UCCS Environmental
Health and Safety
UNIVERSITY OF COLORADO
COLORADO SPRINGS

HANDLING AND STORAGE OF HAZARDOUS MATERIALS

Contents

This document is intended to provide an overview of various groups of hazardous materials and the proper storage and handling requirements for those materials.

Refer to the following documents for additional information. https://ehs.uccs.edu/hazardous-materials-management/hmmp

Appendix A - Glossary of Hazardous Materials Hazard Terms.

Appendix B – Classification of Hazardous Materials

Appendix C - ***Toxicity and Hazard Exposure Assessment*** General Storage

Use and storage of hazardous materials is regulated by federal, state, and local regulations. These regulations include OSHA worker protection standards, emergency response and planning regulations and local building and fire codes. Each of these place limitations on:

- how much materials can be stored in an area
- how much materials can be in use in an area
- where the materials can be stored, or
- how the materials can be stored.

1 Storage Limits

The allowable quantities (both in use and in storage) per IFC are presented in tables 1-4 below. Allowable quantities are based on control areas, defined as "spaces within a building which are enclosed and bounded by exterior walls, fire walls, fire separation assemblies and roofs, or a combination thereof, where quantities of hazardous materials not exceeding the exempt amounts are stored, dispensed, used or handled." Although the code limits appear straightforward, application of the code can be more complicated due to the following:

- While quantities are based on control areas, these may consist of more than one laboratory and the boundary of a control area is not obvious;
- Building features, such as the presence of sprinklers, can affect the allowable quantities;
- The quantities allowed are also dependent on the specific floor the laboratory is located. Generally, the higher the floor level the lower the allowable quantity per control area.
- Also, the number of allowable control areas decrease the higher the floor level;

Due to the complexities of the standards and the university's need to remain compliant with these regulations it is the university's policy that every effort be made to minimize the quantity of hazardous materials within campus buildings.

The tables in this section attempt to portray the limits that are imposed by the codes mentioned above. The maximum allowable quantities (MAQs) listed below are per control area. An individual room is not necessarily a control area – it likely consists of more than one room and in many cases is an entire floor. These limits are therefore guidelines since it is beyond the scope of this document to provide information on each campus building.

Table 1. provides a list of MAQs based on the class of material. The MAQs are defined below for the ground floor level (floor 1). Higher level floors and below grade floors decrease the MAQ as indicated in Table 2. The table includes storage limits and limits for usage in an open or closed system. IFC defines "open" and "closed" systems as the following:
OPEN SYSTEM. The use of a solid or liquid hazardous material involving a vessel or system that is continuously open to the atmosphere during normal operations and where vapors are liberated, or the product is exposed to the atmosphere during normal operations. Examples of open systems for solids and liquids include dispensing from or into open beakers or containers, dip tank and plating tank operations.

CLOSED SYSTEM. The use of a solid or liquid hazardous material involving a closed vessel or system that remains closed during normal operations where vapors emitted by the product are not liberated outside of the vessel or system and the product is not exposed to the atmosphere during normal operations; and all uses of compressed gases. Examples of closed systems for solids and liquids include product conveyed through a piping system into a closed vessel, system or piece of equipment.

Additional definitions are supplied in Appendix A ***Glossary of Hazardous Materials Hazard Terms***.

When viewing Table 1 note the footnotes below the Tables. These indicate building or containment features that may increase the MAQs or, in some instances, are required. Also, the aggregate quantity in use and storage cannot exceed the quantity listed for storage. Table 1 assumes the room is on the ground floor.

Table 1: International Fire Code (IFC 2015) Maximum Allowable Quantities (MAQ) In Storage per Fire Control Areas

Hazardous Material	Class	Storage	Use (closed system)	Use (open system)
Flammable Liquid (gallons)	IA	30[1,2]	30[1,2]	10[1]
	IB or IC	120[1,2]	120[1]	30[1]
	Combination of IA, IB, IC	120[1,2]	120[1]	30[1]
Combustible liquids (gallons)	II	120[1,2]	120[1]	30[1]
	IIIA	330[1,2]	330[1]	80[1]
	IIIB	13,200[2,4]	13,200[2,4]	3,300[4]
Flammable gas, gaseous (cubic feet)		1000[1,2]	1000[1,2]	NA
Flammable gas, liquefied (pounds)		150[1,2]	150[1,2]	NA
Flammable solid (pounds)		125[1,2]	125[1]	25[1]
Cryogenics, flammable (pounds)		45[1]	45[1]	10[1]
Cryogenics, oxidizing (pounds)		45[1]	45[1]	10[1]
Organic peroxides (pounds)	UD	1[2,4]	0.25[4]	0.25[4]
	I	5[1,2]	1[1]	1[1]
	II	50[1,2]	50[1]	10[1]
	III	125[1,2]	125[1]	25[1]
Highly Toxic gases, gaseous (cubic feet)		20[1,3]	20[1,3]	NA

Hazardous Material	Class	Storage	Use (closed system)	Use (open system)
Highly Toxic gases, liquefied (pounds)		$4^{1,3}$	$4^{1,3}$	NA
Highly Toxic liquids or solids (pounds)		$10^{1,2}$	10^{1}	3^{1}
Toxic gases, gaseous (cubic feet)		$810^{1,2}$	$810^{1,2}$	NA
Toxic gases, liquefied (pounds)		$150^{1,2}$	$150^{1,2}$	NA
Toxic liquids or solids (pounds)		$500^{1,2}$	500^{1}	125^{1}
Oxidizing gas, gaseous (cubic feet)		$1500^{1,2}$	$1500^{1,2}$	
Oxidizing gas, liquefied (pounds)		$150^{1,2}$	$150^{1,2}$	
Pyrophoric solids or liquids (pounds)		$4^{2,4}$	1^{4}	0
Pyrophoric gases (cubic feet)		$50^{2,4}$	$10^{2,4}$	0
Unstable (reactive)	4	$1^{2,4}$	0.25^{4}	0.25^{4}
solids or liquids	3	$5^{1,2}$	1^{1}	1^{1}
(pounds)	2	$50^{1,2}$	50^{1}	10^{1}
Unstable (reactive)	4	$10^{2,4}$	$2^{2,4}$	
Gases (cubic feet)	3	$50^{1,2}$	$10^{1,2}$	
	2	$750^{1,2}$	$750^{1,2}$	
Water reactive	3	$5^{1,2}$	5^{1}	1^{1}
(pounds)	2	$50^{1,2}$	50^{1}	10^{1}
Corrosive, solids (pounds)		$5000^{1,2}$	5000^{1}	1000^{1}
Corrosive, liquids (gallons)		$500^{1,2}$	500^{1}	100^{1}
Corrosive, gases (cubic feet)		810^{1}	810^{1}	
Corrosive, liquified gas (pounds)		150^{1}	150^{1}	

NA = Not applicable; a cubic foot = 0.0283 m^3; 1 pound = 0.454 kg.; 1 gallon = 3.785 L.

1. Maximum quantities shall be increased 100% for buildings equipped throughout with an automatic sprinkler. Where note 2 also applies the increase for both notes are to be applied accumulatively.
2. Maximum allowable quantities are to be increased up to 100% when stored in approved storage cabinets, gas cabinets, exhausted enclosures or safety cans as specified in IFC. Where note 1 also applies the increase for both notes are to be applied accumulatively.
3. Allowed only when stored in approved exhausted gas cabinets or exhausted enclosures as specified in

the International Fire Code.
4. Permitted only in buildings equipped throughout with an automatic sprinkler system.

Additional Notes:

- For chemicals that fit into multiple categories, the most restrictive limits apply

The MAQs defined in Table 1 are defined for first floor occupancies. Other floors (both above and below grade) have lower MAQs based on a percentage of the 1st floor MAQ. Table 2 provide these percentages as well as the number of allowable control areas per floor.

Table 2: % MAQs and No. of Control Areas by Floor

Floor Level	% of MAQ per Control Area	No. of Control Areas
1	100	4
2	75	3
3	50	2
4 through 6	12.5	2
Below Grade Level 1	75	1
Below Grade Level 2	50	1

NFPA 45 Standard on Fire Protection for Laboratories Using Chemicals sets limits on the quantities of flammable and combustible liquids that can be stored in any one container based on the construction of the container. Aggregate quantities must still be below the amounts indicated by Tables 1 and 2

Table 3. Maximum Allowable Size of Containers

Container Type	***Flammable Liquids***			***Combustible Liquids***	
	Class IA	Class IB	Class IC	Class II	Class III
Glass or approved plastic	1 pt.	1 qt.	1 gal.	1 gal.	1 gal.
Metal (other than DOT drums)	1 gal.	5 gal.	5 gal.	5 gal.	5 gal.
Safety cans	2 gal.	5 gal.	5 gal.	5 gal.	5 gal.
Metal drums (DOT specifications)	60 gal.	60 gal.	60 gal.	60 gal.	60 gal.
Approved portable tanks	660 gal.	660 gal.	660 gal.	660 gal.	660gal.

The following chart lists the maximum volume of flammables and combustibles that can be stored in a single flammable storage cabinet. Again, quantities in each control area cannot exceed MAQs listed above.

Table 4. Maximum Storage Quantities for a Flammable Storage Cabinet

MAXIMUM STORAGE QUANTITIES FOR CABINETS	
Liquid Class	***Maximum Storage Capacity***
Flammable/Class I	60 Gal.
Combustible/Class II	60 Gal.
Combustible/Class III	120 Gal.
Combination of classes	120 Gal.

Not more than 60 gallons may be Class I and Class II liquids. No more than 120 gallons of Class III liquids may be stored in a storage cabinet, according to OSHA 29 CFR 1910.106(d)(3) and NFPA 30 Section 4-3.1.

2 Hazardous Material Compatibility and Safe Storage

In addition to hazardous material storage limitations imposed by regulations and codes, each person is responsible for following prudent storage practices of hazardous materials. This includes separating incompatible hazardous materials and disposing of unstable compounds (such as peroxide formers) after their indicated expiration date. Hazardous materials must be grouped according to their hazard category (i.e. strong acids, strong bases, oxidizers, flammables, pyrophorics, self-reactives, etc.).

Avoid the hazards of hazardous material incompatibility. Incompatible hazardous material mixtures can cause violent reactions, explosions, fires or generate toxic gases. Containers that are incompatible with their contents can leak or catastrophically fail. In a fire or other disaster, containers break, and hazardous materials could combine to fuel a fire or react to injure emergency responders. Address hazardous material incompatibility hazards from three perspectives:

- Containment: proper containers and closures prevent leaks and releases.
- Storage: keep any aqueous acids away from cyanide salts.
- Mixing: oxidizers, acids, or reactives should not be mixed together in a flammable solvent waste container.

Because of the scope and complexity of this topic, this section is not meant to be comprehensive. For more information consult Bretherick's Handbook of Reactive Chemical Hazards, Fourth Edition (L. Bretherick, Butterworth's, London 1990), and NFPA 491, Guide to Hazardous Chemical Reactions, 1997 Edition, or call the American Chemical Society's Health and Safety Referral Service (1-800-227-5558). This ACS service keeps records of chemical accidents and incompatibility incidents that have been reported in Chemical and Engineering News.

When certain hazardous chemicals are stored or mixed together, violent reactions may occur because the chemicals are unsuitable for mixing or are incompatible. Classes of incompatible chemicals should be segregated from each other during storage, according to hazard class. Always store chemicals by recommended compatible storage group. Alphabetical storage is only used within a compatible storage group, never as a chemical storage plan

No single method of determining chemical compatibility is perfect. The reasons for this are varied and include:

- Many chemicals belong to more than one hazard class. This can lead to confusion as to which class is appropriate for the chemical in question. Examples: Nitric acid is both an acid and an oxidizer; Benzoyl chloride is a combustible liquid, a corrosive, and a lachrymator.
- The hazard class that is most important can change depending on factors such as quantity of material, and other chemicals in the storage area.
- Not all chemicals in each class are compatible. For example, sodium dichloroisocyanurate and calcium hypochlorite are both oxidizers and belong to no other class of chemical, yet the mixing of these two materials can lead to the formation of nitrogen trichloride, a shock sensitive explosive.
- Rigid adherence to a classification scheme often leads to inefficient work practices. An example is the prohibition of storing acids and bases together. While this is a good practice, it is not practical when one has numerous dilute solutions, as in atomic absorption standards made up in both dilute nitric acid and dilute ammonium hydroxide. Clearly, mixing of these acid and base solutions will not result in a hazardous reaction, and forcing workers to store such standards separately is inconvenient and unnecessary.
- The sheer number of exceptions to any classification scheme prevents listing all of them in a convenient reference table.

Relying solely on compatibility classification schemes might provide a false sense of security and it is important that those working with chemicals and those responsible for using and maintaining chemical storage facilities be familiar with the limitations of the classification system and the properties of the materials they are working with.

The following guidelines are provided for the safe storage of hazardous materials in accordance with their hazard classes

Acids:

- Segregate acids from reactive metals such as sodium, potassium, magnesium, etc.
- Segregate oxidizing acids (e.g., nitric acid) from organic acids, flammable and combustible materials.
- Segregate acids from chemicals which could generate toxic or flammable gases upon contact, such as sodium cyanide, iron sulfide, etc.
- Segregate acids from bases.

Bases:

- Segregate bases from acids, metals, organic peroxides and easily ignitable materials.

Solvents (Flammable and Halogenated Solvents):

- Segregate from oxidizing acids and oxidizers.

- Keep away from any source of ignition (heat, sparks, or open flames).

Oxidizers:
- Store in a cool, dry place.
- Keep away from combustible and flammable materials.
- Keep away from reducing agents such as zinc, alkali metals, and formic acid.

Water Reactive Chemicals:
- Store in a cool, dry place away from any water source.
- Make certain that a Class D fire extinguisher is available in case of fire.

Pyrophoric Substance:
- (Materials which will react with the air to ignite when exposed, e.g., white phosphorus or tert-Butyl Lithium.)
- Store in a cool, dry place making provisions for an airtight seal.

Peroxide Forming Chemicals:
- Store in airtight containers in a dark, cool, and dry place.
- Label containers with receiving, opening, and disposal dates.
- Periodically test for the presence of peroxides.

Organic Peroxides:
- Store in area such as a refrigerator where the temperature will remain below the self-accelerating decomposition temperature.

The table below shows combinations of some of the more commonly encountered chemicals that should be avoided. Before mixing any chemicals, refer to this partial list, the chemicals' MSDS, or call the Office of Environmental Health and Safety to verify compatibility

Table 4: Specific Chemical Incompatibilities

Chemical	Kept Out of Contact With:
Acetic Acid	Chromic acid, nitric acid hydroxyl compounds, ethylene, glycol, perchloric acid, peroxides, permanganates
Acetone	Concentrated nitric and sulfuric acid mixtures
Acetylene	Chlorine, bromine, copper, fluorine, silver, mercury
Alkali Metals	Water, carbon tetrachloride or other chlorinated hydrocarbons, carbon dioxide, the halogens
Ammonia, anhydrous	Mercury, chlorine, calcium hypochlorite, iodine, bromine, hydrofluoric acid
Ammonium Nitrate	Acids, metal powders, flammable liquids, chlorates, nitrites, sulfur, finely divided organic or combustible materials
Aniline	Nitric acid, hydrogen peroxide
Arsenical materials	Any reducing agent
Azides	Acids
Bromine	Same as chlorine
Calcium Oxide	Water

Carbon (activated)	Calcium hypochlorite, all oxidizing agents.
Carbon tetrachloride	Sodium
Chlorates	Ammonium salts, acids, metal powders, sulfur, finely divided organic or combustible materials
Chromic Acid	Acetic acid, naphthalene, camphor, glycerin, turpentine, alcohol, flammable liquids in general
Chlorine	Ammonia, acetylene, butadiene, butane, methane, propane (or other petroleum gases), hydrogen, sodium carbide, turpentine, benzene, finely divided metals
Chlorine Dioxide	Ammonia, methane, phosphine, hydrogen sulfide
Copper	Acetylene, hydrogen peroxide
Cumene Hydroperoxide	Acids, organic or inorganic
Cyanides	Acids
Flammable Liquids	Ammonium nitrate, chromic acid, hydrogen peroxide, nitric acid, sodium peroxide, halogens
Hydrocarbons	Fluorine, chlorine, bromine, chromic acid, sodium peroxide
Hydrocyanic Acid	Nitric acid, alkali
Hydrofluoric Acid	Ammonia, aqueous or anhydrous
Hydrogen Peroxide	Copper, chromium, iron, most metals or their salts, alcohols, acetone, organic materials, aniline, nitromethane, flammable liquids, oxidizing gases
Hydrogen Sulfide	Fuming nitric acid, oxidizing gases, acetylene, ammonia (aqueous or anhydrous), hydrogen
Hypochlorites	Acids activated carbon
Iodine	Acetylene, ammonia (aqueous or anhydrous), hydrogen
Mercury	Acetylene, fulminic acid, ammonia
Nitrates	Sulfuric acid
Nitric Acid (concentrated)	Acetic acid, aniline, chromic acid, hydrocyanic acid, hydrogen sulfide, flammable liquids, flammable gases
Nitrites	Acids
Nitroparaffins	Inorganic bases, amines
Oxalic Acid	Silver, mercury
Oxygen	Oils, grease, hydrogen; flammable liquids, solids, or gases
Perchloric Acid	Acetic anhydride, bismuth and its alloys, alcohol, paper, wood
Peroxides, organic	Acids (organic or mineral), avoid friction, store cold
Phosphorus (white)	Air, oxygen, alkalis, reducing agents
Potassium	Carbon tetrachloride, carbon dioxide, water
Potassium Chlorate	Sulfuric and other acids
Potassium Permanganate	Glycerin, ethylene glycol, benzaldehyde, sulfuric acid
Selenides	Reducing agents
Silver	Acetylene, oxalic acid, tartaric acid, ammonium compounds
Sodium	Carbon tetrachloride, carbon dioxide, water
Sodium nitrite	Ammonium nitrate and other ammonium salts
Sodium Peroxide	Ethyl or methyl alcohol, glacial acetic acid, acetic anhydride, benzaldehyde, carbon disulfide, glycerin, ethylene glycol, ethyl acetate, methyl acetate, furfural
Sulfides	Acids
Sulfuric Acid	Potassium chlorate, potassium perchlorate, potassium permanganate (or compounds with similar light metals, such as sodium, lithium, etc.)

Tellurides	Reducing agents

Table 5: Incompatibilities by Groups

Group	Name	Example	Incompatible groups																						
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1	Inorganic Acids	Hydrochloric acid Hydrofluoric acid Hydrogen chloride Hydrogen fluoride Nitric acid Sulfuric acid Phosphoric acid		2	3	4	5	6	7	8		10			13	14		16	17	18	19		21	22	23
2	Organic acids	Acetic acid Butyric acid Formic acid Propionic acid	1		3	4			7							14		16	17	18	19			22	
3	Caustics	Sodium hydroxide Ammonium hydroxide solution	1	2				6	7	8					13	14	15	16	17	18		20			23
4	Amines and Alkanolamines	Aminoethyl ethanolamine Aniline Diethanolamine Diethylamine Dimethylamine Ethylenediamine 2-Methyl-5-ethylpyridine Monoethanolamine Pyridine Triethanolamine Triethylamine Triethylenetetramine	1	2			5		7	8						14	15	16	17	18					23
5	Halogenated Compounds	Allyl chloride Carbon tetrachloride Chlorobenzene Chloroform Methylene chloride Monochlorodifluoromethane 1,2,4-Trichlorobenzene 1,1,1-Trichloroethane Trichloroethylene Trichlorofluoromethane	1		3	4							11			14			17						
6	Alcohols Glycols Glycol Ether	1,4-Butanediol Butanol (iso, n, sec, tert) Diethylene glycol Ethyl alcohol Ethyl butanol Ethylene glycol Furfuryl alcohol Isoamyl alcohol Methyl alcohol Methyl amyl alcohol Propylene glycol	1						7							14		16				20			23
7	Aldehydes Acetaldehyde	Acrolein Butyraldehyde Crotonaldehyde Formaldehyde Furfural Paraformaldehyde Propionaldehyde	1	2	3	4		6		8							15	16	17		19	20			23
8	Ketones	Acetone Acetophenone Diisobutyl ketone Methyl ethyl ketone	1		3	4			7												19	20			

Group	Name	Example	Incompatible groups																						
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
9	Saturated Hydrocarbons	Butane Cyclohexane Ethane Heptane Paraffins Paraffin wax Pentane Petroleum ether																				20			
10	Aromatic Hydrocarbons	Benzene Cumene Ethyl benzene Naphtha Naphthalene Toluene Xylene	1																			20			
11	Olefin	Butylene 1-Decene 1-Dodecene Ethylene Turpentine	1				5															20			
12	Petroleum Oils	Gasoline Mineral Oil																				20			
13	Esters	Amyl acetate Butyl acetates Castor oil Dimethyl sulfate Ethyl acetate	1		3	4															19	20			
14	Monomers Polymerizable Esters	Acrylic acid Acrylonitrile Butadiene Acrylates	1	2	3	4	5	6									15	16			19	20	21		23
15	Phenol	Carbolic acid Creosote Cresols Phenol			3	4			7							14		16			19	20			
16	Alkylene Oxides	Ethylene oxide Propylene oxide	1	2	3	4		6	7							14	15		17	18	19				23
17	Cyanohydrins	Acetone cyanohydrin Ethylene cyanohydrin	1	2	3	4	5		7									16			19				23
18	Nitriles	Acetonitrile Adiponitrile	1	2	3	4												16							23
19	Ammonia	Ammonium Hydroxide Ammonium Gas	1	2					7	8					13	14	15	16	17			20			23
20	Halogens	Chlorine Fluorine			3			6	7	8	9	10	11	12	13	14	15				19		21	22	
21	Ethers	Diethyl Ether THF	1													14						20			
22	Phosphorus	Phosphorus, Elemental	1	2	3																	20			
23	Acid Anhydrides	Acetic anhydride Propionic anhydride	1		3	4		6	7							14		16	17	18	19				

2.1 Containment to Prevent Hazards

Use the right container for the job to keep your hazardous materials safe. Use secondary containment whenever possible. Follow these general guidelines for safe containment of hazardous materials:

- Use containers that are compatible with their contents. The hazardous material should not react with the container material or cap liner. For example, do not store hydrofluoric acid in a glass container. Whenever possible, store hazardous materials in their original containers; transfer hazardous materials only to containers made of like materials.

- Buy smaller quantities. Smaller quantities make safe storage easier, and simultaneously encourages waste minimization. Additionally, smaller bottles are less prone to break when accidentally dropped.
- Use safety cans for storage of flammable liquids. Fire codes allow only 38 liters (10 gallons) of flammable liquids in a lab if stored in conventional containers. But, if stored in UL-approved safety cans or a flammable liquid storage cabinet, up to 76 liters (20 gallons) may be stored in a single fire area (i.e., a fire area may be more than one lab rooms; ask EHS for an evaluation).
- Whenever possible, purchase materials in coated bottles.
- Make sure that all containers are properly labeled.
- Inspect your hazardous material stocks periodically to make sure the containers are sound, and labels are intact.

Some hazardous materials require special devices such as vent caps for alleviating pressure buildup. Dibenzoyl peroxide, for example, requires a container that is non-rigid to prevent shock transfer, has a non-threaded cap to prevent friction when opening and is resistant to static electricity buildup; all these precautions may help to prevent an explosion

Differentiating between glass and plastic for chemical storage is intuitive; selecting the most compatible plastic, well, that’s another story. Labware is constructed from a variety of polymers — polyethylene (low and high density), polypropylene, PVC, etc. — possessing unique and varying degrees of resistance to the laundry list of chemicals. To maintain the structural integrity of the chemical containers and ensure safe handling, please consult the chemical resistance tables before transferring materials.

Table 6: Chemical Resistance and Physical Properties of Plastics

ECTFE:	Ethylene- chlorotrifluoroethylene copolymer	**PFA:**	Perfluoro alkoxy
ETFE:	Ethylene tetrafluoroethylene	**PMMA:**	Polymethyl methacrylate
FEP:	Fluorinated ethylene propylene	**PMP:**	Polymethyl pentene
FLPE:	Fluorinated high-density polyethylene	**PP:**	Polypropylene
FLPP:	Fluorinated polypropylene	**PS:**	Polystyrene
HDPE:	High-density polyethylene	**PSF:**	Polysulfone
LDPE:	Low-density polyethylene	**PTFE:**	Polytetrafluoroethylene
NyL:	Nylon (polyamide)	**PUR:**	Polyurethane
PPCO:	Polypropylene copolymer	**PvC:**	Polyvinyl chloride
PC:	Polycarbonate	**PvDF:**	Polyvinylidene fluoride
PETG:	Polyethylene terephthalate polyester	**TPE:**	Thermoplastic elastomer
PK:	Polyketone	**XLPE:**	Cross-linked high-density polyethylene

	ECT	**FEP/**	**FLP**	**HDP**	**LDP**	**NyL**	**PC**	**PET**	**PK**	**PMM**	**PMP**	**PP/P**	**PS**	**PSF**	**PUR**	**PvC**	**PvD**	**TPE‡**

Classes of substances; temperature 68°F (20°C)																		
Acids, weak or dilute	E	E	E	E	E	F	E	E	E	G	E	E	E	E	G	E	E	E
Acids†, strong or concentrated	G	E	E	E	E	N	N	N	G	N	E	E	F	G	F	E	E	F
Alcohols, aliphatic	E	E	E	E	E	N	G	E	G	N	E	E	E	G	F	E	E	E
Aldehydes	E	E	G	G	G	F	F	N	E	G	G	G	N	F	G	N	E	N
Bases	E	E	F	E	E	F	N	N	G	F	E	E	E	E	N	E	E	E
Esters	E	E	E	G	G	E	N	N	E	N	G	G	N	N	N	N	G	N
Hydrocarbons, aliphatic	E	E	E	G	F	E	F	E	E	G	F	G	N	G	E	E	E	N
Hydrocarbons, aromatic	E	E	E	G	F	E	N	N	E	N	F	F	N	N	N	N	E	N
Hydrocarbons, halogenated	E	E	G	F	N	G	N	N	E	N	N	F	N	N	N	N	N	N
Ketones	G	E	E	G	G	E	N	N	E	N	F	G	N	N	N	N	N	N
Oxidizing agents, strong	F	E	F	F	F	N	N	N	G	N	F	F	N	G	N	G	G	N

E — No damage after 30 days of constant exposure.

G — Little or no damage after 30 days of constant exposure.

F — Some effect after seven days of constant expo sure. Depending on the plastic, the effect may be cracking, crazing, loss of strength or discoloration. Solvents may cause softening, swelling and permeation losses with PPCO, PP, PMP, LDPE and HDPE; the solvent effects on these materials are normally reversible.

N — Not recommended for continuous use. Immediate damage may occur. Depending on the plastic, the effect will be severe cracking, crazing, loss of strength, discoloration, deformation, dissolution or permeation loss.

2.1.1 Effects of Chemicals on Labware

Chemicals may affect the weight, strength, color, dimensions, flexibility and surface appearance of labware. The basic models of interaction that cause these changes are:

- chemical attack on the polymer chain, with resultant reduction in physical properties, including oxidation; reaction of functional groups in or on the chain; and depolymerization;
- physical change, including absorption of solvents, resulting in softening and swelling of the plastic; permeation of solvent through the plastic; or dissolution in a solvent; and
- stress-cracking from the interaction of a ‘‘stress-cracking agent’’ with molded-in or external stresses.

The reactive combination of compounds of two or more classes may cause a synergistic or undesirable chemical effect. Other factors affecting chemical resistance include: temperature, pressure, internal or external stresses (such as centrifugation), and length of exposure to and concentration of the chemical. As temperature increases, resistance to attack decreases.

Warning!

Do not store strong oxidizing agents in plastic containers except those made of Teflon* FEP, PFA or PTFE. Other plastics will become brittle after prolonged exposure.

Table 7: Chemical Resistance of Labware Materials

Chemical	LDPE	HDPE	PP/ PPCO	PMP	FEP/ PTFE / PFA	ECTEE/ ETFE	PC	PVC	PSF	PVDF	PS	NYL	STAINLESS STEEL	GLASS	CERAMIC
Acetaldehyde Acetamide, sat.	GN EE	GF EE	GN EE	GN EE	EE EE	GF EE	FN NN	GN NN	NN NN	EE —	NN EE	EG EE	EE EE	EE EE	EE EE
Acetic acid, 5%	EE	EE	EE	EE	EE	EE	EG	EE	EE	EE	EG	FN	EE	EE	EE
Acetic acid, 50%	EE	EE	EE	EE	EE	EG	EG	EG	GG	EE	GG	NN	EE	EE	EE
Acetone	NN	NN	EE	EE	EE	GF	NN	NN	NN	NN	NN	EE	EE	EE	EE
Acetonitrile	EE	EE	FN	FN	EE	EE	NN	NN	NN	EE	NN	EE	EG	EE	EE
Acrylonitrile	EE	EE	FN	FN	EE	EG	NN	NN	NN	GF	NN	EG	EG	EE	EE
Adipic acid	EG	EE	EE	EE	EE	EE	EE	EG	GG	—	EE	EF	EG	EE	EE
Alanine	EE	EE	EE	EE	EE	EE	NN	NN	NN	—	EE	EG	—	—	—
Allyl alcohol	EE	EE	EE	EG	EE	EE	GF	GF	GF	—	GF	NN	EE	EG	EG
Aluminum hydroxide	EG	EE	EG	EG	EE	EE	FN	EG	GG	EE	GG	EE	EE	NN	EE
Aluminum salts	EE	EE	EE	EE	EE	EE	EG	EE	EE	EE	GG	NN	GG	EE	EE
Amino acids	EE	EE	EE	EE	EE	EE	EE	EE	EE	EE	EE	EG	—	—	—
Ammonia	EE	EE	EE	EE	EE	EE	NN	EG	GF	EE	GF	FF	EE	EE	EE
Ammonium acetate, sat.	EE	EE	EE	EE	EE	EE	EE	EE	EE	EE	EE	EG	EG	EE	EE
Ammonium glycolate	EG	EE	EG	EG	EE	EE	GF	EE	GG	EE	EE	GG	—	—	—
Ammonium hydroxide, 5%	EE	EE	EE	EE	EE	EE	FN	EE	GG	EE	EF	GF	EE	EE	EE
Ammonium hydroxide, 30%	EG	EE	EG	EG	EE	EE	NN	EG	GG	EE	GF	FN	EE	EE	EE
Ammonium oxalate	EG	EE	EG	EG	EE	EE	EE	EE	EE	EE	EE	GF	EE	EE	EE
Ammonium salts	EE	EE	EE	EE	EE	EE	EG	EG	EE	EE	GG	NN	EE	EE	EE
n-Amyl acetate	GF	EG	GF	GF	EE	EE	NN	NN	NN	EE	NN	EE	EE	EE	EG
Amyl chloride	NN	FN	NN	NN	EE	EE	NN	NN	NN	EE	NN	EG	EG	EE	EE
Aniline	EG	EG	GF	GF	EE	GN	FN	NN	NN	EF	NN	GF	EG	EE	EE
Benzaldehyde	EG	EE	EG	EG	EE	EF	FN	NN	FF	EE	NN	EG	GG	EE	EE
Benzene	FN	NN	GF	GF	EE	EG	NN	NN	NN	EE	NN	EE	GG	EE	EE
Benzoic acid, sat.	EE	EE	EG	EG	EE	EE	EG	EG	FF	EE	GG	NN	EG	EE	EE
Benzyl acetate	EG	EE	EG	EG	EE	EG	FN	NN	NN	—	NN	EG	GG	EE	EE
Benzyl alcohol	NN	FN	NN	NN	EE	EE	NN	GF	NN	EE	NN	NN	GG	EE	EE
Bromine	NN	FN	NN	NN	EE	EG	FN	GN	NN	EE	NN	NN	EE	EG	GG
Bromobenzene	NN	FN	NN	NN	EE	GN	NN	NN	NN	EE	NN	EG	GG	GG	GG
Bromoform	NN	NN	NN	NN	EE	GF	NN	NN	NN	EE	NN	FF	GG	EE	EE
Butadiene	NN	FN	NN	NN	EE	EE	NN	FN	NN	EE	NN	FF	GG	EE	EE
n-Butyl acetate	GF	EG	GF	GF	EE	EG	NN	NN	NN	EE	NN	EE	GG	EE	EE
n-Butyl alcohol	EE	EE	EE	EG	EE	EE	GF	GF	GF	EE	EG	NN	EE	EE	EE
sec-Butyl alcohol	EG	EE	EG	EG	EE	EE	GF	GG	GF	EE	GG	NN	EE	EE	EE
tert-Butyl alcohol	EG	EE	EG	EG	EE	EE	GF	EG	GF	EE	EE	NN	EE	EE	EE
Butyric acid	NN	FN	NN	NN	EE	EE	FN	GN	GG	EE	NN	FN	GG	EE	EE
Calcium hydroxide, conc.	EE	EE	EE	EE	EE	EE	NN	EE	GG	EE	GG	NN	GG	NN	EE
Calcium hypochlorite, sat.	EE	EE	EE	EG	EE	EE	FN	GF	EE	EE	GF	NN	EE	EE	EE
Carbazole	EE	EE	EE	EE	EE	EE	NN	NN	NN	—	EE	EE	—	—	—
Carbon disulfide	NN	NN	NN	NN	EE	EF	NN	NN	NN	EE EE	NN	EG	EE	EE	EE
Cedarwood oil	NN	FN	NN	NN	EE	EG	GF	FN	FF	EE	NN	EG	—	—	—
Cellosolve acetate	EG	EE	EG	EG	EE	EG	FN	FN	NN	EG	NN	EE	GG	EE	EE

Chemical	LDPE	HDPE	PP/ PPCO	PMP	FEP/ PTFE / PFA	ECTEE/ ETFE	PC	PVC	PSF	PVDF	PS	NYL	STAINLESS STEEL	GLASS	CERAMIC
Chlorine, 10% in air	GN	EF	GN	GN	EE	EE	EG	EE	NN	EE	FN	NN	FF	EE	EE
Chlorine, 10% (moist)	GN	GF	FN	GN	EE	EE	GF	EG	NN	EE	NN	NN	FF	EE	EE
Chloroacetic acid	EE	EE	EG	EG	EE	EE	FN	FN	NN	E–	GN	NN	GG	EE	EE
p-Chloroacetophenone	EE	EE	EE	EE	EE	EE	NN	NN	NN	—	NN	EG	—	—	—
Chloroform	FN	FN	GF	NN	EE	GF	NN	NN	NN	EE	NN	FF	EE	EE	EE
Chromic acid, 10%	EE	EE	EE	EE	EE	EE	GF	EG	NN	EE	EE	NN	GG	EE	EE
Chromic acid, 50%	EE	EE	GF	GF	EE	EE	FN	EF	NN	EG	FF	NN	FF	EE	NN
Cinnamon oil	NN	FN	NN	NN	EE	EG	GF	NN	FF	—	NN	GF	EE	—	—
Citric acid, 10%	EE	EE	EE	EE	EE	EE	EG	GG	EE	EE	EG	NN	GG	EE	EE
Cresol	NN	FN	GF	NN	EE	EG	NN	NN	NN	EE	NN	NN	EE	EE	EE
Cyclohexane	FN	FN	FN	NN	EE	EG	EG	GF	NN	EE	NN	EE	EE	EE	EE
DeCalin	GF	EG	GF	FN	EE	EE	NN	EG	NN	—	NN	EE	—	—	—
o-Dichlorobenzene	FN	FF	FN	FN	EE	EF	NN	NN	NN	EE	NN	EG	GG	EE	EE
p-Dichlorobenzene	FN	GF	GF	GF	EE	EF	NN	NN	NN	EE	NN	EG	GG	EE	EE
Diethyl benzene	NN	FN	NN	NN	EE	EG	FN	NN	NN	—	NN	EE	GG	EE	EE
Diethyl ether	NN	FN	NN	NN	EE	EG	NN	FN	NN	EG	NN	EE	GG	EE	EE
Diethyl ketone	NN	NN	GG	GF	EE	GF	NN	NN	NN	NN	NN	EE	GG	EE	EE
Diethyl malonate	EE	EE	EE	EG	EE	EE	FN	GN	FF	EG	NN	EE	—	—	—
Diethylene glycol	EE	EE	EE	EE	EE	EE	GF	FN	GG	EE	GG	EE	EE	EE	EE
Diethylene glycol ethyl ether	EE	EE	EE	EE	EE	EE	FN	FN	FF	—	NN	EE	EE	EE	EE
Dimethyl formamide	EE	EE	EE	EE	EE	GG	NN	FN	NN	NN	NN	GF	EE	EE	EE
Dimethyl sulfoxide	EE	EE	EE	EE	EE	EG	NN	NN	NN	—	EG	EE	EE	EE	EE
1,4-Dioxane	GF	GG	GF	GF	EE	EF	GF	FN	GF	NN	NN	EF	GG	EE	EE
Dipropylene glycol	EE	EE	EE	EE	EE	EE	GF	GF	GG	—	EE	EE	—	—	—
Ether	NN	FN	NN	NN	EE	EG	NN	FN	NN	EG	NN	EE	EE	EE	EE
Ethyl acetate	EE	EE	EE	FN	EE	EE	NN	NN	NN	NN	NN	EE	GG	EE	EE
Ethyl alcohol (absolute)	EG	EE	EG	EG	EE	EE	EG	EG	EG	EE	FN	NN	EE	EE	EE
Ethyl alcohol, 40%	EG	EE	EG	EG	EE	EE	EG	EE	EG	EE	GF	NN	EE	EE	EE
Ethyl benzene	FN	GF	FN	FN	EE	GF	NN	NN	NN	—	NN	EE	GG	—	—
Ethyl benzoate	FF	GG	GF	GF	EE	EG	NN	NN	NN	NN	NN	EE	—	—	—
Ethyl butyrate	GN	GF	GN	FN	EE	EG	NN	NN	NN	NN	NN	EE	EG	—	—
Ethyl chloride, liquid	FN	FF	FN	FN	EE	EE	NN	NN	NN	EE	NN	GF	EE	EE	EE
Ethyl cyanoacetate	EE	EE	EE	EE	EE	EE	FN	FN	FF	NN	GN	GF	—	—	—
Ethyl lactate	EE	EE	EE	EE	EE	EE	FN	FN	FF	NN	FN	EG	—	—	—
Ethylene chloride	GN	GF	FN	NN	EE	EE	NN	NN	NN	EE	NN	EG	GG	EE	EE
Ethylene glycol	EE	EE	EE	EE	EE	EE	GF	EE	EE	EE	EE	EE	GG	EE	EE
Ethylene glycol methyl ether	EE	EE	EE	EE	EE	EE	FN	FN	FF	— EE	NN	EE	—	—	—
Fluorides	EE	EE	EE	EE	EE	EE	EE	EE	EE	EE	GG	EE	—	—	—
Fluorine	FN	GN	FN	FN	EG	EF	GF	EG	NN	—	NN	NN	EG	EE	—
Formaldehyde, 10%	EE	EE	EE	EG	EE	EE	EG	GF	GF	EE	FN	GF	EE	EE	EE
Formaldehyde, 40%	EG EG	EE EE	EG EG	EG EG	EE EE	EE EE	EG EG	GF GF	GF GG	EE EE	NN EG	GF NN	EE GG	EE EE	EE EE
Formic acid, 3%															
Formic acid, 50%	EG	EE	EG	EG	EE	EE	EG	GF	GG	EE	FF	NN	GG	EE	EE

Chemical	LDPE	HDPE	PP/ PPCO	PMP	FEP/ PTFE / PFA	ECTEE/ ETFE	PC	PVC	PSF	PVDF	PS	NYL	STAINLESS STEEL	GLASS	CERAMIC
Formic acid, 98 to 100%	EG	EE	EG	EF	EE	EE	EF	FN	FF	EE	FF	NN	GG	EE	EE
Freon® TF	EG	EG	EG	FN	EE	EG	GF	GF	EG	EE	FN	—	EE	EE	EE
Fuel oil	FN	GF	EG	GF	EE	EE	EG	EE	EG	EE	NN	EE	EE	EE	EE
Gasoline	FN	GG	GF	GF	EE	EE	FF	GN	FF	EE	NN	EE	EE	EE	EE
Glacial acetic acid	EG	EE	EG	EG	EE	EE	NN	EG	FN	EG	NN	NN	EG	EE	EE
Glycerin	EE	EE	EE	EE	EE	EE	EE	EE	EE	EE	EE	EE	EE	EE	EE
n-Heptane	FN	GF	FF	FF	EE	EE	EG	GF	EG	EE	NN	EE	EE	EE	EE
Hexane	NN	GF	GF	FN	EE	EE	FN	GN	EG	EE	NN	EE	EE	EE	EE
Hydrochloric acid, 1 to 5%	EE	EE	EE	EG	EE	EE	EE	EE	EE	EE	EE	NN	NN	EE	EE
Hydrochloric acid, 20%	EE	EE	EE	EG	EE	EE	GF	EG	EE	EE	EE	NN	NN	EE	EE
Hydrochloric acid, 35%	EE	EE	EG	EG	EE	EE	NN	GF	EE	EE	FF	NN	NN	EE	EE
Hydrofluoric acid, 4%	EG	EE	EG	EG	EE	EE	GF	GF	GF	EE	GF	NN	NN	NN	—
Hydrofluoric acid, 48%	EE	EE	EE	EE	EE	EE	NN	GF	FN	EE	NN	NN	NN	NN	NN
Hydrogen peroxide, 3%	EE	EE	EE	EE	EE	EE	EE	EE	EE	EE	EG	NN	GG	EE	EG
Hydrogen peroxide, 30%	EG	EE	EG	EG	EE	EE	EE	EE	EE	EE	EG	NN	GG	EE	EG
Hydrogen peroxide, 90%	EG	EE	EG	EG	EE	EE	EE	EG	EE	E-	EG	NN	GG	EE	EG
Isobutyl alcohol	EE	EE	EE	EG	EE	EE	EG	EG	EG	EE	GG	NN	EE	EE	EE
Isopropyl acetate	GF	EG	GF	GF	EE	EG	NN	NN	NN	—	NN	EE	GG	EE	EE
Isopropyl alcohol	EE	EE	EE	EE	EE	EE	EE	EG	EE	EE	EG	NN	GG	EE	EE
Isopropyl benzene	FN	GF	FN	NN	EE	EG	NN	NN	NN	—	NN	EG	—	—	—
Kerosene	FN	GG	GF	GF	EE	GF	EE	EE	GF	EE	NN	EE	EE	EE	EE
Lactic acid, 3%	EG	EE	EG	EG	EE	EE	EG	GF	EE	EG	GG	NN	GG	EE	EE
Lactic acid, 85%	EE	EE	EG	EG	EE	EG	EG	GF	EE	GF	GG	NN	GG	EE	EE
Methoxyethyl oleate	EG	EE	EG	EG	EE	EE	FN	NN	NN	—	NN	EG	—	—	—
Methyl alcohol	EE	EE	EE	EE	EE	EE	GF	EF	GF	EE	FN	NN	EE	EE	EE
Methyl ethyl ketone	NN	NN	EG	NN	EE	GF	NN	NN	NN	NN	NN	EE	EE	EE	EE
Methyl isobutyl ketone	NN	NN	GF	FF	EE	GF	NN	NN	NN	GN	NN	EE	GG	EE	EE
Methyl propyl ketone	GF	EG	GF	FF	EE	EG	NN	NN	NN	NN	NN	EE	EE	—	—
Methylene chloride	FN	FN	FN	FN	EE	GG	NN	NN	NN	NN	NN	GF	GG	EE	EE
Mineral oil	GN	EE	EE	EG	EE	EE	EG	EG	EE	EE	EE	EE	EE	EE	EE
Nitric acid, 1 to 10%	EE	EE	EE	EE	EE	EE	EG	EG	EF	EE	GN	NN	EE	EE	EE
Nitric acid, 50%	GN	GN	FN	GN	EE	EE	GF	GF	GF	EG	NN	NN	EG	EG	NN
Nitric acid, 70%	FN	GN	NN	GF	EE	EE	NN	FN	NN	GF EN	NN	NN	GG	EE	NN
n-Octane	EE	EE	EE	EE	EE	EE	GF	FN	GF	EE	NN	EE	EE	EE	EE
Orange oil	FN	GF	GF	FF	EE	EE	FF	FN	FF	EE	NN	GF	EE	EE	EE
Ozone	EG	EE	EG	EE	EE	EE	EG	EG	EE	EE	FF	EG	EG	—	—
Perchloric acid	GN	GN	GN	GN	GF	EG	NN	GN	NN	EE	GF	NN	FF	EE	EE
Perchloroethylene	NN	NN	NN	NN	EE	EE	NN	NN	NN	EE	NN	EE	EG	EE	EE
Phenol, crystals	GN	GF	GN	FG	EE	EE	NN	FN	FF	EE	NN	NN	GG	EE	EE
Phosphoric acid, 1 to 5%	EE	EE	EE	EE	EE	EE	EE	EE	EE	EE	GG	NN	NN	EE	EE
Phosphoric acid, 85%	EE	EE	EG	EG	EE	EE	EG	EG	EE	EE	EG	NN	NN	EE	EE
Pine oil	GN	EG	EG	GF	EE	EG	GF	FN	FF	EE	NN	GF	EE	—	—
Potassium hydroxide, 1%	EE	EE	EE	EE	EE	EE	FN	EE	EE	EE	GG	FF	EG	GF	GF
Potassium hydroxide, conc.	EE	EE	EE	EE	EE	EE	NN	EG	EE	EG	GG	FF	EG	NN	NN
Propane gas	NN	FN	NN	NN	EE	EE	FN	EG	FF	EE	NN	FF	GF	NN	NN

Chemical	LDPE	HDPE	PP/ PPCO	PMP	FEP/ PTFE / PFA	ECTEE/ ETFE	PC	PVC	PSF	PVDF	PS	NYL	STAINLESS STEEL	GLASS	CERAMIC
Propylene glycol	EE	EE	EE	EE	EE	EE	GF	FN	GG	—	EE	EE	GG	EE	EE
Propylene oxide	EG	EE	EG	EG	EE	FN	GF	FN	GG	FN	NN	EE	EE	—	—
Resorcinol, sat.	EE	EE	EE	EE	EE	EE	GF	FN	NN	—	GF	NN	—	—	—
Resorcinol, 5%	EE	EE	EE	EE	EE	EF	GF	GN	NN	—	GF	NN	—	—	—
Salicylaldehyde	EG	EE	EG	EG	EE	EN	GF	FN	FF	EG	NN	EG	—	—	—
Salicylic acid, powder	EE	EE	EE	EG	EE	EE	EG	GF	EE	EE	EE	EG	GG	EE	EE
Salicylic acid, sat.	EE	EE	EE	EE	EE	EE	EG	GF	EE	EE	EG	NN	GG	EE	EE
Salt solutions, metallic	EE	EE	EE	EE	EE	EE	EE	EE	EE	EE	GG	FF	EG	—	—
Silver acetate	EE	EE	EE	EE	EE	EE	EG	GG	EE	EE	GG	EF	—	—	—
Silver nitrate	EG	EE	EG	EE	EE	EE	EE	EG	EE	EE	GF	NN	GG	EE	EE
Sodium acetate, sat.	EE	EE	EE	EE	EE	EE	EG	GF	EE	EE	GG	FF	GG	EE	EE
Sodium hydroxide, 1%	EE	EE	EE	EE	EE	EE	FN	EE	EE	EE	GG	EE	GG	GE	GE
Sodium hydroxide, 50% to sat.	GG	EE	EE	EE	EE	EE	NN	NN	EG	EG	EE	GF	GF	NN	NN
Sodium hypochlorite, 15%	EE	EE	GF	EE	EE	EE	GF	EE	EE	EE	EE	NN	NN	EE	EG
Stearic acid, crystals	EE	EE	EE	EE	EE	EE	EG	EG	GG	EE	EG	EF	EG	EE	EE
Sulfuric acid, 1 to 6%	EE	EE	EE	EE	EE	EE	EE	EG	EE	EE	EG	NN	FN	EE	EG
Sulfuric acid, 20%	EE	EE	EG	EG	EE	EE	EG	EG	EE	EE	EG	NN	NN	EE	GG
Sulfuric acid, 60%	EG	EE	EG	EG	EE	EE	GF	EG	EE	EE	GN	NN	NN	EE	NN
Sulfuric acid, 98%	GG	GG	FN	GG	EE	EE	NN	GN	NN	EG	NN	NN	NN	EE	NN
Sulfur dioxide, liq., 46 psi	NN	FN	NN	NN	EE	EG	GN	FN	GG	EE	NN	NN	FN	NN	NN
Sulfur dioxide, wet or dry	EE	EE	EE	EE	EE	EE	EG	EG	GG	GE	FN	NN	FN	EE	EE
Sulfur salts	FN	GF	FN	FN	EE	EG	FN	NN	GG	GF	NN	NN	—	—	—
Tartaric acid	EE	EE	EE	EE	EE	EE	EG	EG	EE	EE	GG	EF	FF	EE	EE
Tetrahydrofuran	FN	GF	GF	FF	EE	GF	NN	NN	NN	FN	NN	EE	EE	EE	EE
Thionyl chloride	NN	NN	NN	NN	EE	EE	NN	NN	NN	—	NN	NN	NN	EE	EE
Toluene	FN	GG	GF	FF	EE	EE	FN	NN	NN	EE	NN	EE	EE	EE	EE
Tributyl citrate	GF	EG	GF	GF	EE	EG	NN	FN	FF	EF	NN	EG	—	—	—
Trichloroethane	NN	FN	NN	NN	EG	NN	NN	NN	NN	—	NN	EE	GG	EE	EE
Trichloroethylene	NN	FN	NN	NN	EE	EG	NN	NN	NN	EE	NN	EE	GG	EE	EE
Triethylene glycol	EE	EE	EE	EE	EE	EE	EG	GF	EE	—	EG	EE	—	—	—
Tripropylene glycol	EE	EE	EE	EE	EE	EE	EG	GF	EE	—	EE	EE	—	—	—
Turpentine	FN	GG	GF	FF	EE	EE	FN	GF	NN	EE	NN	EE	EE	EE	EE
Undecyl alcohol	EF	EG	EG	EG	EE	EG	GF	EF	FF	EE	GG	EE	—	—	—
Urea	EE	EE	EE	EG	EE	EE	NN	GN	FF	EE	EG	EE	GG	EE	EE
Vinylidene chloride	NN	FN	NN	NN	EE	GF	NN	NN	NN	EE	NN	NN	GG	—	—
Xylene	GN	GF	FN	FN	EE	EG	NN	NN	NN	EE	NN	EE	GG	EE	EE
Zinc stearate	EE	EE	EE	EE	EE	EE	EE	EG	EE	EE	EE	EE	EE	EE	EE

Use This Chart as a General Guide Only. Test each chemical before storing in labware. The first letter of each pair represents the resistance rating at 20°C; the second at 50°C.

E — No damage after 30 days of constant exposure.

G — Little or no damage after 30 days of constant exposure.

F — Some effect after 7 days of constant exposure. Depending on the material, the effect may be cracking, crazing, loss of strength or discoloration. Solvents may cause softening, swelling, and permeation losses with PA, PP, PMP, LDPE and HDPE; the solvent effects on these materials are normally reversible.

N — Not recommended for continuous use. Immediate damage may occur. Depending on the material, the effect will be severe cracking, crazing, loss of strength, discoloration, deformation, dissolution or permeation loss.

Secondary Containment. For liquid and high hazard hazardous materials, secondary containers are effective tools to prevent reactions between incompatible hazardous materials. When storing reactive materials, secondary containment can prevent degradation and reactions that occur during storage (i.e., use a wide-mouthed jar to protect smaller bottles). For transporting bottles in hallways, place them in a specially-designed carrier or a five-gallon plastic bucket to prevent spills. It is best to use secondary containers made of materials that are non-reactive, e.g. polyethylene.

2.2 Spatial Considerations for Safe Storage

Storage risks can also be minimized by considering the configuration of your storage area and the proximity of incompatible substances. Follow the guidelines below

- When determining how to store the chemical, always check the chemical label and SDS first for the manufacturer’s recommended compatible storage.
- Keep chemicals away from ignition sources. Store flammable and combustible chemicals in an approved flammable chemicals storage cabinet.
- Avoid storing chemicals in direct sunlight or near a localized heat source.
- Store flammable and potentially explosive chemicals according to the manufacturer’s directions or according to SDS instructions.
- Use secondary containers to physically segregate incompatible chemicals when they are stored in the same physical location.
- Label and date chemical containers when received and opened. Label working solutions or chemicals removed from their original container so that all individuals know what is in each container.
- Maintain chemical identification labels, containers, and lids in good condition.
- Keep chemical containers closed with properly fitted caps when not in use.
- Hazardous chemicals must not be stored above shoulder height.
- Do not store stock chemical supplies in a fume hood. This interferes with proper hood airflow and can provide fuel if there is a fire within the fume hood. Flammable chemicals should not be stored in a fume hood.
- Chemicals should never be stored on the floor.
- Chemical shelving should have containment lips or trays to contain small leaks/spills. Chemical cabinets should have a leak proof door sill.
- Shelving should be strong enough to hold the weight of chemicals being stored on them. Do not overload shelves. Always secure shelving to a permanent structure. Shelves should be coated with a chemical- resistant material such as chemical-resistant paint or another coating such as epoxy.
- Do not store chemicals in a domestic refrigerator or walk-in cooler. These refrigeration devices contain ignition sources such as unsealed electrical contacts. Flammable-safe refrigerators should be used whenever flammable chemicals need to be refrigerated. Additionally, walk-in coolers are not vented, creating the potential for accumulation of chemical vapors.
- Do not store bottles of liquids above your containers of solids, and never above eye level. Keep your bottles of liquids stored close to the floor to lessen the chance of

breakage and prevent them from reacting with hazardous materials on lower shelves. This will also prevent injuries to laboratory personnel from liquids leaking at eye level.

3 Compressed gas

Below are a few general requirements for gas cylinder usage. Due to the hazards posed by highly toxic, corrosive, and pyrophoric gases all procedures involving these gases should be reviewed by EHS staff prior to use (. To ensure safe use and storage, all gas cylinders must be:

3.1 To ensure safe storage of gas cylinders:

a. Transport cylinders on a cylinder cart with a safety chain. Never move a gas cylinder unless the cylinder cap is in place. Do not move a cylinder by rolling it on its base. Do not lift cylinders by the cap.
b. Check the label. The cylinder must be clearly marked with its contents and with any hazard warnings. Do not rely on color to identify container contents.
c. Secure all cylinders to a wall or bench using brackets, clamping devices or chains designed for such. The strapping device/chain should be above the midpoint but below the shoulder. Cylinders may also be stored in gas cylinder racks. Cylinders less than 18” tall may be secured by approved stands. A cylinder dolly should not be used for storage.
d. Fasten cylinders individually (not ganged or grouped).
e. Fasten cylinders with a sturdy chain or strap; bungee cords and rope are not acceptable as a means of securing compressed gas cylinders.
f. Store cylinders in a well-ventilated area that is cool and dry, away from damp areas, salts or corrosive atmospheres, and away from exit routes.
g. Ignition sources such as heat, sparks, flames, and electrical circuits should be kept away from gas cylinders.
h. When not in use (i.e., the regulator has been removed), gas cylinders should be stored with a safety cap attached.
i. Minimize the number of hazardous gas cylinders in a laboratory. Do not exceed the following:
    - Three 10" x 50" flammable gas and/or oxygen cylinders, and
    - Two 9" x 30" liquefied flammable gas cylinders, and
    - Three 4" x 15" cylinders of severely toxic gases (e.g., arsine, chlorine, diborane, fluorine, hydrogen cyanide, methyl bromide, nitric oxide, phosgene).
j. Store cylinders of flammables and oxidizing agents at least 20 feet apart or separate these items with a fire wall.
k. Do not store cylinders with corrosive materials.
l. Do not store cylinders on the tops of shelves or cabinets.
m. Keep flammable gases away from doorways or exit routes.
n. Stored in an upright position with full cylinders separated from empty cylinders. Label empty cylinders “Empty.”
o. Do not store gas cylinders in hallways or public areas. Cylinders should be stored in a secure area.

p. Close valves, and release pressure on the regulators when cylinders are not in use.
q. Dispose of old lecture bottles. Return lecture bottles to the supplier or dispose of them as hazardous waste.

3.2 Handling and working with compressed gas cylinders:

a. Never move a gas cylinder unless the cylinder safety cap is in place.
b. When working with particularly hazardous gases use special procedures and work in approved gas storage cabinets.
c. The gas cylinder should be chained or otherwise secured to an approved cylinder cart or dolly when being transported. Do not move a cylinder by rolling it on its base.
d. Only use regulators approved for the type of gas in the cylinder. Do not use adapters to interchange regulators. Also, never try to repair or modify a gas regulator or its pressure gauges.
e. Do not use Teflon tape when attaching the regulator.
f. When opening a cylinder valve, follow these guidelines:
  - Direct the cylinder opening away from people.
  - Open the valve slowly. Never open a cylinder valve without a regulator.

g. For a leaking cylinder:
  - Close the valve if it is open and contact the supplier to pick it up.
  - If the valve is already closed, leave the laboratory and shut the door behind you. Contact EHS immediately.

h. Do not use oil or other lubricant on valves and fittings.
i. Do not use oxygen as a substitute for compressed air.
j. Do not lift cylinders by the safety cap.
k. Do not tamper with the safety devices on a cylinder. Have the manufacturer or supplier handle cylinder repairs.
l. Do not change a cylinder's label or color. Do not refill cylinders yourself.
m. Do not heat cylinders to raise internal pressure.
n. Do not use compressed gas to clean your skin or clothing.
o. Before using, check all connections under pressure for leaks. Swab connections with a soap solution and look for bubbles.
p. Don't leave regulators and valves on corrosive gas cylinders except when they are in frequent use. Work the valve stem of a corrosive gas cylinder often to keep it from freezing.
q. Do not force valve stems; they can easily snap off.
r. Turn off both the main valve and regulator when not using the cylinder
s. Do not completely empty cylinders. Maintain at least 30 psi pressure.
t. Do not use copper (>65% copper) connectors or tubing with acetylene. Acetylene can form explosive compounds with silver, copper, and mercury.
u. Always wear impact resistant glasses or goggles when working with compressed gases.
v. Store according to compatibility.
w. Separate flammable gases from oxidizing gases with noncombustible partitions.
x. Store hazardous gases with poor warning properties in exhausted enclosures
y. Do not subject compressed gas cylinders to cryogenic temperatures.

3.3 Precautions for Lecture Bottles

Exotic and toxic gases (e.g., arsine, phosgene and nitrogen dioxide) are often supplied in lecture bottles. Old lecture bottles can leak or spontaneously rupture. Here are some steps to take to minimize the hazards of lecture bottles:

a. Annually inspect your lecture bottles. Examine your lecture bottles for the integrity of their markings, tare weight tags and for corrosion.
b. Use a soap solution to check for leaks at the valves.
c. If labels and valve tags do not agree or if there is any question as to the contents, call EHS. Dispose of all lecture bottles that you have no plans to use in the immediate future.
d. Store them safely. Lecture bottles should be stored in a separate ventilated cabinet where the temperatures do not exceed normal room temperatures. Because lecture bottles may contain gases that are liquified at pressures below the 150 atmospheric limits, they can be more susceptible to increased pressure with heating; especially if critical temperature is attainable near room temperatures.
e. Lay them on their sides with their valves pointed toward the ventilation port.
f. Do not store corrosives with lecture bottles. The corrosive vapors of chemicals such as hydrochloric acid or nitric acid can destroy markings and damage valves.
g. Track their use. Attach a clipboard to the cabinet or a tag to the cylinder to record dates and the weight of bottles before and after use.
h. Return unwanted or surplus cylinders or lecture bottles to the vendor. Some vendors will take back surplus gas and empty lecture bottles.
i. Don't mark a bottle "empty" unless you know that it is actually empty.

Table 8. The following table provides information on the hazards associated with common gases. This will aid risk assessments and help determine MAQs. Since gases can fall into multiple categories (such as flammable and highly toxic) the most restrictive MAQ applies.

Table 8. Hazards of Common Gases

Gas	Asphyxiant	Flammable	Oxidizer	Corrosive	Toxic	Highly Toxic	Pyrophoric	LC_{50}/PEL (ppm)
Ammonia (NH_3)				X	X			4000/50
Arsine (AsH_3)		X				X		20/0.05
Boron Tribromide (BBr_3)				X	X			380/1
Boron Trichloride (BCl_3)				X	X			2541/5

Gas	Asphyxiant	Flammable	Oxidizer	Corrosive	Toxic	Highly Toxic	Pyrophoric	LC_{50}/PEL (ppm)
Bromine (Br_2)			X	X		X		113/0.1
Chlorine (Cl_2)			X	X	X			293/1
Chlorine Dioxide (ClO_2)			X		X			250/0.1
Chlorine Trifluoride (ClF_3)			X		X			299/0.1
Diborane (B_2H_6)		X				X	X	80/0.1
Dichlorosilane (SiH_2Cl_2)		X		X	X			314/5
Ethylene Oxide (C_2H_4O)		X			X			4350/1
Fluorine (F_2)			X	X		X		185/0.1
Germane (GeH_4)		X			X			622/0.2
Hydrogen (H_2)	X	X						
Hydrogen Bromide (HBr)				X				2860/3
Hydrogen Chloride (HCl)				X				2810/5
Hydrogen Cyanide (HCN)		X				X		40/10
Hydrogen Fluoride (HF)				X	X			1300/3
Methyl Bromide (CH_3Br)		X			X			1007/20
Nickel Carbonyl [$Ni(CO)_4$]		X				X		18/0.001
Nitrogen Dioxide (NO_2)			X		X			115/5
Oxygen (O_2)			X					
Phosgene ($COCl_2$)						X		5/0.1
Phosphine (PH_3)						X	X	20/0.3
Silane (SiH_4)		X			X		X	9600/5
Sulfur Dioxide (SO_2)				X				2520/5

Note: Argon, carbon dioxide, helium and nitrogen are asphyxiating gases.
PEL: Permissible exposure limit.
LC_{50}: For inhalation experiments, the concentration of the chemical in air that kills 50% of the test animals in each time (usually four hours) is the LC_{50} value.

4 Corrosives

Laboratory Chemicals

Acids
Organic Acids
Acetic Acid
Citric acid
Formic acid
Oxalic acid

Bases
Ammonium hydroxide

Calcium hydroxide
Potassium hydroxide
Sodium hydroxide
Tri-sodium phosphate

Inorganic Oxidizing Acids
Chromic acid
Nitric acid
Perchloric acid
sulfuric acid

Inorganic Non-Oxidizing Acids
Hydrochloric acid
Phosphoric Acid

Non-Laboratory Chemicals

Acids
Muriatic acid
(contains hydrochloric acid)

Bases
Drain declogger
(containing sodium hydroxide)
Wall cleaner
(containing tri-sodium phosphate)

4.1 Safe Handling and Storage Guidelines for Corrosives

To ensure safe handling of corrosives, the following special handling procedures should be used:

a. Segregate acids from bases and inorganics from organics.
b. Organic acids should be stored with flammable materials, separate from oxidizers and oxidizing acids.
c. It is particularly important to avoid storing ammonium hydroxide and strong mineral acids in the same cabinet.
d. Store oxidizing acids, such as perchloric and nitric, separately in a secondary container within an acid cabinet. Polypropylene boxes for use in acid cabinets are available commercially. Glacial acetic acid is both corrosive and flammable; store it in secondary containment in a flammable storage cabinet.

e. Always wear a laboratory coat, gloves and chemical splash goggles when working with corrosives. Wear other personal protective equipment, as appropriate.
f. To dilute acids, carefully add the acid to the water, not the water to the acid. This will minimize any reaction.
g. Corrosives, especially inorganic bases (e.g., sodium hydroxide), may be very slippery; handle these chemicals with care and clean any spills, leaks, splashes, or dribbles immediately.
h. Work in a chemical fume hood when handling fuming acids or volatile irritants (e.g., ammonium hydroxide).
i. A continuous flow eye wash station should be in every work area where corrosives are present. An emergency shower should also be within 75 feet of the area.

A good guide to storage of strong, liquid acids is based upon its hazardous material classification. For this consideration, acids that are relatively weak (i.e., plCa > 2.3), dilute aqueous or non-volatile solids are not of concern. The classification is based upon one of 9 categories the acid fall within.

Oxidizing	**Ox**	crossed with	Water reactive	**WR**
Non-oxidizing, non-reducing	**NRedOx**		Non-water reactive, non-aqueous	**NAqWR**
Reducing or organic	**Red**		Aqueous	**Aq**

Table 9: Examples of acids and their resulting category

Acid Categories		
Ox + WR	**Ox + NAqWR**	**Ox + Aq**
◆ Chromyl chloride ◆ Nitric acid 100% ◆ Perchloric acid 100% ◆ Bromine pentafluoride ◆ Chromic - sulfuric acid mixture		◆ Nitric acid 67% ◆ Perchloric acid 72% ◆ Chromic acid (Chromerge solution)

NRedOx - WR ◆ Sulfuric acid ◆ Fuming sulfuric ◆ Chlorosulfonic acid ◆ Sulfuryl chloride ◆ Fluorosulfonic acid ◆ Phosphorus oxychloride ◆ Trifluoroacetic anhydride or chloride ◆ Trifluoromethanesulfonic anhydride or chloride ◆ Boron tribromide ◆ Silicon tetrachloride ◆ Titanium tetrachloride ◆ Antimony pentafluoride ◆ Vanadium tetrachloride	**NRedOx - NAqWR** ◆ Phosphoric acid 85% ◆ Fluoboric ◆ Trifluoromethanesulfonic acid ◆ Trifluoroacetic acid ◆ Hydrofluoric 100%	**NRedOx -Aq** ◆ Hydrofluoric acid 50% ◆ Hydrochloric acid 36% ◆ Hydrobromic acid 48% ◆ Trichloroacetic acid solution 30% ◆ Fluoboric acid 50%
Red - WR ◆ Acetyl chloride ◆ Chloroformate esters ◆ Oxaly1 chloride ◆ Methyl fluorosulfonate ◆ Diethylaminosulfurtrifluoride (DAST) ◆ Thionyl chloride ◆ Phosphorus trichloride	**Red - NAqWR** ◆ Dichloroacetic acid	**Red - Aq** ◆ Hydroiodic acid ◆ Sulfurous acid (saturated) ◆ Hypo phosphorus 50%

Once an acid has been classified into one of the nine categories, then storage can be done with these considerations:

- NRedOx is generally compatible with Red and Ox
- NAqWR is compatible with Aq and WR.
- Generally, Red versus Ox is a worse incompatibility than Aq versus WR
- Organic acids like formic, acetic, lactic, pyruvic, acetic anhydride and dichloroacetic acid are best placed with the organic solvents.
- Chloroformates and acetyl chloride, even though they're flammable, are best with the Red – WR group

4.2 Hydrogen Fluoride Gas or Hydrofluoric Acid prior use approval

Contact EHS prior to obtaining HF gas or liquid. EHS must review and pre-approve experimental and research protocols (see Appendix A -Questionnaire for Use of Hydrogen Fluoride Gas and Hydrofluoric Acid).

Laboratory Information Required:

A completed Experimental Protocol outlining proposed use of HF. Protocol must include details such as:

- HF quantities, concentration, pressure, temperature, flow rate, etc.
- Personal Protective Equipment - gloves, eye/face protection, etc.

- Engineering Controls - fume hood, gas cabinet, special exhaust device, alarm monitoring system, etc.
- Safe Handling Requirements - routine leak detection, emergency evacuation procedure in case of accidental release/exposure, location of emergency shower and eye/face wash unit(s), location of 2.5% calcium gluconate gel, posted emergency room contact phone numbers, etc.
- A complete laboratory Chemical and Gas Inventory is required to determine if incompatibilities exist for ventilation and storage needs.

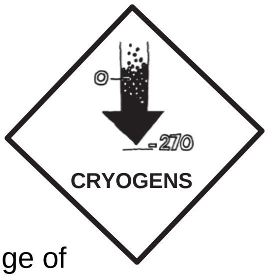
Storage and Engineering Requirements:

- Maximum quantity of HF allowed will be determined on a case by case basis for each Experimental Protocol.
- HF gas cylinders must be stored in an approved vented gas cylinder cabinet with a HF alarm sensor that will detect an immediate HF release.
- Alarm monitoring system should be easy to calibrate by Laboratory User(s).
- Alarm monitoring system should have battery back-up in case of power outage.
- HF acid container(s) are required to be stored in an approved vented corrosive cabinet.

EHS and Facilities Management will conduct a code review to determine additional Engineering Control requirements. Controls may include, but not be limited to, fume hood or other ventilation containment, room pressurization, duct work and exhaust fan(s), exhaust scrubbers, system alarms, placarding, etc.

In HF exposures, time is crucial. Immediately wash the affected area(s) with copious amounts of water to minimize the extent and the depth of the burn. Never let a HF burn go untreated, as extensive damage could result. Any area that is exposed to HF must be treated immediately with calcium gluconate or another appropriate material to stop its reaction with human tissue. Medical attention should be sought as quickly as possible. Ensure medical personnel are aware that HF is involved. Mistakes in treatment can occur if a miscommunication results in treatment for a hydrochloric acid burn instead of a hydrofluoric acid burn.

5 Cryogenic Materials



Cryogenic liquids are hazardous because of the physical and chemical characteristics of their super-cooled state. Cryogenic liquids may cause explosions, fires, asphyxiation, tissue destruction or embrittlement of structural materials. Follow these guidelines for using cryogenic liquids:

- Before working with cryogenic liquids, acquire a thorough knowledge of cryogenic procedures, equipment operation, safety devices, and material properties. Cryogenic training should be documented.
- Reject delivery of unsafe cylinders.
- Keep equipment and systems extremely clean.
- Avoid skin and eye contact with cryogenic liquids. Always wear eye protection, preferably goggles and a face shield. Don't use gloves that can be frozen to the skin. Thermal insulated or leather gloves should be loose fitting, so they are able to be

removed quickly if necessary. Wear long sleeved clothing and pants. Use closed-toe shoes

- Keep cryogenic liquids away from all sources of ignition.
  - Work in an open, well-ventilated location and NEVER directly over an open vat of liquid nitrogen or other cryogenic liquid.
- Store cryogenic liquids in a well-ventilated area to avoid buildup of flammable gases or the displacement of air. Do not inhale cryogenic vapors.
- Store cryogenic liquids in double-walled, insulated containers (e.g., Dewar flasks). Handle Dewar flasks carefully.
- Tape exposed glass on cryogenic containers. In the event the container breaks or implodes, the tape will reduce fragmentation and violent dispersal of glass shards.
- Pre-cool receiving vessels to avoid thermal shock and splashing.
- Boiling and splashing can occur when inserting objects into cryogenic liquids such as nitrogen. Perform these tasks slowly to minimize splashing
- Select work materials wisely. Cryogenic liquids alter the physical characteristics of some materials. Accidents have been reported where Pyrex tubes have failed causing injury.
- Use tongs to place and remove items in cryogenic liquid. Rubber and plastic may become very brittle in extreme cold, handle these items carefully when removing them from cryogenic liquids.
- Do not touch anything that has been immersed in liquid nitrogen until it has reached room temperature.
- Use extreme care in transporting cryogenic containers. Use a cart for large cryogenic containers.
- When discharging cryogenic liquids, purge the line slowly. Only use transfer lines specifically designed for cryogenic liquids.
- Do not store cylinders of cryogenic liquids in hallways or other public areas.

Standard Operating Procedure for transferring Liquid Nitrogen

- Use a special separator or special filling funnel to prevent splashing and spilling when transferring liquid nitrogen into or from a dewar. The top of the funnel should be partly covered to reduce splashing
- Use only small, easily handled dewars for pouring liquid.
- Use only fitted transfer tubes designed for use with dewar containers. Cracked or damaged insulation on transfer tubes should be replaced.
- Do not pour liquid while holding secondary container. The container should be on a stable stand or hung so that the transfer tube rests securely on the neck of the secondary container.

Ventilation/Engineering Controls

- Local exhaust should be used to prevent oxygen deficiency
- Mechanical or general exhaust ventilation may be used if it can maintain an adequate supply of air.
- Depending upon the size of the room and the volume of liquid nitrogen, oxygen monitoring may be required. Check with EHS.

Containers

- Liquid nitrogen containers are insulated, vacuum-jacketed pressure vessels. They are equipped with relief valves and rupture discs to protect against pressure build up. NEVER

CLOSE RELIEF VALVES. The containers operate at pressures up to 250 psig. They can hold from 80 to 450 liters of liquid. Cryogenic containers and dewars should not be filled to more than 80% of capacity.

6 Flammable and Combustible Liquids

Laboratory Chemicals	Non-Laboratory Chemicals
Flammable Solids	Flammable Solids
naphthalene (HT)	Moth balls (HT) (containing Naphthalene
finely divided metal (e.g., aluminum, cadmium, chromium, titanium, zinc) (P)	Calcium carbide (WR)
Flammable Gases	Flammable Gases
Hydrogen	Acetylene
methane	
Flammable Liquids	Flammable Liquids
alcohols - methanol, ethanol	gasoline
esters - ethyl acetate	Lighter fluid
ethers - diethyl ether	Paint thinner
ketones - acetone, cyclohexane	
Combustible Liquids	Combustible Liquids
acetic acid (CA)	Antifreeze
cumene	Diesel fuel
phenol (CA, T)	Engine oil
propionic acid (CA)	

Flammable liquids are easily ignited and difficult to extinguish. Combustible liquids require heating for ignition and are easier to extinguish. Flammable and combustible liquids produce a high heat release rate once ignited (i.e., fires produce high temperatures in a short period of time), and associated fires spread rapidly.

Vapors from flammable and combustible liquids can be present at room temperature and can form explosive mixtures with air. Some liquids are unstable or very reactive (e.g., burn when exposed to air without an ignition source, susceptible to spontaneous heating, react violently with other materials including water). These characteristics combine to create a significant fire and/or explosion hazard.

Since the vapors generated from flammable liquids are most often heavier than air, they will seek the lowest available level in a building. This movement of vapors can produce potentially dangerous conditions far removed from the actual vapor source. Flammable vapor, if not removed by ventilation, can flow to an ignition source and flash back to the vapor source. The volatility of the liquid is increased when externally heated at or above its flash point. Overall, an increase in temperature will increase the hazard created by a flammable or combustible liquid by increasing its vapor's flammable range. Due to this, heated Class II and Class III liquids should be subject to all applicable requirements for Class I and Class II liquids respectively.

Table 10: Flammable and Combustible Class Characteristics per NFPA.

	Flammable			**Combustible**	
	I-A	I-B	I-C	II	III
Flash Point	< 23 °C (73 °F)	< 23 °C (73 °F)	≥ 23°C (73 °F) < 38 °C (100°F)	≥38°C <60°C (100°F) (140°F)	≥60°C(140°F) <93°C (200°F)
Boiling Point	<38 °C (100 °F)	≥ 38 °C (100 °F)	---	---	---

The volume of flammable and combustible liquids in a lab, room or location is restricted by University guidelines, and International Fire Codes. EHS should be contacted regarding any questions or for additional guidance.

Below grade locations should not be used for Class I flammable liquids. If this is unavoidable, EHS must be contacted for review and guidance.

Volumes of flammable and/or combustible liquids in laboratories should be kept to the minimum necessary for the work being done. Refer to Section 1 for:

- storage limits based on hazard classification
- storage limits for flammable cabinets
- maximum allowable container size based on hazard classification

The use of plastic containers (except for small squeeze bottles) for flammable and combustible liquids should be avoided where possible. If flammable liquids are handled in glass or plastic containers, carriers designed to protect the containers during transit should be used to prevent spillage.

Flammable aerosols and unstable liquids should be treated as Class IA liquids.

6.1 Safe Handling Guidelines for Flammables

a. Handle flammable chemicals in areas free from ignition sources.
b. Unless a cabinet is marked as approved for storage of flammable liquids, flammable solvents may not be stored there. In general, do not store flammable liquids in cabinets below fume hoods or sinks unless they are specifically designed for this kind of storage.
c. Storage cabinets must be conspicuously labeled to indicate that they contain flammable liquids.

d. Store flammables, combustibles and other fuels away from strong oxidizers, such as perchloric and nitric acids.
e. Do not store in or adjacent to exits, elevators, or routes that provide access to exits.
f. If flammable liquids are to be stored cold, the refrigerators and freezers must be approved for flammables. Conventional refrigerators in laboratories and cold rooms are not safe for flammable storage and must be labeled "NO FLAMMABLES". Two kinds of refrigerators are approved for storage of flammables:
   - Flammable liquid storage refrigerators. These have no spark sources within the refrigerator cabinet. There are, however, spark sources outside the refrigerator cabinet from switches, motors, relays, etc. These spark sources can ignite flammable vapors present outside of the refrigerator. A bottle of flammable liquid that drops and breaks near one of these refrigerators can easily be ignited by the sparks.
   - Explosion-proof refrigerators. These refrigerators are considerably more expensive because they have all spark sources completely sealed inside and are safe for flammable atmospheres both within and outside of the refrigerator cabinet.
g. Use plastic trays when storing chemicals in freezers. This prevents the bottles from becoming embedded in ice and frost that often forms in freezers. It also contains spills and drips.
h. Use a fume hood when there is a possibility of dangerous vapors.
i. Use ground straps when transferring flammable chemicals between metal containers to avoid generating static sparks.
j. Static electricity can ignite flammable gases or vapors. If static electricity is a problem, minimize static electricity by spraying with an antistatic agent. Use nonconductive materials (floors, mats, etc.) and grounding straps on instruments and machines, especially when transferring flammable chemicals between metal containers. These reduce the risk of generating static sparks. The greatest hazard from static electricity is in the winter when the air is dry.
k. Work in an area with good general ventilation and use a fume hood when there is a possibility of dangerous vapors. Ventilation will help reduce dangerous vapor concentrations, thus minimizing this fire hazard.
l. Restrict the amount of stored flammables in the laboratory and minimize the amount of flammables present in a work area.

NOTE: The NFPA has established formal limits on the total amounts of flammable liquids that may be stored or used in laboratories. (NFPA 30 and 45). See Section 1 of this document.

m. Only remove from storage the amount of chemical needed for an experiment or task.
n. Spark-proof tools should be used to eliminate friction sparks made by metal striking metal contact.
o. Oil or solvent soaked wiping clothes, rags or waste must be stored in a UL/FM Approved metal container with a self-closing lid. The containers should be marked, identifying the contents of the container (e.g. “Oil Soaked Rags”). Soaked means that there is still free liquid which can be released from the rag (i.e. if you squeeze it you get liquid out).

In addition to the IFC code requirements, the following university limits have been set (in instances in which the building limits are more stringent, those limits will apply):

- No more than ten (10) gallons of flammable liquids per typical laboratory may be stored outside a flammable storage cabinet (except for materials stored in approved safety cans).
- Further limitations are placed on the quantities that can be placed in an individual container based on the type of container (glass, metal, etc.). See Table 9 in Appendix D;
- On your benchtop, limit the storage of flammable liquids to those in immediate use. Handle flammable hazardous materials in areas free from ignition sources

The IFC limits the quantities of flammable liquids that can be stored in a control area. The MAQs are based on the classification of the flammable liquids. The following table provides NFPA classification information for some common solvents. The NFPA fire diamond information is often found on containers or in SDSs. Liquids with a flammability rating of 3 are considered Class IB and IC liquids while those with a flammability rating of 4 are Class IA. Note that Class IA, IB, and IC are flammable liquids. Class II liquids are combustible.

Table 11. Flammable Liquid Storage, Properties and Classification

Chemical	Flash Point (^{o}F/ ^{o}C)	Boiling Point (^{o}F/ ^{o}C)	NFPA Classification
Acetic acid	103/39	245/118	II
Acetone	-4/-20	133/56	1B
Acetaldehyde	-38/-39	70/21	IA
Acetonitrile	42/6	179/82	IB
Acrylonitrile	32/0	171/77	IB
Benzene	12/-11	176/80	IB
t-Butyl Alcohol	52/11	181/83	IB
Cyclohexene	20/-7	181/83	IB
Dioxane	54/12	214/101	IB
Ethyl Acetate	24/-4	171/77	IB
Ethyl Alcohol	55/13	173/78	IB
Ethyl Ether	-49/-45	95/35	IA
Gasoline	-45/-43	100-400/38-204	IB
Hexane	-7/-22	156/69	IB

Chemical	Flash Point (oF/ oC)	Boiling Point (oF/ oC)	NFPA Classification
Isopropanol	53/12	183/83	IB
Methanol	52/11	174/64	IB
Methylene Chloride	none	104/40	-
Methyl Ethyl Ketone	16/-9	176/80	IB
Pentane	-40/	97/36	IA
Petroleum Ether	0/-18	95-140/35-60	IA-IB
Propyl Alcohol	74/23	207/97	IC
n-Propyl Ether	70/21	194/90	IB
Pyridine	68/20	239/115	IB
Tetrahydrofuran	6/-14	151/66	IB
Toluene	40/4	230/111	IB
Triethylamine	16/-7	193/89	IB
m-Xylene	77/25	282/138	IC

6.2 Heating Equipment for Flammable and Combustible Liquids

- Heating equipment or heating baths with flammable liquids or combustible liquids heated to their flash points shall be placed in a chemical fume hood or shall be vented to a safe location to control vapors.
- All unattended electrical heating equipment shall be equipped with a manual reset over-temperature shutoff switch, in addition to normal temperature controls, if overheating could result in a fire or explosion.
- Heating equipment with circulation fans shall be equipped with an interlock arranged to disconnect current to the heating element if the fan fails.
- Electrically heated constant temperature baths shall be equipped with overtemperature shutoff switches in addition to normal temperature controls, if overheating could result in a fire or an explosion.
- Bath containers shall be of noncombustible materials.
- Burners, induction heaters, ovens, furnaces, and other heat-producing equipment shall be located a safe distance from areas where temperature-sensitive and flammable materials and compressed gases are handled.
- Never heat flammable chemicals with an open flame. Use a water bath, oil bath, heating mantle, hot air bath, hot plate, etc. Such equipment should be intrinsically safe, with no open sparking mechanisms.

NOTE: When using an oil bath, make sure the temperature is kept below the oil flash point.

7 Nanomaterials

7.1 General Precautionary Measures

Given the limited amount of information about health risks that may be associated with nanomaterials (NM), taking measures to minimize worker exposures is prudent.

- For most processes and job tasks, the control of airborne exposure to Nano aerosols can be accomplished using a variety of engineering control techniques like those used in reducing exposure to general aerosols.
- The implementation of a risk management program in workplaces where exposure to NMs exists can help to minimize the potential for exposure to nanoparticles. Elements of such a program should include the following:
    - Evaluating the hazard posed by the nanomaterial based on available physical and chemical property data, toxicology, or health-effects data
    - Assessing the worker’s job task to determine the potential for exposure
    - Educating and training workers in the proper handling of NMs (e.g., good work practices)
    - Establishing criteria and procedures for installing and evaluating engineering controls (e.g., exhaust ventilation) at locations where exposure to NMs might occur
    - Developing procedures for determining the need for and selecting proper personal protective equipment (e.g., clothing, gloves, respirators)
    - Systematically evaluating exposures to ensure that control measures are working properly and that workers are being provided the appropriate personal protective equipment

- Ensure that comprehensive standard operating procedures (SOPs) are in place. SOPs should document ways to minimize exposure, such as by reconstituting nanoparticles (NPs) inside vials and not weighing powder, performing procedures inside containment; working atop disposable absorbent pads; selecting and requiring the use of personal protective equipment (PPE) such as gloves, safety goggles, etc.; transporting NPs in sealed containers inside a secondary containment system; and, pre-planning spill procedures. Train staff on SOPs prior to work.
- Consider adding bindings or coatings which have been shown to reduce the toxicity of similar engineered nanoparticles (ENPs), if your research goals allow their addition to your ENP.
- Be sure to consider the hazards of precursor materials in evaluating process hazards.
- Prevent skin and eye contact with NPs or NP-containing solutions by using appropriate personal protective equipment (PPE). Specify PPE to protect all skin areas which may become contaminated with NPs (lab coats, sleeves, aprons, etc. in addition to gloves). EH&S generally recommends a glove thickness of at least 15 mil, or double gloves if using thin gloves. If NPs are in solution, the glove

must be impermeable to the solvent. Neoprene gloves work well for most dry applications.

- Clean surfaces so they are visibly clean at the end of each shift or earlier if the process is complete, using high efficiency particulate air (HEPA)-filtered vacuums or wet wipe methods with damp, soapy towels. Dispose of the towels as hazardous waste; do not dry and re-use them.
- Engineering control techniques such as source enclosure (i.e., isolating the generation source from the worker) and local exhaust ventilation systems should be effective for capturing airborne nanoparticles. Current knowledge indicates that a well-designed exhaust ventilation system with a high-efficiency particulate air (HEPA) filter should effectively remove NMs.
- The use of good work practices can help to minimize worker exposures to NMs. Examples of good practices include cleaning of work areas using HEPA vacuum pickup and wet wiping methods, preventing the consumption of food or beverages in workplaces where NMs are handled, providing hand-washing facilities, and providing facilities for showering and changing clothes.
- No guidelines are currently available on the selection of clothing or other apparel (e.g., gloves) for the prevention of dermal exposure to Nano aerosols. However, some clothing standards incorporate testing with nanometer-sized particles and therefore provide some indication of the effectiveness of protective clothing.
- Respirators may be necessary when engineering and administrative controls do not adequately prevent exposures. Currently, there are no specific limits for airborne exposures to engineered nanoparticles although occupational exposure limits exist for some larger particles of similar chemical composition. It should be recognized that exposure limits recommended for non-nanoscale particles may not be health protective for nanoparticle exposures (e.g., the OSHA Permissible Exposure Limit [PEL] for graphite may not be a safe exposure limit for carbon nanotubes). The decision to use respiratory protection should be based on professional judgment that considers toxicity information, exposure measurement data, and the frequency and likelihood of the worker's exposure. While research is continuing, preliminary evidence indicates that NIOSH-certified respirators will be useful for protecting workers from nanoparticle inhalation when properly selected and fit tested as part of a complete respiratory protection program.
- Consider if there are ways to destroy waste NPs or to reduce their potential hazards and implement the procedures if possible rather than disposing of the NPs into the environment.
- Manage waste NPs as if they are hazardous waste. The particles may not strictly qualify as hazardous waste under current rules. However, carefully controlled disposal as hazardous waste is far preferable to disposal in solid waste or wastewater, where particles will very likely escape into the environment.
- Equipment previously used with NPs should be evaluated for potential contamination prior to disposal or reuse for another purpose.
- Facility components including exhaust systems and internal filters should be evaluated and cleaned if necessary prior to maintenance, modification or demolition

Additional Resources:

- National Institute of Occupational Safety and Health's Approaches to Safe Nanotechnology: http://www.cdc.gov/niosh/docs/2009-125/
- National Nanotechnology Initiative: http://www.nano.gov/
- Environmental Protection Agency Perspective on Nanotechnology: http://epa.gov/ncer/nano/index.html

7.2 Working with Engineered Nanomaterials

Use the table below to identify the controls needed to work with the risk level of your nanomaterial (Category 1, 2, or 3).

Table 12: Risk Levels and Associated Controls for Nanomaterials

Risk level	Controls	
Category 1 Low Exposure Potential	**Engineering**	• **Fume Hood or Biosafety Cabinet**. Perform work with open containers of nanomaterials in liquid suspension or gels in a laboratory-type fume hood or biosafety cabinet, as practical.
	Work Practices	• **Storage and labeling**. Store in sealed container and secondary containment with other compatible chemicals. Label chemical container with identity of content (include the term "nano" in descriptor)**.** • **Preparation.** Line workspace with absorbent materials. • **Transfer in secondary containment.** Transfer between laboratories or buildings in sealed containers with secondary containment. • **Housekeeping.** Clean all surfaces potentially contaminated with nanoparticles (i.e., benches, glassware, apparatus) at the end of each operation using a HEPA vacuum and/or wet wiping methods. DO NOT dry sweep or use compressed air. • **Hygiene.** Wash hands frequently. Upon leaving the work area, remove any PPE and wash hands, forearms, face, and neck. • **Notification.** Follow institution's hazard communication processes for advanced notification of animal facility and cage labeling/management requirements if dosing animals with the nanomaterial
	PPE	• **Eye protection**. Wear proper safety glasses with side shields (for powders or liquids with low probability for dispersion into the air) • **Face protection.** Use face shield where splash potential exists. • **Gloves.** Wear disposable gloves to match the hazard, including consideration of other chemicals used in conjunction with nanomaterials (refer to Table 1. Glove Choices for Nanomaterials) • **Body protection.** Wear laboratory coat and long pants (no cuffs). • **Closed toe shoes.**
Category 2 Moderate Exposure Potential	**Engineering**	• **Fume Hood, Biosafety Cabinet, or Enclosed System**. Perform work in a laboratory-type fume hood, biosafety cabinet* (must be ducted if used in conjunction with volatile compounds), powder handling enclosure, or enclosed system (i.e., glove box, glove bag, or sealed chamber).

	Work Practices	• **Category 1 Work Practices**. Follow all work practices listed for Category 1. • **Access.** Restrict access. • **Signage.** Post signs in area. • **Materials.** Use antistatic paper and/or sticky mats with powders.
	PPE	• **Category 1 PPE**. Wear all PPE listed for Category 1. • **Eye protection**. Wear proper chemical splash goggles (for liquids with powders with moderate to high probability for dispersion into the air). • **Gloves.** Wear two layers of disposable, chemical-protective gloves. • **Body protection.** Wear laboratory coat made of non-woven fabrics with elastic at the wrists (disposable Tyvek®-type coveralls preferred). • **Closed toe shoes.** Wear disposable over-the-shoe booties to prevent tracking nanomaterials from the laboratory when working with powders and pellets. • **Respiratory Protection.** If working with engineering controls is not feasible, respiratory protection may be required. Consult an EHS professional for more information (i.e., N95 respirator, or one fitted with a P-100 cartridge).
Category 3 High Exposure Potential	**Engineering**	• **Enclosed System**. Perform work in an enclosed system (i.e., glove box, glove bag, or sealed chamber).
	Work Practices	• **Category 2 Work Practices**. Follow all work practices listed for Category 2.
	PPE	• **Category 2 PPE**. Wear all PPE listed for Category 2. • **Body protection.** Wear disposable Tyvek®-type coveralls with head coverage. • **Respiratory Protection.** If working with engineering controls is not feasible, respiratory protection may be required. Consult an EHS professional for more information (i.e., N95 respirator, or one fitted with a P-100 cartridge).

8 Oxidizers

Laboratory Chemicals

Solids
Ammonium nitrate
Calcium nitrate
Potassium chlorate
Potassium nitrate
Sodium dichromate
Sodium nitrate

Non-Laboratory Chemicals

Solids
Fertilizers
(e.g. ammonium nitrate)
Pool chemicals
(e.g. bromine tablets)

Liquids
Bleaching agents

Liquids
Bromine
Chromic acid
Hydrogen peroxide
Nitric acid
Perchloric acid
Sulfuric acid

Gases
Chlorine
Fluorine
Nitrogen dioxide
Oxygen
ozone

(e.g. hydrogen peroxide,
sodium hypochlorite)

Gases
Oxygen
chlorine

The combination of a strong oxidizer and a reducer can result in a violent reaction. Take extra care to avoid accidental combination of oxidizers and reducers. By segregating oxidizers and reducers, you will further reduce the problems involved with storage of oxidizing hazardous materials.

- Do not use wooden pallets or other combustible pallets for storing containers of oxidizing materials.
- Take care that the oxidizing materials do not contact combustible or other incompatible materials when they are dispensed.
- Remember that perchloric acid, nitric acid, and hydrogen peroxide are oxidizers and must not be stored on wooden shelves or in cardboard boxes.
- Store oxidizing materials in dry, cool areas, out of direct sunlight and away from steam pipes, boilers or other sources of heat. Follow the chemical supplier's recommendations for storage temperatures. Some dangerously reactive oxidizing materials start to decompose at temperatures only a little above normal room temperature. The decomposition can lead to an explosion under some conditions.
- For oxidizing materials requiring temperature control, the recommended storage temperature range should be plainly marked on the container.
- Normally keep containers tightly closed when storing unless the supplier's instructions state otherwise. Some oxidizing agents, such as solutions of 8% or higher hydrogen peroxide in water, must be stored with specially vented caps. Hydrogen peroxide gradually decomposes at room temperature to produce oxygen gas and water. The properly working vent will prevent the build-up of pressure inside containers. The normal build-up of pressure could rupture an unvented container. Check vent caps regularly to ensure that they are working properly. Keep vented containers in the upright position. NEVER stack vented containers on top of each other.
- Store oxidizer containers at a convenient height for handling, below eye level if possible, to reduce the risk of dropping containers.
- Store oxidizers separate from flammable or combustible materials and reducing agents e.g. nitrates; chromates; permanganates; chlorates; peroxides
- Avoid overcrowding in storage areas. Do not store containers in out-of-the-way locations where they could be forgotten.

- Store containers away from doors. Although it is convenient to place frequently-used materials next to the door, they could cut off the escape route if an emergency occurs.
- NEVER transfer liquids by pressurizing their usual shipping containers with air or inert gas.
- Since some solid oxidizers may be shock sensitive, do not chip or grind lumps to break them up. If crystals have precipitated in containers of an oxidizing agent, contact your health and safety officer about their safe handling and disposal
- In laboratories, do not use corks, rubber stoppers or stopcock grease to seal containers of strong oxidizing materials
- Use fiberglass heating mantles or sand baths instead of oil baths to heat reaction vessels containing significant amounts of oxidizing materials.
- Segregate oxidizers from flammable and combustible materials (paper, wood).
- Segregate oxidizers from reducing agents (zinc, alkaline metals, formic acid).
- Segregate inorganic oxidizers from organic peroxides.
- Take care not to contaminate oxidizers. Some oxidizers, such as perchloric acid, can become explosive mixtures if contaminated with trace amounts of organic materials or metals
- "Empty" drums, bottles, bags, sacks and other "oxidizing agent" containers usually have hazardous oxidizing residues inside them. NEVER use these containers for anything else, no matter how clean they seem

9 Reactives

9.1 Organic Peroxides

Much of the information here is adapted from the publication, Prudent Practices in the Laboratory, Handling and Management of Chemical Hazards, Updated Edition, National Research Council. Some common laboratory chemicals can form peroxides. Once peroxides are formed, these chemicals can become extremely sensitive to thermal or mechanical shock and may explode violently. Peroxides are formed through a spontaneous reaction with oxygen. Simply opening the container can initiate peroxide formation, while light and heat act to accelerate the process.

Manufacturers may add an inhibitor to peroxide forming chemicals to counter peroxide formation. For many peroxide-forming solvents, butylated hydroxy toluene (BHT) is commonly added. BHT ‘scavenges’ oxygen in the solvent and prevents it from reacting with the solvent to form peroxides. Over time, BHT or other inhibitor in the solvent can become exhausted allowing peroxides to form. Distilling the solvent can completely remove the BHT and make the solvent immediately susceptible to peroxide formation.

9.1.1 Safe Handling Guidelines for Organic Peroxides

a. When received, label indicating date of receipt, date of opening, and test date. > Attach a highly visible notice: WARNING -- PEROXIDE FORMER.
b. Keep a record to indicate date of receipt and date the container was first opened.
c. Store away from heat and light.

d. The best method for managing potential peroxide forming chemicals is to purchase them in quantities that will allow them to be completely used before they have to be tested for formation of peroxides and/or before their expiration dates. Most potential peroxide forming chemicals have a shelf life of 18 months if not opened and 12 months once opened and exposed to air, unless noted otherwise.
e. Store all peroxidizable compounds in tightly closed, air-impermeable, light-resistant containers, away from light, heat, direct sunlight, sources of ignition, oxidizers, and oxidizing agents. Refer to the SDS, storage under Nitrogen may be advisable.
f. Make sure caps are replaced promptly after use. Store in the original manufacturer's container whenever possible. Protect containers from shock, friction, and do not shake.
g. Protect from physical damage and ignition sources.
h. If a peroxide-forming chemical or container is of unknown age or history, if crystals or solid masses are visibly present on or in the container or lid, or if the chemical shows discoloration, string-like formations, or liquid stratification, do not open the container. Contact EHS for assistance.
i. Do not use any peroxide forming chemical if a precipitate forms or an oily, viscous layer appears.
j. Most peroxides are not volatile. Loss of solvent via an ill-fitting lid can concentrate any peroxides that are present. A nearly empty container, for which the solvent cannot be accounted, may be a hazard. Contact EHS.
k. Test for peroxides before distilling or evaporating peroxide forming solvents. If peroxides are present, treat the solvent to remove the peroxides. Failure to remove peroxides can result in concentration during distillation and could result in accumulation to the point of an explosive reaction.
l. Immediately rinse empty containers that once held peroxide-forming solvents. Do not allow residues to evaporate.
m. Organic peroxides are a special class of compounds that are very hazardous in low concentrations. They are generally produced from auto-oxidation of solvents that are exposed to air and light. They are extremely sensitive to heat, friction, impact and light. excessive or rapid heating, or surface to surface friction by removing a cap or lid from a bottle
n. Do not heat solutions containing peroxides in volatile solvents because the solvent may vaporize, thereby increasing the concentration of the peroxide.
o. Do not use metal spatulas to handle solid peroxides. Ceramic, Teflon, or wooden spatulas may be used if they do not generate a static charge.
p. Do not permit open flames near peroxides.
q. Avoid friction, grinding and all forms of impact near peroxides, especially solid peroxides. Do not use screw cap lids with glass bottles, or ground glass joints to contain peroxides. Polyethylene bottles that have screw cap lids may be used.
r. Store peroxides at the lowest possible temperature, but not lower than the freezing point, as peroxides in this form are extremely shock-sensitive.
s. Use, dispose, or test for peroxides according to the appropriate time limits listed in Lists A through C below.

THE SINGLE MOST EFFECTIVE APPROACH TO HANDLING PEROXIDE FORMERS IS TO ELIMINATE THESE MATERIALS FROM LABORATORIES. When use of these chemicals is required, modification of the process and substitution of less hazardous chemicals should be practiced for hazard minimization.

Containers should be monitored for evaporation and tested for the presence of peroxides prior to each use. Record test data for the next user. **PEROXIDE FORMERS SHOULD ALWAYS BE CONSIDERED TO CONTAIN PEROXIDES AND HANDLED WITH THE APPROPRIATE PRECAUTIONS.**

9.1.2 Common Peroxide Forming Compounds

These tables provide specific, but not all-inclusive, examples of chemicals that present a serious hazard due to peroxide formation. **Time limits are based on the date the original container is first opened or when the material is first synthesized and are guidelines for testing or disposal.** Peroxides form at varying rates depending on the substance, length of exposure to air or light, and the type of container.

List A: Severe Peroxide Hazard on Storage with Exposure to Air

Use or test within 3 months

- Peroxide hazard after prolonged storage.
- Form potentially explosive peroxides without concentrating.
- All have been responsible for fatalities.
- The usual peroxide test will only work for isopropyl ether.

Diisopropyl ether (isopropyl ether)	Divinylacetylene (DVA)
Potassium metal	Potassium amide
Sodium amide (sodamide)	Vinylidene chloride (1,1-dichloroethylene)
Divinyl ether	

List B: Peroxide Hazard on Concentration

DO NOT DISTILL OR EVAPORATE WITHOUT FIRST TESTING FOR PEROXIDES.
Use or test within 6 months

- Common solvents that can accumulate peroxide products that are a risk on heating and concentration.
- These compounds form peroxides with age.
- Exposure to air is necessary for peroxide formation.
- Light promotes peroxide formation in the presence of oxygen.
- Manage containers to minimize headspace or inert container contents.

- Do not attempt to test containers outside of safe storage limits.
- Concentration of peroxides by distillation or evaporation is typically necessary for explosivity. However, concentrations of peroxides that have caused crystallization or have phase separation are extremely dangerous

Acetaldehyde diethyl acetal (acetal)	Butadiene
Cellosolve	Cumene (isopropylbenzene)
Cyclohexene	Cyclopentene
Decalin (decahydronaphthalene)	Diacetylene (butadiene)
Dicyclopentadiene	Diethyl ether (ether)
Diethylene glycol dimethyl ether (diglyme)	Dioxane, p-Dioxane
Ether	Ethylene glycol dimethyl ether (glyme)
Ethylene glycol ether acetates	Ethylene glycol mono-ethers (cellosolves)
Ethylene Glycol Dimethyl Ether (Glyme)	Furan
Methyl Isobutyl Ketone	Methylacetylene
Methylcyclopentane	Tetrahydrofuran (THF)
Tetralin (tetrahydronaphthalene)	Vinyl ethers

List C: Hazard of Rapid Polymerization Initiated by Internally Formed Peroxides

Use or test within 6 months

- Liquids and liquefied compressed gases that can be initiated by oxygen to polymerize.
- Chemicals which are a hazard due to peroxide initiation of polymerization.
- The usual peroxide test may not show peroxides.
- But there are indicators of polymerization.
- When inspecting liquids, look for an increase in viscosity.
- When inspecting gases, look for residue after evaporation of a sample.
- Either of these may suggest a polymer

Chloroprene (2-chloro-1, 3-butadiene)	Styrene
Vinyl acetate	Vinylpyridine
Chlorotrifluoroethylene	Chlorobutadiene
Tetrafluoroethylene	Acrylonitrile
Vinyl Chloride	Vinyl Acetylene

9.1.3 Testing

CAUTION: Testing should ONLY be performed by a chemist properly trained in the procedure.

The following test procedures may be used on most organic solvents. However, there is not a suitable, simple test procedure for detection of peroxides in substances such as alkali metals, alkali metal alkoxides, amides, or organometallics.

Iodide Test
Add 0.5-1.0 ml of the solvent to be tested to an equal volume of glacial acetic acid to which has been added about 0.1 g of sodium iodide or potassium iodide crystals. A yellow color indicates a low concentration of peroxide in the sample; a brown color indicates a high concentration. A blank determination should be made. Always prepare the iodide/acetic acid mixture at the time the test is made, because air oxidation slowly turns the blank to a brown color.

Ferrothiocyanate Test
A drop of the solvent to be tested is mixed with a drop of sodium ferrothiocyanate reagent, which is prepared by dissolving 9 g of FeSO4-7H2O in 50 ml of 18% hydrochloric acid. Add 0.5- 1.0 g granulated zinc followed by 5 g sodium thiocyanate. When the transient red color fades, add 12 g more of sodium thiocyanate and decant the liquid from the unused zinc into a clean, stoppered bottle. Pink or red coloration indicates the presence of peroxides.

Peroxide Test Strips
Test strips are commercially available from several vendors. Fisher Scientific currently offers a potassium iodide/starch test strip. VWR offers more elaborate test kits manufactured by EM Science and J.T. Baker. Follow the manufacturer's instructions for using the strips/kits to ensure adequate colorimetric detection.

Results:

- 0-30 ppm (KI reagent turns slightly yellow): Little of no threat of violent reaction. Should be stabilized with hydroquinone, t-butyl catechol or ferrous sulfate (between 1 and 250 ppm or about 0.1 mg inhibitor/ Liter of solvent).
- 30-80 ppm (KI reagent turns brilliant yellow): Expired or mismanaged compounds that may pose a threat to persons and structures. The available literature shows that attempts to stabilize these compounds may initiate exothermic reactions that may pose a threat to persons and structures. Tag the container for EH&S Hazardous Waste pickup and contact EHS.
- Greater than 80 ppm: (K1 reagent turns brilliant yellow to red): Expired or mismanaged compounds that pose a threat to persons and structures. Do not attempt to stabilize. Tag the container for EH&S Hazardous Waste pickup

9.2 Pyrophorics (Air Reactives)

Pyrophorics are those substances that ignite spontaneously upon contact with air.

Solids	**Liquid**	**Gases**
Sodium	Aluminum borohydride	Diborane
Finely divided metal (e.g. aluminum, chromium, zinc)	Diethylzinc	Silane

- Store in a cool, dry place. Prevent contact with air.
- Take extreme care to prevent containers of pyrophorics from leaking or breaking. The use of corrosion- and shatter-resistant secondary containers for storage and transportation of pyrophoric reagent bottles is encouraged.
- Many pyrophorics are also water reactives and/or toxics

9.3 Water Reactive

Some common laboratory hazardous materials have a great affinity for or react vigorously with water. It is important to understand situations in which water reactivity may occur and take care not to store or use these hazardous materials in damp areas.

Solids	**Liquids**
Aluminum chloride (anhydrous)	Acetyl chloride
Calcium carbide	Chlorosulfonic acid
Magnesium	Stannic chloride
Phosphorus pentachloride	Thionyl chloride
Sodium	

The first step in understanding water reactivity is to note that there are a variety of ways in which water reacts with hazardous materials and a variety of outcomes; some are hazardous, some are annoying, and others are desired.

Reactions include:

☐ Heat of reaction generated
☐ Hydrolysis of a bond
☐ Hydration, water as a ligand
☐ Solution by water, dissociation of ions or solvation
☐ Oxidation by water, forming hydrogen
☐ Reduction by water, forming oxygen
☐ Disproportionation of an oxidation state to (a) higher and lower one(s)

Factors affecting the outcome can be kinetic and thermodynamic:

☐ Heat of reaction relative to the heat capacity of what is involved
☐ Rate of interaction or mixing with water
☐ Rate of reaction with water once mixed

Possible outcomes include:

☐ Hydrolysis liberates a gas
☐ Hydrolysis generates acid protons
☐ Hydration liquifies a solid
☐ Hydrogen is generated
☐ Oxygen is generated

The specific type water interaction is also important:
☐ Limited water is added to material
☐ Material is added to water that is in excess
☐ Humidity in air invades a container or exposed material

- Store in a cool, dry place. Keep away from water.
- In case of fire, do not use water. Use a dry chemical extinguisher.

9.4 Explosive and Potentially Explosive Chemicals

Explosive chemicals can rapidly release tremendous amounts of destructive energy. Explosive chemicals can cause death, serious injury, or severe property damage. Heat, shock, friction, or even static electricity can initiate explosions of these chemicals. The family includes pure chemicals (e.g., TNT) and mixtures (e.g., ammonium nitrate/ fuel mixtures).

In addition to explosive chemicals, which constitute a known high hazard, there are chemicals that may become explosive, depending on how they are handled. This category is commonly referred to as potentially explosive chemicals and includes:

- Pure chemicals or mixtures that may become explosive through contamination (e.g., perchloric acid contaminated with organic compounds or metals); and
- Pure chemicals or mixtures that may degrade over time and become explosive (e.g. hydrated picric acid, which becomes explosive upon drying).

Storage Precautions

- Identify all explosive and potentially explosive chemicals in your inventory.
- For chemicals that may degrade to become potentially explosive, record the opening date and discard date directly onto the container or onto a potentially explosive chemical warning label (available from EH&S).
- Keep explosive chemicals away from all ignition sources: open flames, hot surfaces, direct sunlight, spark sources.
- Store explosive chemicals in an explosive magazine and inspect areas weekly
- Consider designating a special area to store and use potentially explosive chemicals.

- Make sure everyone who uses explosive or potentially explosive chemicals is thoroughly trained in safe storage methods, conditions to avoid (e.g., contamination), the hazards of the chemical, and disposal procedures.
- Contact EH&S immediately if you suspect a material may have become explosive. Post warning signs so others do not handle or disturb the material.
- Note: Most explosions occur while purifying or distilling mixtures. Therefore, use extreme caution before concentrating or purifying any mixture that may contain an explosive chemical (e.g., a peroxide forming chemical or perchlorate).

9.5 Special Precautions for Perchloric Acid

Perchloric acid can be dangerously reactive. Aqueous perchloric acid at concentrations less than 70% at room temperatures is a strong acid. At elevated temperatures or concentrations greater than 70% it is a strong oxidizing agent and can cause violent explosions if misused. Anhydrous perchloric acid (greater than 85%) is unstable even at room temperatures and ultimately decomposes spontaneously with a violent explosion. Contact with oxidizable material can cause an immediate explosion.

Follow these guidelines for the proper use of perchloric acid in the laboratory:
Perchloric acid in concentrations greater than 70% is not recommended.

a. Any procedure involving heating of perchloric acid must be conducted in a properly functioning perchloric acid fume hood with the sash down.
b. Do not allow perchloric acid to come into contact with organic material or dehydrating agents.
c. Anhydrous perchloric acid should only be made as required and should never be stored. Only experienced faculty should handle anhydrous perchloric acid. EHS should be contacted prior to any work with anhydrous perchloric acid.
d. Do not allow contact with metals to prevent the formation of metal perchlorates which are very unstable and can explode.
e. Do not allow contact with wood or paper as fires can result from such contact.

Safe Handling Guidelines for Reactives

a. Store in cool, dry area away from normal work areas and protected from shock, vibration, incompatible chemicals, elevated temperatures, and rapid temperature changes
b. Store as required according to the nature of their individual hazards e.g. metal hydrides; some hydrogenation catalysts; picric acid; dinitrophenol; trinitrotoluene
c. For air reactive chemicals use a glove box or fill the head space of the container with an inert gas before sealing the container.
d. Water sensitive chemicals
    a. Store in cool, dry areas designed to prevent accidental contact with water and other incompatible substances.
    b. Storage construction should be fire-resistant.
    c. Protect chemicals from water from sprinkler systems.
e. Secondary containment is recommended.

10Toxics and Highly Toxics

Laboratory Chemicals

Solids
Acrylamide
Cadmium chloride
Potassium fluoride
Arsenic salts (HT)
Calcium cyanide (HT)
Organic mercury compounds (HT)

Liquids
Aniline
chlordane
phenol
Acrolein (HT)
Hydrocyanic acid (HT)
Nicotine (HT)

Gases
Ammonia
Hydrogen fluoride
Vinyl bromide
Diborane (HT)
Fluorine (HT)
Nitrogen Dioxide (HT)

Non-Laboratory Chemicals

Solids
diazinon

Liquids
Copper sulfate

- Segregate toxics from other hazard classes and store in a cool, well ventilated area, away from light and heat.
- Containers should be tightly sealed to minimize exposure to personnel and contamination of other chemicals.
- Maintain the lowest possible quantities of highly toxics.
- Use highly toxic chemicals in a designated area or laboratory. Highly toxic chemicals that produce fumes or dust should always be handled within a chemical fume hood.

10.1 Special Precautions for Mercury

Mercury and its compounds are very common in laboratories. Because of its widespread use, mercury’s hazardous nature may be overlooked or ignored. Elemental mercury is volatile, and its vapors are extremely toxic. Because of the vapors’ high toxicity, it is very important to clean up mercury spills promptly and thoroughly. If this is not done, mercury can accumulate and vaporize over time. Inorganic and organic mercury compounds are also highly toxic.

Follow these guidelines for the proper use of mercury in the laboratory:

a. All work with elemental mercury should be performed over trays to capture and contain any spillage.
b. All work involving mercury should be done in a properly functioning chemical fume hood.
c. Clean up all mercury spills immediately. If you do not have the appropriate spill-control equipment, do not clean the spill yourself, as you can make the situation worse by creating small droplets that can end up in inaccessible locations such as cracks and crevices. For assistance, contact EHS.
d. Be careful not to heat any surfaces that may contain mercury residue, as increased temperature greatly increases the vapor pressure of mercury.
e. Red spirit thermometers are a nontoxic alternative to mercury thermometers and should be used whenever possible.

11 Radioactive Materials

The Nuclear Regulatory Commission (NRC) regulates radioactive materials used in research or academic applications at the University. The State of Colorado has entered into an agreement with the NRC to govern the safe use of radioactive materials, designating the Colorado Department of Public Health and Environment (CDPHE) as responsible for developing and implementing applicable State regulations. The University of Colorado Boulder has been issued a radioactive materials license and is responsible for the safe use of these materials on the Boulder and the Colorado Springs campuses through the Radiation Safety / Health Physics Unit at Environmental Health and Safety at CU Boulder. The Radiation Safety Handbook provides details on the program as implemented.

If you are utilizing radioactive material and/or radiation generating equipment, this needs to be coordinated with both UCCS EHS and CU-Boulder Radiation Safety group.

11.1 Storage and Use of Radioactive Materials

Cabinets, freezers and all other equipment used to store radioactive materials must have a Caution Radioactive Materials sign or label with the radiation trefoil visible. Radioactive materials should be stored only in areas properly marked and approved for their use. Storage equipment should be equipped with a lock to ensure security of the material.

11.2 Designated Radiation Use Areas Radioactive

materials should be stored and/or used only in designated areas. If materials need to be moved to another room, the radiation license will need to be amended to include the new space. Security requirements remain the same for all radiation use areas and required signs and labels need to be posted. It is also a good idea for laboratories to designate an area(s) for eating, drinking and food storage outside of the laboratory.

11.3 Security of Radioactive Materials

Each laboratory must ensure the security of radioactive materials and/or radiation-producing machines. The following security procedures should be in place in all laboratories using radioactive materials: o Doors to the laboratory should be locked if no one is present o Strangers to the laboratory should be challenged. o Radiation storage and use areas should be consolidated and minimized whenever possible. o Radioactive materials removed from secure storage should always be under direct observation ("line of sight") by a member of the laboratory who has completed radiation safety training. o Storage cabinets and refrigerators/freezers containing radioactive materials (stock vials and aliquots of radioisotope, as well as sealed sources) must be locked when not actively in use. o Radioactive waste containers should be closed and kept secured when not actively in use.

12 Synthesized Chemicals

Some laboratories synthesize or develop new chemical substances during the course of their research. For the safe handling and management of a newly synthesized chemical, the researcher must label the substance with the IUPAC name or a clearly identifiable lab-designated name; a chemical structure may be included as well. Also, label the substance with the material's hazardous properties (e.g., toxic, reactive, flammable, corrosive), determined to the best of the researcher's ability. If the composition of a new chemical substance or mixture is unknown, it must be assumed to be hazardous.

If the lab transfers newly synthesized chemicals to another user outside of the university or if any adverse health or environmental effects are observed by laboratory personnel working with newly synthesized chemicals, contact EHS at 719-255-3212 for assistance.

Form A - ***Questionnaire for Use of Hydrogen Fluoride Gas and Hydrofluoric Acid***

Building: ___________ Department: ________________ Room: ________________

Principle Investigator: _________________________ Phone #: _________________

Lab Contact: _______________________ Phone #: __________________________

Do you use:

Hydrofluoric Acid ☐ Stock Concentration___________ Total Vol. _________

Hydrogen Fluoride Cylinder☐ Concentration_________ Total Vol. ____________

Does the lab have a fume hood? ☐ Yes ☐ No

Has a current laboratory Chemical/Gas Inventory been submitted to EH&S? ☐ Yes ☐ No

Hydrofluoric Acid:
What is the HF working solution concentration?
____
Where will the HF be used in the Lab?
____
Where will the HF be stored in the Lab?
____

Has an Experimental Protocol been written for HF use? ☐ Yes ☐No
(If "No" Please prepare and submit Experimental Protocol to EH&S; see "Requirements for Use of Hydrogen Fluoride Gas and Hydrofluoric Acid" for guidance)

Hydrogen Fluoride Gas:
What is the HF Gas working concentration?
____
Where will the HF Gas be used in the Lab?
____
Where will the HF Gas be stored in the Lab?
____

Has an Experimental Protocol been written for HF Gas use? ☐ Yes☐ No
(If "No" Please prepare and submit Experimental Protocol to EHS; see section 6.4 for guidance)

Please complete this questionnaire and return it to EHS