. Likewise, connecting each of the gas sources to an emergency shutoff controller will automatically shut down gas flow at the source in the event of an elevated risk of fire. The emergency shutoff controller can be activated by safety monitors such as excess flow switches, leak detectors, and emergency stop buttons located anywhere from the gas source to the point of use.

Inert gases such as helium, nitrogen, and air do not require gas cabinet storage. Inert gases requiring uninterrupted supply require delivery from a 316L stainless steel switchover while those gases not requiring continuous supply can be supplied from a 316L stainless steel dual-stage regulator with protocol station. Check valves installed on the downstream side prevent possible backflow of radioactive material into the supply line.

Laboratory and Cyclotron Vault

Gases being delivered into the laboratory or cyclotron vault require point-of-use panels with 316L stainless steel single-stage regulators installed with isolation valves on the outlet side. For flammable gases such as hydrogen, deuterium, methane, and propane, flashback arrestors are required between the analyzer and point-of-use panel to eliminate flame transmission into the supply line and possible backflow of radioactive material. Similarly, hazardous and inert gases such as fluorine, air, nitrogen, and ammonia require stainless steel check valves between the analyzer and panel to mitigate hazardous material transmission into the supply line.

432 Series
Regulator with Protocol Station

527 Series
Automatic Switchovers

585 Series
Emergency Shut Off Controller

C Series
Gas Cabinets

54 Series
Point-of-Use Panels

532 Series
Flashback Arrestors & Check Valves

580 Series
Safety Monitors

586 Series
Emergency Shut Off Valves

Materials Compatibility and System Design in Cyclotron Gas Systems

Although typically located in medical facilities, systems for containment chamber and laboratory gases used to support and operate cyclotrons have vastly different requirements from those of traditional medical gas systems. The unique properties of ultra-high purity, flammable, and hazardous gases along with the potential for radiation from isotope generation demand robust materials of construction and safety devices for the gas delivery system. *Table 1* below summarizes the distinctions between cyclotron and traditional medical gas delivery systems.

Cyclotron Systems vs. Medical Gas Systems

Requirement	Cyclotron Systems	Medical Gas Systems
Regulator and valve seat materials	Polymer	Elastomer
Regulator and valve diaphragm material	316L stainless steel	Neoprene
Regulator and valve helium leak integrity	1×10^{-8} scc/sec (minimum)	Bubble-tight
Piping system	Orbital-welded 316L stainless steel pipe	Silver-brazed copper pipe
Leak detection	Excess flow switches and gas detection	Line pressure monitors
Emergency shutoff	Automatic	Manual

Regulations Affecting Cyclotron Gas Systems

Several national and international organizations provide extensive guidelines for the safe use of flammable gases in control areas, most prominently the National Fire Protection Association (NFPA) and the International Code Council (ICC). *Table 2* below summarizes the Maximum Allowable Quantities (MAQ) of flammable gas allowable in control areas based on whether the building has an approved automatic sprinkler system or whether all cylinders containing hazardous gases are in cabinets or both.

Floor Level	Unsprinklered building AND Not all cylinders in gas cabinets	Sprinklered building OR All cylinders in gas cabinets	Sprinklered building AND All cylinders in gas cabinets	Number of control areas per floor	Fire resistance rating for barriers
1 above grade	1000 scf / 150 lbs	2000 scf / 300 lbs	4000 scf / 600 lbs	4	1 hour
1 below grade	750 scf / 112.5 lbs	1500 scf / 225 lbs	3000 scf / 450 lbs	3	1 hour
2 below grade	500 scf / 75 lbs	1000 scf / 150 lbs	2000 scf / 300 lbs	2	1 hour

Table 2. **Maximum quantity of flammable gas allowable in a control area. Adapted from NFPA 55 (6.2.1, 6.3.1.1), IFC (5003.1.1), IBC (307.1)**

Based on the references below and decades of industry experience designing gas control systems, CONCOA makes the following general recommendations for the safe delivery of non-corrosive, flammable gases in laboratory and medical environments.

- Flammable gases shall be stored in and dispensed from gas cabinets containing not more than three cylinders of compatible gases, constructed of 12 gauge steel with self-closing doors, noncombustible windows, and an exhaust ventilation system designed to operate at a negative pressure relative to the surrounding area. (NFPA 55 6.17)
- Fail-safe emergency shut-off shall be provided at the source and points of use. For gases with a similar or greater flammability rating than hydrogen carried in pressurized piping above 15 PSIG, excess flow control shall be provided at the source. (IBC 5003.2)
- Leak detection shall be used at the source (and should be used in each point-of-use area if dispensed remotely) that provides audible and visual warning of danger and that automatically shuts down supply as the lower explosive limit is approached. (IFC 5303.16.10)
- To maintain purity, all shut-off valves and pressure regulators (including those in manifolds) shall use metal diaphragms. Pressure regulators with metal diaphragms shall be designed to withstand 10,000 cycles of operation without mechanical failure. (CGA E-4 4.6)

References

The information presented in this document addresses only guidelines related to CONCOA products and does not constitute the comprehensive code review required to specify a gas delivery system for cyclotron gases. For more information, consult the following publications, in addition to any local regulations.

National Fire Protection Agency (NFPA), 1 Batterymarch Park, Quincy, MA.
- NFPA 1, *Fire Code*, 2015 edition
- NFPA 2, *Hydrogen Technologies Code*, 2016 edition.
- NFPA 55, *Compressed Gases and Cryogenic Fluids Code*, 2016 edition.

American Society of Mechanical Engineers (ASME), Two Park Avenue, New York, NY.
- ASME A13.1, *Scheme for the Identification of Piping Systems*, 2007 edition.
- ASME B31.3, *Process Piping*, 2012 edition.
- ASME B31.12, *Hydrogen Piping and Pipelines*, 2011 edition.

Compressed Gas Association (CGA), 14501 George Carter Way, Suite 103, Chantilly, VA.
- CGA E-4, *Standard for Gas Pressure Regulators*, 2010 edition.
- CGA P-1, *Safe Handling of Compressed Gases in Containers*, 2015 edition.

International Code Council (ICC), 500 New Jersey Avenue, NW, 6th Floor, Washington, DC.
- *International Building Code* (IBC), 2012 edition (first printing).
- *International Fire Code* (IFC), 2012 edition (second printing).