Laboratory Flammable/Combustible Liquid
&
Compressed Gas Handling/Storage Procedure

1. Purpose and Scope
   1.1. This procedure describes methods for safely using, storing, and handling flammable and combustible liquids and compressed gases within laboratories.

   1.2. This procedure applies to all individuals participating in research or teaching conducted in a laboratory environment, including those conducted off-campus and at field sites as referenced in the Laboratory Integrated Safety Program (LISP) or who handle flammable and combustible liquids or compressed gases for laboratories.

2. Responsibilities - As described in the University's Laboratory Integrated Safety Program (LISP), PIs, administrators, and RM&S have duties and responsibilities associated with this policy; refer to the LISP. Additional responsibilities specific to this procedure are noted below.

   2.1. Risk Management and Safety shall maintain this procedure to regulatory and national consensus standards.

   2.2. University of Notre Dame's Fire Department shall be the authority having jurisdiction (AHJ) regarding flammable storage on the campus of the University of Notre Dame.

3. Definitions
   3.1. Combustible Liquid –A liquid having a closed cup flash point at or above 100°F (37.8°C). A list of common combustible liquids can be found here.
   - Class II liquids have flash points at or above 100°F (37.8°C) and below 140°F (60°C).
   - Class IIIA liquids have flash points at or above 140°F (60°C) and below 200°F (93°C).
   - Class IIIB liquids have flash points above 200°F (93°C).

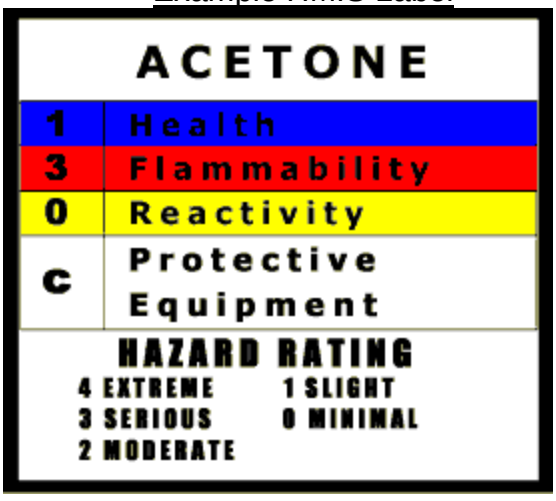
   3.2. Flammable Liquid - A liquid having a closed cup flash point below 100°F (37.8°C) and having a vapor pressure not exceeding 40 psi at 100°F. A list of common flammable liquids can be found here.
   - Class IA liquids have flash points below 73°F (22.8°C) and have a boiling point below 100°F (37.8°C).

- Class IB liquids have flash points below 73°F (22.8°) and have a boiling point above 100°F (37.8°C).
- Class IC liquids have flash points at or above 73°F (22.8°C) and below 100°F (37.8°C).

3.3. Hazardous Locations – These areas are separated by classes, divisions, and groups to define the level of safety required for electrical equipment installed in these locations. There are 3 classes of hazardous locations:
- Class I – Hazardous because flammable gases or vapors are present in the air in quantities sufficient to produce explosive or ignitable mixtures.
- Class II – Hazardous because combustible or conductive dusts are present.
- Class III – Hazardous because ignitable fibers or flyings are present, but not likely to be in suspension in sufficient quantities to produce ignitable mixtures. Typical wood chips, cotton, flax and nylon.

3.4. HMIS Rating System – The Hazardous Materials Identification System (HMIS) is a numerical hazard rating that incorporates the use of labels with color-coded bars. This is similar to the NFPA 704 System in that it also rates the health, fire and reactivity hazards of a chemical on a scale of 0-4 where zero is minimal hazard and four is an extreme hazard. The HMIS Rating System denotes the type of personal protective equipment (PPE) required for handling. It is denoted by the use of a rectangle that is divided into 5 sections, the blue health hazard, a red for fire hazard, a yellow for reactivity, and the white for special PPE.

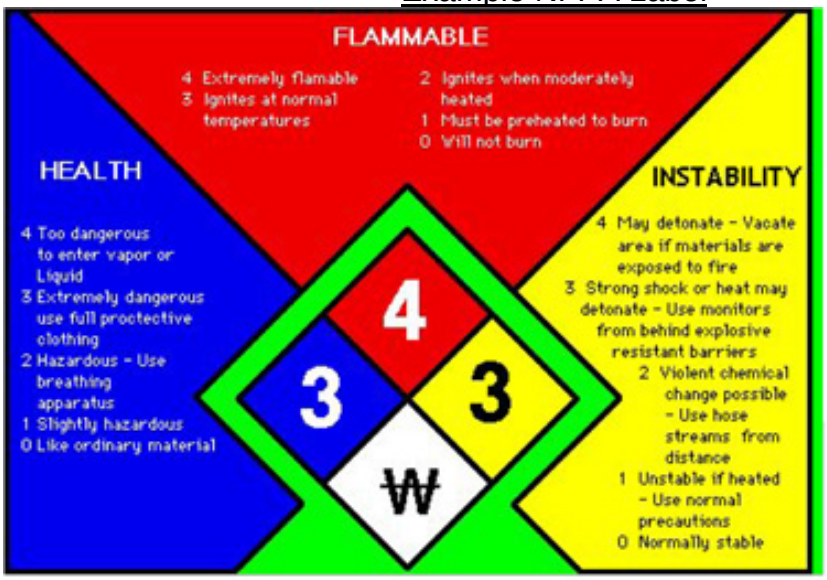
Example HMIS Label

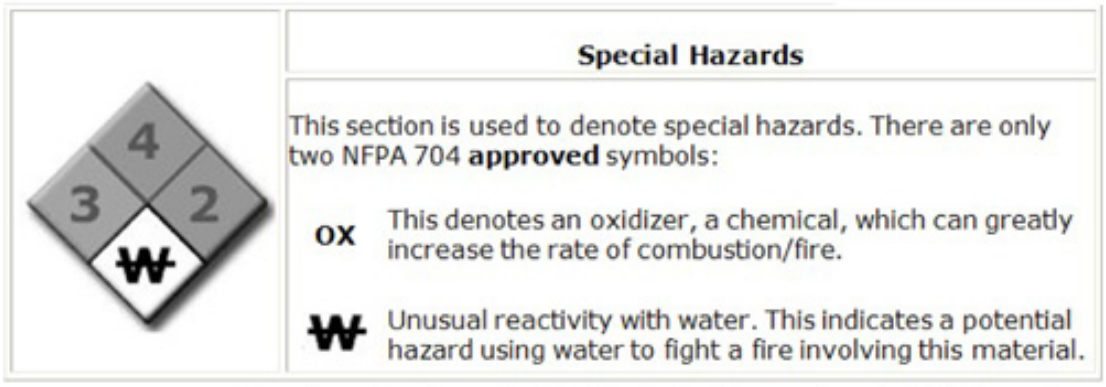


3.5. Laboratory – As defined in the Laboratory Integrated Safety Program (LISP).

3.6. NFPA 704 System – A hazards identification system developed by the National Fire Protection Association (NFPA). This system rates the health, fire and reactivity hazards of a chemical on a scale of 0-4 where zero is minimal hazard and four is an extreme hazard. In addition this system notes special hazards such as acids, alkalis, corrosives, oxidizers, radioactives, or water reactives. It is denoted by the use of a diamond that is divided into four boxes. The colors include: a blue box for health hazard, a red box for fire hazard, a yellow box for reactivity, and a white box for special hazards.

Example NFPA Label





4. Flammable and Combustible Liquid Handling and Storage Requirements

4.1. All flammable and combustible chemicals shall be stored in properly sealed, labeled containers. (Refer to Hazard Communication Plan)

4.2. Secondary containment shall be used whenever possible to minimize the flow of material during a spill or rupture.

4.3. Incompatible chemicals shall be stored separate from each other and isolated by distance or barriers to prevent intermingling in the event of an accidental spill. At a minimum, chemicals shall be separated according to similar hazards, such as flammability, corrosiveness, sensitivity to water or air, and toxicity. Review the Chemical Hygiene Plan for additional information and Table 3 in this document for segregation of compressed gas cylinders.

4.4. Table 1 shows the maximum container size of flammable and combustible liquids permitted by container type.

4.4.1. For teaching laboratories, additional restrictions on Class I or Class II liquid containers shall not exceed the following capacity:

- Safety cans – maximum of 2 gallons (8 L)
- All other containers – maximum of 1 gal (4 L) unless a smaller container is noted.

Table 1
Maximum Container Size
NFPA 45

	Flammable Liquid			Combustible Liquid	
Container Type	**IA**	**IB**	**IC**	**II**	**IIIA/B**
Glass	1 pt* 500 ml	1 qt* 1 L	1 gal 4 L	1 gal 4 L	5 gal 20 L
Metal (other than DOT Drums) or Approved Plastic	1 gal 4 L	5 gal 20 L	5 gal 20 L	5 gal 20 L	5 gal 20 L
Safety Cans (FM or UL)	2.5 gal 10 L	5 gal 20 L	5 gal 20 L	5 gal 20 L	5 gal 20 L
Metal Container (DOT Specifications)	1 gal 4 L	5 gal 20 L	5 gal 20 L	60 gal 227 L	60 gal 227 L
Polyethylene Container (DOT Specifications 34, UN 1H1, or as authorized by DOT Exemption)	1 gal 4 L	5 gal 20 L	5 gal 20 L	60 gal 227 L	60 gal 227 L

Table 1 Notes:
* Glass containers as large as one (1) gallon (3.78 L) may be used if the purity would be adversely affected by storage in a metal or an approved plastic container or if the liquid would cause excessive corrosion or degradation of a metal or plastic container.

Contact the University of Notre Dame's Fire Department (Authority Having Jurisdiction) and the Risk Management and Safety Department if alternative container sizes are required.

4.5. The maximum quantities of flammable and combustible liquids within a laboratory are limited based on the material classification and the laboratory's location and function. Refer to Table 2 for liquids.

Table 2
Maximum Quantities of Flammable and Combustible Liquids Permitted in Laboratories
Teaching Laboratories shall be limited to 50% of the quantities noted below.
NFPA 45 – Values represent a Low Fire Hazard Classification

	Quantities In Use Outside Flammable Storage Cabinets	Quantities In Use & Storage
Flammable & Combustible Liquid Classification (Includes waste)	Max Quantity per 100 ft^2	Max Quantity per 100 ft^2
I	2 Gal (7.5 L) Not to exceed 150 Gal (570 L) per lab	4 Gal (15 L) Not to exceed 300 Gal (1,136 L) per lab
I, II, and IIIA	4 Gal (15 L) Not to exceed 200 Gal (757 L) per lab	8 Gal (30 L) Not to exceed 400 Gal (1,515 L) per lab
Laboratories located on 4th and 5th floors shall reduce the quantities by 25%		

Table 2 Note – A laboratory with multiple rooms may be considered as one laboratory.

4.6. Flammable Liquid Storage Cabinets

4.6.1. Storage of chemicals inside cabinets – Class I flammable liquids shall not exceed 60-gallons and the total of Class I-III combustible liquids shall not exceed 120 gallons or the rated capacity of the cabinet whichever is less.

4.6.2. Not more than 3 storage cabinets shall be stored in any one laboratory. If additional storage is required, contact RMS for guidance. The NDFD shall be included as the AHJ.

4.6.3. Flammable cabinets do not need to be ventilated. If not vented the vent openings shall be sealed. If vented, the vent openings shall be equipped with spark arrestors. The supply and exhaust shall be ducted to the outside and the flow shall be installed with supply provided at the top and exhaust exiting at the bottom of the cabinet.

4.6.4. Grounding is not required unless Class IA flammable liquids are being dispensed from the cabinet. If grounding is necessary, the

cabinets shall be grounded to a static grounding terminal and not to the ground of an electrical receptacle.

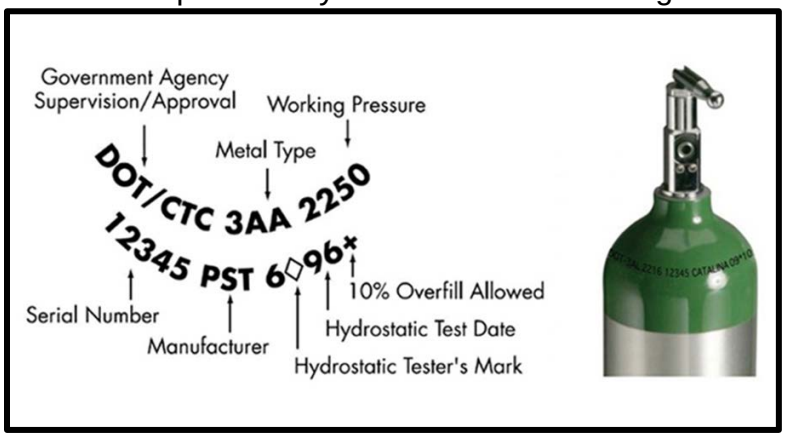
4.7. Refrigerator being used to store flammable liquids shall be rated as laboratory-safe or rated as a flammable material refrigerator/freezer.
  4.7.1. Explosion proof refrigerator/freezers shall be used for the storage of flammable liquids in hazardous locations.

4.8. Do not heat flammable and combustible liquids with an open flame. Preferred heat sources include hot plates, steam baths, water baths, oil and wax baths, salt and sand baths, heating mantles, and hot-air or nitrogen baths.

5. Cylinder Use, Storage and Transport

5.1. Do not accept shipment of cylinders unless:
  5.1.1. There is a hydrostatic test date stamped on the cylinder and it is within the last 5 years.
  5.1.2. There is a label identifying the cylinder's contents.
  5.1.3. There is a valve protection cap.

Example Gas Cylinder Shoulder Markings



5.2. Compressed Cylinder Storage
  5.2.1. Compressed gas cylinders, containers, and tanks shall be secured to prevent them from falling or being knocked over by corralling or securing them to a cart, framework, or fixed object by use of a restraint.
    - When securing cylinders use appropriate chain, plastic coated wire cable, cylinder straps, etc., at a point approximately 2/3 of the cylinder's height to a secure structure such as a wall.
    - If used, cloth straps are designed to secure only one cylinder.

- Cylinders less than 18 inches tall may be secured by stands or wall brackets.
- Cylinder carts shall only be used to secure a cylinder during transport not while the cylinder is in use or storage.
- Nesting of cylinders is not permitted. Cylinder Nesting is a method of securing cylinders in a tight mass using a contiguous three-point contact system where all cylinders in the group have at least three points of contact with other cylinders, walls, or bracing.

5.2.2. Cylinders shall be stored upright unless designed to be stored horizontal or have a capacity less than 1.3 gallons (5 L).

5.3. Cylinders shall be segregated by hazard class and empty cylinders shall be isolated from filled cylinders and where the cylinder is not subject to damage. When the cylinders are placed in storage they shall be separated as outlined in Table 3.

Table 3
Separation of Gas Cylinders by Hazard
NFPA 55

Gas Hazard Category	Non-Flammable	Oxidizing	Flammable	Pyrophoric	Toxic
Toxic	C	20 ft (6.1 m)	20 ft (6.1 m)	20 ft (6.1 m)	—
Pyrophoric	C	20 ft (6.1 m)	20 ft (6.1 m)	—	20 ft (6.1 m)
Flammable	C	20 ft (6.1 m)	—	20 ft (6.1 m)	20 ft (6.1 m)
Oxidizing	C	—	20 ft (6.1 m)	20 ft (6.1 m)	20 ft (6.1 m)
Non-Flammable	—	C	C	C	C

Table 3 Notes:
C = Compatible, no separation required.
The 20-ft (6.1 m) distance shall be permitted to be reduced without limit when separated by a barrier of noncombustible materials at least 5 ft (1.5 m) high that has a fire resistance rating of at least ½ hour.

5.4. Storage of flammable gas cylinders shall be stored a minimum distance of 20 feet (6.1 m) from the storage of flammable and combustible liquids or solids.

5.5. Stored cylinders shall have valve protection cap in place and stored away from heat sources and flame. Do not store cylinders in areas that may exceed 125 degrees Fahrenheit.

5.6. Storage Areas

5.6.1. Indoor storage areas of flammable or toxic gases shall be equipped with an exhaust ventilation system capable of providing

a minimum air movement of 1 cfm/ft^2 of floor area. Natural ventilation is acceptable if it prevents the accumulation of gases or vapors.

5.6.2. Outdoor storage of toxic gases shall be stored a minimum of 75 feet (22 m) from the property line. Outdoor storage areas shall be kept clear of vegetation and combustible material for a minimum distance of 15 feet (4.6 m). Cylinders shall not be placed on the ground (earth) or on surfaces where water can accumulate.

5.7. Lecture bottle sized cylinders of the following gases shall be kept in a continuously mechanically ventilated hood or other continuously mechanically ventilated enclosure:

5.7.1. All gases that have health hazard ratings of 3 or 4 (NFPA 704 or HMIS Rating).

5.7.2. All gases that have a health hazard rating of 2 (NFPA 704 or HMIS Rating) without physiological warning properties.

5.7.3. Pyrophoric gases – In addition to a mechanically ventilated cabinet, the gas cabinet shall be equipped with fire suppression e.g., sprinkler head.

5.8. Cylinders of all gases that are greater than lecture bottle size and have health hazard ratings of 3 or 4 (NFPA 704 or HMIS Rating) and cylinders of gases that have a health hazard rating of 2 (NFPA 704 or HMIS Rating) without physiological warning properties (e.g., lack of odor) shall be stored in gas cabinets that are continuously mechanically ventilated.

5.9. System Design Rules

5.9.1. Dedicated high pressure purge gas cylinders shall be used for compatible groupings of highly toxic or pyrophoric gases.

5.9.2. Purge gas cylinders shall only be shared between compatible gases.

5.9.3. Piping/tubing through a wall shall be sleeved to physically protect them.

5.9.4. Piping/tubing hidden behind walls, ceilings or floors shall be welded. There should be no hidden mechanical connections.

5.9.5. Piping shall be designed for a pressure greater than the maximum system pressure that can be developed under abnormal conditions.

5.10. General cylinder safety requirements

5.10.1. Cylinders shall be equipped with a pressure regulator appropriate for the gas and marked for its maximum cylinder pressure.

5.10.2. The regulator system shall be equipped with two gauges, either on the regulator or remote from the regulator, installed so as to show both the cylinder pressure and the outlet pressure.
5.10.3. Cylinders shall have a shutoff valve. A quick connect shall not be used in place of a shutoff valve.
5.10.4. Maintenance of the containers, valves, regulators or pressure relief devices shall be performed only by the manufacturer's authorized individual.
5.10.5. Color coding shall not be relied upon to identify contents of a cylinder.
5.10.6. A manufacturer label or other label providing the cylinder content name and hazards shall be affixed to all cylinders. (Refer to Hazard Communication Plan)
5.10.7. Cylinders shall only be moved using a suitable hand truck or cart.
5.10.8. Properly designed carts shall only be used for a maximum of 2 cylinders.
5.10.9. Teflon tape or pipe thread may not be used on any cylinder.
5.10.10. Gas systems set up for one type of gas may not be used for other services unless formally reviewed and approved by PI and/or department safety committee as appropriate. RMS is available for consultation.
5.10.11. Additional cylinder safety requirements are noted in the University of Notre Dame's Chemical Hygiene Plan.
5.10.12. The maximum number of lecture bottles per any one laboratory is 25 except teaching laboratories shall be limited to a maximum of 10 lecture bottles.

6. Gases with Special Handling and Storage Requirements.

6.1. Fluorine
6.1.1. Strong fluorine gases may only be used that have been oxygen cleaned and fluorine passivated. Passivation is a process that makes a system less vulnerable to corrosion.
6.1.2. Use a buddy system when changing highly toxic or pyrophoric gas cylinders.

6.2. Hydrogen and Acetylene (Extremely Flammable Gases)
6.2.1. High pressure releases of hydrogen almost always ignite and burns without a visible flame.
6.2.2. Proper system grounding and bonding and use of intrinsically safe electrical devices is required.
6.2.3. Equipment that comes into contact with hydrogen shall be inspected routinely for brittleness and/or fractures.

6.2.4. Because hydrogen will permeate to the exterior surface, non-metal tubing shall not be used.

6.3. Oxygen

6.3.1. Equipment for use with oxygen must be properly designed, cleaned, and maintained.

- Valves shall be opened slowly to avoid adiabatic compression heat which is the rise in gas temperature as the pressure of the gas increases.
- Systems shall be made with compatible materials.
  - Flammable tubing such as polyethylene (PE) is unsafe to use. It can readily ignite and burn with high energy output. Most materials become more flammable as pressures increase.
  - Since nearly all polymer materials are flammable in 100 percent oxygen at atmospheric pressure, their use is not recommended.
- Systems shall be marked and dedicated for oxygen service:
  - Surface contaminates in the system including oil or metals may result in oxygen fires.
  - Metals such as aluminum or titanium shall not be used in high pressure oxygen surface.
  - Use of a CGA (Compressed Gas Association) connector with non-oxygen systems can result in accident or fire.

6.3.2. Incompatible contaminants in oxygen systems that may act as initial fuel sources in a fire include:

- Machining oils
- Hydrocarbon based grease and lubricants
- Soaps, solvents, detergents and cleaning solutions that contain organic compounds.
- Skin lotions, emollients, and cosmetics
- Human skin oil and body fluids
- Insects and insect body parts
- Paint, wax, and marking crayons
- Carbon dust from filtration systems
- Metal fines, filings, scale, and burrs
- Chrome chips
- Dust
- Metallic oxides
- Airborne soot

- Pipe thread and sealants
- Residue from soapy water and leak detection fluids used to check for leaks.
- Lint from cloths used in cleaning
- Any other material containing organic compounds and hydrocarbons

6.3.3. An oxygen compatibility assessment should be completed prior to setting up a system using O_2. It should give consideration to the following criteria:

- Identify the worst case operating conditions.
- Assess the flammability of system materials.
- Evaluate the presence and probability or ignition mechanisms.
- Determine the kindling chain, which is the potential for a fire to breach the system.
- Analyze the reaction effect, which is the potential loss of life, mission, and system functionality as a result of a fire.
- Identify the history of use.

7. Training – Personnel handling cylinders shall be properly trained. This shall include a review of the contents of this procedure and completion of the General Laboratory Safety training.

8. Evaluation
   8.1. This procedure shall be reviewed through the Joint Assessment process to ensure compliance and understanding.

   8.2. This procedure shall be reviewed at least bi-annually by RMS? to ensure the requirements stay current with regulations and national consensus standards.

9. References
   9.1. National Fire Protection Association (NFPA) – NFPA 30 Flammable and Combustible Liquids Code
   9.2. National Fire Protection Association (NFPA) – NFPA 45 Standard on Fire Protection for Laboratories Using Chemicals
   9.3. National Fire Protection Association (NFPA) – NFPA 55 Standard for the Storage, Use, and Handling of Compressed and Liquefied Gases in Portable Cylinders, 1998 Edition
   9.4. Occupational Safety and Health Administration, 29 CFR 1910.1450 Occupational Exposure to Hazardous Chemicals in Laboratories
   9.5. Occupational Safety and Health Administration, 29 CFR 1910.101 Compressed Gases (General Requirements)

9.6. Occupational Safety and Health Administration, 29 CFR 1910.106 Flammable Liquids
9.7. *Prudent practices in the laboratory handling and management of chemical hazards*. Updated ed. Washington, D.C.: National Academies Press, 2011. Print.
9.8. University of California Center for Laboratory Safety (2016) *Report to the University of Hawaii at Manoa on the Hydrogen/Oxygen Explosion of March 16, 2016 Report 2: Recommendations for Improvements in UH Laboratory Safety Programs*

Revision History Table

History	Effective Date
Gas Cylinder Marking Diagram (Section 5.1)	8/18/2016
Changed to bullet points (Section 5.2.1)	8/18/2016
Added section on system design (5.9)	8/18/2016
Added section 5.10.9-13	8/18/2016
Added Specialty gases (Section 6)	8/18/2016
Added reference 9.8	8/18/2016