University of Minnesota Rochester
Center for Learning Innovation
Laboratory Safety Plan

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Referenced from DEHS-University of Minnesota Twin Cities
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Chapter 1 – Introduction

1. Purpose
This Laboratory Safety Plan (LSP) describes policies, procedures, equipment, personal protective equipment and work practices that are capable of protecting employees from the health hazards in laboratories. This Plan is intended to meet the requirements of the federal Laboratory Safety Standard, formerly known as "Occupational Exposure to Hazardous Chemicals in Laboratories", a copy of which is found in Appendix A (p.38). This LSP also addresses the concerns of the Minnesota Employee Right to Know Act (MERTKA) and the federal Toxic Substance Control Act (TSCA).

This LSP is intended to safely limit laboratory workers' exposure to OSHA- and MERTKA-regulated substances. Laboratory workers must not be exposed to substances in excess of the permissible exposure limits (PEL) specified in OSHA rule 29 CFR 1910, Subpart Z, Toxic and Hazardous Substances. PELs for regulated substances can be viewed at http://www.dehs.umn.edu/ressafety_rsp_lte.htm. PELs refer to airborne concentrations of substances and are averaged over an eight-hour day. A few substances (listed under Individual Chemical Standard in the Federal column in Appendix B (p.49) also have "action levels". Action levels are air concentrations below the PEL which nevertheless require that certain actions such as medical surveillance and workplace monitoring take place. An employee's workplace exposure to any regulated substance must be monitored if there is reason to believe that the exposure will exceed an action level or a PEL. If exposures to any regulated substance routinely exceed an action level or permissible exposure level there must also be employee medical exposure surveillance.

MERTKA requires employers to evaluate their workplaces for the presence of hazardous substances, harmful physical agents, and infectious agents and to provide training to employees concerning those substances or agents to which employees may be exposed. Written information on agents must be readily accessible to employees or their representatives. Employees have a conditional right to refuse to work if assigned to work in an unsafe or unhealthful manner with a hazardous substance, harmful physical agent or infectious agent. Labeling requirements for containers of hazardous substances and equipment or work areas that generate harmful physical agents are also included in MERTKA.

Toxic Substances Control Act (TSCA) requires that prudent laboratory practices be developed and documented for research involving new chemicals that have not had their health and environmental hazards fully characterized. Laboratories engaged in research must consider the applicability of the Toxic Substances Control Act (TSCA) on their operation. TSCA, administered by the U.S. Environmental Protection Agency (EPA) under the New Chemicals Program (http://www.epa.gov/oppt/newchems/), is intended to ensure that the human health and environmental effects of chemical substances are identified and adequately addressed prior to commercial use or transport of those substances. A new chemical is a chemical substance that is produced or imported and not yet listed on the TSCA Chemical Substance Inventory. Each
laboratory or research group that synthesizes or imports new chemicals must determine if and how TSCA applies to their laboratory activities – see Appendix J (p.170).

2. Scope and Application

The Laboratory Safety Standard applies where 'laboratory use' of hazardous chemicals occurs. Laboratory use of hazardous chemicals means handling or use of such chemicals in which all of the following conditions are met:

i. the handling or use of chemicals occurs on a 'laboratory scale', that is, the work involves containers which can easily and safely be manipulated by one person,

ii. multiple chemical procedures or chemical substances are used, and

iii. protective laboratory practices and equipment are available and in common use to minimize the potential for employee exposures to hazardous chemicals.

At a minimum, this definition covers employees (including student employees, technicians, supervisors, lead researchers and physicians) who use chemicals in teaching, research and clinical laboratories at the University of Minnesota Rochester. Certain non-traditional laboratory settings may be included under this standard at the option of individual departments within the University. Also, it is the policy of the University that laboratory students, while not legally covered under this standard, will be given training commensurate with the level of hazard associated with their laboratory work.

This standard does not apply to laboratories whose function is to produce commercial quantities of material. Also, where the use of hazardous chemicals provides no potential for employee exposure, such as in procedures using chemically impregnated test media and commercially prepared test kits, this standard will not apply. The researchers listed in the following table are covered by this Laboratory Safety Plan.

<table>
<thead>
<tr>
<th>Principal Investigator</th>
<th>Building</th>
<th>Room #</th>
<th>Primary research hazards</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dr. Rajeev Muthyala</td>
<td>USq</td>
<td>424</td>
<td>Inhalation/Explosion/Flammable</td>
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<tr>
<td>Dr. Robb Dunbar</td>
<td>318</td>
<td>3</td>
<td>None Currently</td>
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<tr>
<td>Dr. Kelsey Metzger</td>
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<td>4</td>
<td>None Currently</td>
</tr>
<tr>
<td>Dr. Xavier Prat-Resina</td>
<td>USq</td>
<td>424</td>
<td>None Currently</td>
</tr>
<tr>
<td>Dr. Bijaya Aryal</td>
<td>USq</td>
<td>418</td>
<td>None Currently</td>
</tr>
</tbody>
</table>

3. Coordination with Other Standards and Guidelines

The Laboratory Safety Standard and MERTKA address occupational safety issues. Other federal, state and local standards that address use of hazardous chemicals and other materials are
listed in Appendix B (p.49). Note particularly the listed chemicals with individual standards in the ‘Federal’ column, since these compounds generally have *action limits* (usually set at half the TLV), *air monitoring requirements*, and *medical monitoring requirements*. If a researcher is using one of these chemicals, or in the unlikely event that there is a conflict between provisions of various standards, the Department of Environmental Health and Safety should be contacted.

4. Responsibilities

Implementation of the Laboratory Safety Standard at the University is a shared responsibility. Employees, supervisors, Research Safety Officers, department heads, deans, upper administrative staff, and DEHS staff all have roles to play. These roles are outlined below.

A. **President, Vice Presidents, Provosts and Chancellors (Central Administration)**
   Upper level administrators are responsible for:
   - promoting the importance of safety in all activities;
   - promoting the same attitude among all levels of employment at the University;
   - supporting a broad-based laboratory safety/chemical hygiene program that will protect U of MN laboratory employees from health effects associated with hazardous chemical, physical or biological agents; and
   - ensuring that deans, directors and department heads provide adequate time and recognition for employees who are given laboratory safety responsibilities.

   Performance will be measured by:
   - DEHS's documentation and annual reporting of the level of compliance within each of the reporting units.

B. **Deans, Directors and Department Heads**
   DDDs are responsible for:
   - identifying at least one technically-qualified research safety officer for the unit. (Colleges or institutes that are made up of a number of large laboratory-based departments are urged to assign research safety officers within each department. Large departments may assign one research safety officer for each division);
   - transmitting the name of the designated research safety officer to the U of MN's Chemical Hygiene Officer;
   - ensuring that the designated research safety officer is adequately trained regarding the roles and responsibilities of the position;
   - ensuring that the designated research safety officer modifies this generic Laboratory Safety Plan to incorporate location-specific information;
   - carries out his/her assigned responsibilities
   - evaluating the performance of the research safety officer(s) as part of overall job performance; and
   - taking appropriate measures to assure that college/department/division activities comply with University and OSHA laboratory safety policies;
Performance will be measured by:
- DEHS's record of a trained, research safety officer for the unit.
- DEHS's record of a current, tailored Laboratory Safety Plan for the unit.

C. **Department of Environmental Health and Safety (DEHS)**

The Chemical Hygiene Officer for UMR is Dawn Errede, and the entire DEHS staff will participate in providing resources for departments in the development of their individual health and safety programs. The Department of Environmental Health and Safety is responsible for:
- preparing and updating the University's generic Laboratory Safety Plan;
- distributing the LSP to departments or other units who will tailor and implement the plan;
- training designated departmental research safety officers regarding their responsibilities for safety and compliance with regulations and University standards that apply to research; and
- monitoring the progress of departments toward achieving compliance.

Performance will be measured by:
- DEHS's documentation that review and evaluation of the generic LSP occurs at least annually, updates as necessary;
- annual feedback to DDDs regarding DEHS's records of Health and Safety compliance status for each unit.

D. **Research Safety Officer**

The RSO's roles and responsibilities are described in greater detail in the RSO Toolkit. Briefly, the RSO will:
- serve as liaison between employing department and the Department of Environmental Health and Safety;
- know the rules, to help researchers comply with applicable state, federal and university requirements;
- develop and implement a Laboratory Safety Plan for the department;
- coordinate training to ensure all researchers understand their responsibilities and the policies that apply to their research.
- coordinate inspections of laboratories and ensure laboratory supervisors address any noted deficiencies;
- keep records to document compliance with state, federal and university requirements.

Performance will be measured by DEHS's documentation in a letter to the DDDs that:
- review and evaluation of the tailored LSP occurs at least annually;
- the research safety officer's personal training records are current;
- update training for lab researchers and supervisors occurs at least annually;
- labs are audited at least annually

E. **Supervisors/Principal Investigators**

The immediate supervisor of a laboratory employee is responsible for:
• assuring that potential hazards of specific projects have been identified and addressed before work is started;
• ensuring there are written, laboratory-specific standard operating procedures for the protocols carried out in the laboratory that incorporate directions about how to mitigate the hazards of the procedures.
• informing and training employees regarding the specific hazards in their area and in the work they will be doing;
• scheduling time for the employee to attend designated training sessions;
• enforcing U of MN safety policies and safe work practices;
• conducting periodic audits of the research space under the supervisor's control;
• reporting hazardous conditions to the college or departmental research safety officer;
• investigate laboratory accidents and send an Accident Investigation Worksheet (Appendix I (p.169)) with recommendations to the departmental research safety officer for review.

Performance will be measured by:
• home department's documentation of current, pertinent safety training for the supervisor and each employee in the supervisor's group;
• home department's documentation of regular audits for laboratory space under the control of the supervisor.

F. **Employee**
Employees who have significant responsibility for directing their own laboratory work are responsible for assuring that potential hazards of specific projects have been identified and addressed before work is started. All laboratory employees however, are responsible for:
• attending safety training sessions;
• following safety guidelines applicable to the procedures being carried out;
• assuring that required safety precautions are in place before work is started; and
• reporting hazardous conditions as they are discovered.

Performance will be measured by:
• supervisor's assessment of employee's adherence to topics covered in safety training.
Chapter 2 - Standard Operating Procedures

As noted in Chapter 1, Principal Investigators are responsible for ensuring there are written standard operating procedures (SOPs) for the research protocols conducted in their area. The SOPs must identify the hazards of the protocol, as well as measures to be taken to mitigate those hazards. The references listed below may provide enough detail to serve as the SOPs for some research protocols. Other protocols may require more tailoring, as described in Section 5 of this chapter.

1. Chemical Procedures

A. Prudent Practices in the Laboratory (Appendix C (pp.153))

Laboratory standard operating procedures found in Prudent Practices in the Laboratory: Handling and Disposal of Chemicals (National Research Council, 1995) are adopted for general use at the University of Minnesota Rochester. Departmental Research Safety Officers have hard copies of this text, and the entire contents are accessible on the web. Note especially the following topics which are covered in Chapters 5 and 6 of Prudent Practices:

Chapter 5 Working with Chemicals
- Introduction
- Prudent Planning
- General Procedures for Working with Hazardous Chemicals
- Working with Substances of High Toxicity
- Working with Biohazardous and Radioactive Materials
- Working with Flammable Chemicals
- Working with Highly Reactive or Explosive Chemicals
- Working with Compressed Gases

Chapter 6 Working with Laboratory Equipment
- Introduction
- Working with Water-Cooled Equipment
- Working with Electrically Powered Laboratory Equipment
- Working with Compressed Gases
- Working with High/Low Pressures and Temperatures
- Using Personal Protective, Safety, and Emergency Equipment
- Emergency Procedures
B. Controlled Substances and Alcohol

In conducting research with controlled substances, University authorized employees must comply with federal and state laws and regulations regarding their uses, including registration with the Drug Enforcement Administration (DEA), storage requirements, inventory maintenance and substance disposal. A condensed guide to federal regulations as well as policies and forms pertaining to controlled substances are available on the Controlled Substances webpage at http://www.research.umn.edu/riop/controlsubst.htm

Alcohol used for education, scientific research, or medicinal purposes can be purchased tax-free through University Stores (www.ustores.umn.edu), which holds the University of Minnesota site license for alcohol purchases with the Federal Bureau of Alcohol, Tobacco, and Firearms (BATF). Further information and regarding ordering forms are available in Tax Free Alcohol Ordering Procedures in Appendix.

C. The American Chemical Society's "Safety in Academic Chemistry Laboratories"

ACS’s "Safety in Academic Chemistry Laboratories" is another useful text. This manual presents information similar to that found in Prudent Practices, but in a considerably condensed format.

D. Hazardous Waste Management

Extensive and detailed policies regarding hazardous waste management are specified in the University's guidebook "Hazardous Chemical Waste Management, 5th edition". Please refer to this text for approved waste handling procedures.

E. Emergency Procedures for Chemical Spills

The procedures listed below are intended as a resource for your department in preparing for emergencies before they happen. If you are currently experiencing an emergency such as a chemical or blood spill, please contact the Rochester Fire Department at 507-328-2800 or William Simmons at 507-258-8423(office) or 612-810-7623(cell).

Complete spill response procedures are described in the Hazardous Chemical Waste Management Guidebook at http://www.dehs.umn.edu/hazwaste_chemwaste_umn_cwmgbk_sec3.htm#qrcsep

However, the quick reference guide is included for convenience in this Laboratory Safety Plan.
Quick Reference Guide

Evacuate

- Leave the spill area; alert others in the area and direct/assist them in leaving.
- Without endangering yourself: remove victims to fresh air, remove contaminated clothing and flush contaminated skin and eyes with water for 15 minutes. If anyone has been injured or exposed to toxic chemicals or chemical vapors, call 911 and seek medical attention immediately.

Confine

- Close doors and isolate the area. Prevent people from entering spill area.

Report

- From a safe place, call the Rochester Fire Department at 507-328-2800 during working hours, 911 after hours.
- Report that this is an emergency and give your name, phone and location; location of the spill; the name and amount of material spilled; extent of injuries; safest route to the spill.
- Stay by that phone, the Rochester Fire Department will advise you as soon as possible.
- The Rochester Fire Department will clean up or stabilize spills, which are considered high hazard (fire, health or reactivity hazard). In the case of a small spill and low hazard situation, the Rochester Fire Department will advise you on what precautions and protective equipment to use.

Secure

- Until emergency response personnel arrive: block off the areas leading to the spill, lock doors, post signs and warning tape, and alert others of the spill.
- Post staff by commonly used entrances to the area to direct people to use other routes.

After an accident, supervisor(s) must complete and fax in reporting forms within 24 hours. Workers’ Compensation policy and reporting forms are available on the web (Appendix J).

2. Biohazardous Procedures (Not Currently at UMR)

All researchers working with human blood or body fluids, or other pathogens must follow the University’s Exposure Control Plan, and complete Blood-borne Pathogens Training, available on the web. All researchers working with infectious material including attenuated lab & vaccine strains (bacteria, viruses, parasites, fungi, prions), biologically-derived toxins, rDNA, and artificial gene transfer must follow requirements of the University’s Biosafety Program detailed in the Biosafety Manual and on the Institutional Biosafety Committee’s website.
A. Biosafety Manual

The University’s Biosafety Manual is made up of three components; researchers must implement all three components in their lab safety manual.

- Biosafety Principles and Practices;
- CDC/NIH's text Biosafety in Microbiological and Biomedical Laboratories (BMBL).
- Individual lab-specific Standard Operating Procedures (SOPs) that:
  - specify the biohazards being used
  - identify the material handling steps that may pose a risk of exposure (sharps, injecting animals, centrifugation, aerosol production, transport, etc.)
  - describe equipment and techniques used to reduce the above risk of exposure
  - give instructions for what to do in case of an accidental exposure/spill
  - list wastes that will be generated and how to properly dispose of wastes

B. Institutional Biosafety Committee (IBC)

The IBC is charged under Federal Regulations (NIH) and University of Minnesota Regents’ Policy with the oversight of all teaching and research activities involving:

- Recombinant DNA
- Artificial gene transfer
- Infectious agents including attenuated lab & vaccine strains
- Biologically derived toxins

See the IBC web site for procedures to apply for approval for the above work.

C. Select Agents

Labs in possession of organisms or toxins that are federally designated as select agents are required to be registered with the Centers for Disease Control if quantities exceed the exemption amounts. See the Biosafety Section of the DEHS web site for a list of select agents, exemption quantities, and procedures for their use.

D. Additional Biosafety References


3. Radioactive Procedures (Not Currently at UMR)

All researchers using radioactive materials at the University of Minnesota Rochester must:

- obtain a permit for the possession and use of radioactive materials (contact the Radiation Protection Division);
- complete required training modules; and
- comply with the radiation policies and procedures of the university (contained in the Radiation Protection manual)

The Radiation Protection manual contains information on a number of topics including license committees, the permitting process, purchasing procedures, transfer procedures, general safety, personnel dosimetry, waste management, emergency management (spill control), record keeping, and regulatory guides on occupational exposure and prenatal exposure.

Training is required for all personnel who require access to areas where radioactive materials are used or stored. This training can be completed online. (http://www.dehs.umn.edu/rad_radmat_training.htm)

4. General Safety Procedures

Other lab and general safety information is available on the University of Minnesota website as indicated below.

A. Lab Safety

- Emergency Eyewash and Safety Shower Installation (http://www.cppm.umn.edu/standards/AppendixS.pdf)
- Personal Protective Equipment for Animal Care and Use (http://www.ohs.umn.edu/ppe/home.html)
- Respiratory Protection for Lab Animal Allergens (http://www.ohs.umn.edu/laa/home.html)
- Controlled Substances (http://www.research.umn.edu/riop/controlsubst.htm)
- Lock Out/Tag Out (http://www.dehs.umn.edu/train_factsheet_lkouttagout.htm)
- Respiratory Protection Program (http://www.dehs.umn.edu/Docs/Respiratory%20Protection%20Program%20Instruction.doc)
- Hearing Conservation Program (http://www.ohs.umn.edu/hcp/home.html)
• Laboratory Close-out Procedure
  (http://www.dehs.umn.edu/Docs/LaboratoryCloseout.doc)

B. General Safety

• Emergency Procedures
  (http://www1.umn.edu/prepared/)
• Temperature Standard
  (http://www.dehs.umn.edu/iaq_tempstandards.htm)
• University of Minnesota Campus Smoke-Free Indoor Air Policy
  (http://www.policy.umn.edu/Policies/Operations/Safety/SMOKING.html)
• Supervisors Injury/Illness Investigation Form
  (http://www.policy.umn.edu/prod/groups/president/@pub/@forms/@hr/documents/form/supincidentinv.doc)

5. Laboratory-Specific Standard Operating Procedures

Each PI must have written Standard Operating Procedures (SOPs) for the research protocols conducted in his or her laboratory. Like the Lab Safety Plan, the SOPs must be accessible to researchers. Keeping hard copies in the lab or having them on a computer in the laboratory fulfills the accessibility requirement. SOPs developed through DEHS will be posted periodically at http://www.dehs.umn.edu/ressafety_rsp_ssop.htm.

Laboratory-specific SOPs are valuable research tools that supplement the departmental Laboratory Safety Plan. The process of writing SOPs requires an individual to think through all steps of a procedure and perform a risk assessment before beginning work. The SOP provides a written means to inform and advise researchers about hazards in their work place, allows for standardization of materials and methods, and improves the quality of the research. A well-written SOP can be used to comply with the Federal Laboratory Safety Standard, which states that the Laboratory Safety Plan must include:

"standard operating procedures relevant to safety and health considerations to be followed when laboratory work involves the use of hazardous chemicals."

SOPs should include exposure controls and safety precautions that address both routine and accidental chemical, physical or biological hazards associated with the procedure. A laboratory safety information sheet is available in Appendix D (p.154). This checklist, which prompts researchers to identify hazards and safety measures for the protocol, can be attached to existing procedures which may lack safety information. A template for writing new SOPs is available in Appendix F (p.159) and guidance for writing biologically-related SOPs is available on the Biosafety section of the DEHS website.
6. General Emergency Procedures

Definition of an “Event"
An “event” is considered an undesirable experimental occurrence in the laboratory. This includes, but is not limited to, a fire, explosion, and chemical spill. This does not include events where an injury occurs; they are covered under protocols related to lab injuries and must be reported.

Lab Event Protocol
1. An event which is contained in a secondary container (for example: a reaction in a flask, inside an ice bath) and does not breach the secondary container can likely be handled by the researcher/instructor and does not require further reporting.

2. An event which breaches secondary containment, but is contained inside a fume hood can be handled by a researcher/instructor and does not require further reporting.

   However, such an event should be considered carefully by the researcher/instructor; as events of this nature can be significantly larger than first assessed. If an event of this nature damages infrastructure: cracks a fume hood, escapes down the drain, causes even minor fire damage to any equipment; it must be reported.

3. An event of magnitude #2 (above) which occurs outside of a fume hood or breaches a fume hood due to scale should trigger an evacuation of the room and potentially the building. Events of this nature require reporting.

Lab Event Reporting
Any of the following events must be reported:

1. Any event where an injury occurs.
2. Any event where building or laboratory infrastructure is damaged (fire damage, chemical damage to paint, broken equipment, etc.)
3. Any event where a measurable quantity of chemicals is released into the environment.
4. Any event where a room/floor/building requires evacuation.
5. Any event where a fire extinguisher is discharged.
Chemical Spill
Emergency Procedures

Quick Reference Guide:

**Evacuate**
- Leave the spill area; alert others in the area and direct them to leave.
- Without endangering yourself, remove victims to fresh air, remove contaminated clothing, and flush contaminated skin and eyes with water for 15 minutes. If anyone has been injured or exposed to toxic chemicals or chemical vapors, call 911; call Premier Security (507-281-4952); and seek medical attention immediately.

**Confine**
- Close doors and isolate the area. Prevent people from entering spill area.

**Report**
- From a safe place, call the Rochester Fire Department (911); then call Premier Security (507-281-4952).
- Report that this is an emergency and give your name, phone number and current location; location of the spill; the name and amount of material spilled; extent of injuries; and safest route to the spill.
- Stay by that phone. The Rochester Fire Department will advise you as soon as possible. The Rochester Fire Department will clean up or stabilize spills which are considered high hazard (fire, health, or reactivity hazard). In the case of a small spill and low hazard situation, the Rochester Fire Department will advise you on what precautions and protective equipment to use.

**Secure**
- Until emergency response personnel arrive – block off the areas leading to the spill, lock doors, post signs and warning tape, and alert others of the spill.
- Post staff by commonly used entrances to the area to direct people to use other routes.

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Needle Stick and Other Infectious Exposure

If you or one of your employees is exposed to blood borne or other infectious pathogens, by a needle-stick or other exposure, it is necessary to seek medical attention within 1-2 hours so that treatment will be the most effective.

**Types of Hazardous Exposures**

**Hazardous exposures include:**
- Percutaneous inoculation/puncture with blood or body fluid by a sharp instrument or sharp needle
- Contact with blood or body fluid through fresh (less than 24 hours) cut or mucous membrane contact (e.g. splash to the eye or mouth, or mouth-to-mouth resuscitation)
- Skin exposure involving large amounts of blood or prolonged contact with blood, especially when the exposed skin is chapped, abraded, or afflicted with dermatitis.

**Emergency Procedures**
- Administer first aid if necessary. An Automated External Defibrillator (AED) is located on third floor in the student lounge.
- Call 911; then call Premier Security (507-281-4952) and seek medical attention.
- Employees should report the incident to their supervisor(s) as soon as possible. It is important to fill out all of the appropriate documentation. Please contact the Director of Human Resources (507-258-8010) for assistance.
  - Employee First Report of Injury
  - Supervisor Incident Investigation Report
- Send Incident Report Form to the Institutional Biosafety Committee (IBC) if exposure has occurred during work on an IBC protocol.
- Report all biohazard exposures to the Office of Occupational Health and Safety (612-626-5008 or uohs@umn.edu).

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<table>
<thead>
<tr>
<th>Emergency</th>
<th>911</th>
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</thead>
<tbody>
<tr>
<td>Premier Security</td>
<td>507-281-4952</td>
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<tr>
<td>Rochester Fire Department</td>
<td>507-328-2800</td>
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<tr>
<td>Director of Human Resources</td>
<td>507-258-8010</td>
</tr>
<tr>
<td>Office of Occupational Health and Safety</td>
<td>612-626-5008</td>
</tr>
</tbody>
</table>
The procedures listed below are intended as a resource for your department in preparing for emergencies **before** they happen. If you are currently experiencing an emergency such as a chemical or blood spill, please contact the Rochester Fire Department at 507-328-2800.

For University employees who have been exposed to blood-borne or other infectious pathogens, please follow the procedures below under "Needle Stick." For all other emergencies call 911.

Campus Safety Information Guidebook

- bomb threats
- medical emergencies
- fire
- severe weather
- utility outages
- warning systems/sirens

**Chemical Spills**
(http://www.dehs.umn.edu/hazwaste_chemwaste_umn_cwmgbk_sec3.htm)

**First Aid for Laboratory and Research Staff**
(http://www.dehs.umn.edu/Docs/Lab_First_Aid.doc)

**Needle Sticks**
(http://www.dehs.umn.edu/bio_pracprin_blood_needle.htm)

**Radioactive Material Incidents**
(http://www.dehs.umn.edu/rad_radmat_incidents.htm)

**Workplace Violence**
(contact Human Resources ([ohr@umn.edu](mailto:ohr@umn.edu)) for a hard-copy)

**7. Planning for Shutdowns**

Researchers should develop written procedures to deal with events such as loss of electrical power (affecting fume hoods, coolers etc.) or other utilities (water), or temporary loss of personnel due to illnesses such as pandemic flu. Guidance on factors to consider when developing shut-down plans is included in the Lab Hibernation Checklist in Appendix L (p.181).
Chapter 3 - Criteria for Implementation of Chemical Control Measures

Engineering controls, personal protective equipment, hygiene practices, and administrative controls each play a role in a comprehensive laboratory safety program. Implementation of specific measures must be carried out on a case-by-case basis, using the following criteria for guidance in making decisions. Assistance is available from the Department of Environmental Health and Safety.

1. Engineering controls

a) Fume Hoods
The laboratory fume hood is the major protective device available to laboratory workers. It is designed to capture chemicals that escape from their containers or apparatus and to remove them from the laboratory environment before they can be inhaled. Characteristics to be considered in requiring fume hood use are physical state, volatility, toxicity, flammability, eye and skin irritation, odor, and the potential for producing aerosols. A fume hood should be used if a proposed chemical procedure exhibits any one of these characteristics to a degree that (1) airborne concentrations might approach the action level (or permissible exposure limit), (2) flammable vapors might approach one tenth of the lower explosion limit, (3) materials of unknown toxicity are used or generated, or (4) the odor produced is annoying to laboratory occupants or adjacent units.

Procedures that can generally be carried out safely outside the fume hood include those involving (1) water-based solutions of salts, dilute acids, bases, or other reagents, (2) very low volatility liquids or solids, (3) closed systems that do not allow significant escape to the laboratory environment, and (4) extremely small quantities of otherwise problematic chemicals. The procedure itself must be evaluated for its potential to increase volatility or produce aerosols.

In specialized cases, fume hoods will contain exhaust treatment devices, such as water washdown for perchloric acid use, or charcoal or HEPA filters for removal of particularly toxic or radioactive materials.

b) Safety Shields
Safety shields, such as the sliding sash of a fume hood, are appropriate when working with highly concentrated acids, bases, oxidizers or reducing agents, all of which have the potential for causing sudden spattering or even explosive release of material. Reactions carried out at non-ambient pressures (vacuum or high pressure) also require safety shields, as do reactions that are carried out for the first time or are significantly scaled up from normal operating conditions.
c) Biological Safety Cabinets (Not Currently at UMR)

Biological Safety Cabinets (BSC), also known as tissue culture hoods or laminar flow hoods, are the primary means of containment for working safely with infectious microorganisms. Cabinets are available that either exhaust to the outside or that recirculate, HEPA filtered air to the laboratory. They are not to be used for working with volatile or hazardous chemicals unless they are specifically designed for that purpose and are properly vented. Generally, the only chemical work that should be done in a BSC is that which could be done safely on a bench top involving chemicals that will not damage the BSC or the HEPA filter. For proper cabinet selection and use see, the CDC publication Primary Containment for Biohazards at http://www.cdc.gov/biosafety/.

d) Other Containment Devices (Not Currently at UMR)

Other containment devices, such as glove boxes or vented gas cabinets, may be required when it is necessary to provide an inert atmosphere for the chemical procedure taking place, when capture of any chemical emission is desirable, or when the standard laboratory fume hood does not provide adequate assurance that overexposure to a hazardous chemical will not occur. The presence of biological or radioactive materials may also mandate certain special containment devices. High strength barriers coupled with remote handling devices may be necessary for safe use of extremely shock sensitive or reactive chemicals.

Highly localized exhaust ventilation, such as is usually installed over atomic absorption units, may be required for instrumentation that exhausts toxic or irritating materials to the laboratory environment.

Ventilated chemical storage cabinets or rooms should be used when the chemicals in storage may generate toxic, flammable or irritating levels of airborne contamination.

2. Personal Protective Equipment

a) Skin Protection

As skin must be protected from hazardous liquids, gases and vapors, proper basic attire is essential in the laboratory. Long hair should be pulled back and secured. Loose clothing (sleeves, bulky pants or skirts) should be avoided to prevent accidental contact with chemicals or open flames. Bare feet, sandals and open-toed or perforated shoes are not permitted in any laboratory. Short pants and short skirts are not permitted unless covered by a lab coat. Long pants should be worn to cover skin that could be exposed during a spill.

Lab coats are strongly encouraged as routine equipment for all laboratory workers. Remember that lab coats should be worn to protect employees against both chemical and biological hazards. Working in a biosafety level 1 laboratory does not excuse an employee from wearing a lab coat. It is the responsibility of the employer to purchase and wash lab coats for employees who request them or are required to wear them. Lab coats cannot be taken home for laundering. Lab coats are required when working with radioactive materials, biologically-derived toxins, Biosafety Level II organisms, carcinogens, reproductive toxins, substances which have a high degree of acute toxicity, and any substance on the OSHA PEL list carrying a "skin" notation. See http://www.dehs.umn.edu/ressafety_rsp_lte.htm for chemical listings. Lab coats cannot be assumed to provide complete protection against all agents, but will provide an extra layer that
can be removed if accidentally contaminated, buying time for the researcher to get to the emergency shower and minimize direct skin contact. For strong acids and bases, a lab apron impervious to liquids would be a more appropriate choice.

Gloves made of appropriate material are required to protect the hands and arms from thermal burns, cuts, or chemical exposure that may result in absorption through the skin or reaction on the surface of the skin. Gloves are also required when working with particularly hazardous substances where possible transfer from hand to mouth must be avoided. Thus, gloves are required for work involving pure or concentrated solutions of select carcinogens, reproductive toxins, substances which have a high degree of acute toxicity, strong acids and bases, and any substance on the OSHA PEL list carrying a "skin" notation.

Since no single glove material is impermeable to all chemicals, gloves should be carefully selected using guides from the manufacturers. General selection criteria are outlined in Prudent Practices, p. 132, and glove selection guides are available on the web. However, glove-resistance to various chemicals materials will vary with the manufacturer, model and thickness. Therefore, review a glove-resistance chart from the manufacturer you intend to buy from before purchasing gloves. When guidance on glove selection for a particular chemical is lacking, double glove using two different materials, or purchase a multilayered laminated glove such as a Silver-shield or a 4H.

b) Eye Protection
Eye protection is required for all personnel and any visitors whose eyes may be exposed to chemical or physical hazards. Side shields on safety spectacles provide some protection against flying particles, but goggles or face shields are necessary when there is a greater than average danger of eye contact with liquids. A higher than average risk exists when working with highly reactive chemicals, concentrated corrosives, or with vacuum or pressurized glassware systems. Contact lenses may be worn under safety glasses, goggles or other eye and face protection. Experts currently believe the benefits of consistent use of eye protection outweigh potential risks of contact lenses interfering with eye flushing in case of emergency.

c) Respiratory Protection
Respiratory protection is generally not necessary in the laboratory setting and must not be used as a substitute for adequate engineering controls. Availability of respiratory protection for emergency situations may be required when working with chemicals that are highly toxic and highly volatile or gaseous. If an experimental protocol requires exposure above the action level (or PEL) that cannot be reduced, respiratory protection will be required. Rarely, an experimental situation may potentially involve IDLH (immediately dangerous to life or health) concentrations of chemicals, which will require use of respiratory protection. All use of respiratory protective equipment is covered under the University of Minnesota Respiratory Protection Program.

3. Hygiene Practices
Eating, drinking and chewing gum are all strictly prohibited in any laboratory with chemical, biological or radioactive materials. Researchers must also be careful to restrict other actions
(such as applying lip balm, rubbing eyes or using i-pods or cell phones) which could inadvertently cause exposure to research materials. Consuming alcohol or taking illegal drugs in a research laboratory is strictly prohibited as such actions potentially endanger the health and safety of not only the user, but everyone in the building. Infractions will be met with serious disciplinary action. Before leaving the laboratory, remove personal protective equipment/clothing (lab coat and gloves) and wash hands thoroughly. DO NOT wear laboratory gloves, lab coats or scrubs in public spaces such as hallways, elevators or cafeterias.

4. Administrative Controls

Supervisors shall consider the hazards involved in their research; and in written research protocols, detail areas, activities, and tasks that require specific types of personal protective equipment as described above. Researchers are strongly encouraged to prioritize research so that work with hazardous chemical, biological or physical agents occurs only during working hours (8 am – 5 pm, Monday through Friday). After-hours work (on nights and weekends) should be restricted to nonhazardous activities such as data analysis and report writing. If hazardous materials must be used at nights or on weekends, ensure that at least one other person is within sight and ear-shot to provide help in an emergency. Undergraduate workers are prohibited from working alone in the laboratory unless there is a review and formal approval by the department’s RSO and/or safety committee.

Research Safety Officers must coordinate and/or conduct inspections of laboratories in their area of responsibility and ensure laboratory supervisors address any noted deficiencies. An audit checklist is available in Appendix E (p.157). RSOs can report cases of continued non-compliance to the unit head and to the Department of Environmental Health and Safety (DEHS). The RSO, in conjunction with DEHS and the unit head, has the authority to halt research activities that present an imminent hazard.

In the event that a research lab is moving or leaving the University altogether, the principle investigator is responsible for cleaning up the lab space. If the principle investigator does not take proper care to clean-up the laboratory, then the department for which they worked under becomes responsible. We strongly encourage departments to develop administrative controls to prevent this from happening. A good tool to use is the laboratory closeout checklist available on the DEHS website. Otherwise, DEHS does offer laboratory clean-up services for an hourly fee.
Chapter 4 - Management of Chemical Fume Hoods and Other Protective Equipment

1. Monitoring Safety Equipment

Fume hoods must be monitored daily by the user to ensure that air is moving into the hood. Any malfunctions must be reported immediately to UMR-William Simmons (507-258-8423) and Paramark-Mark Malan (507-208-1852). The hood should have a continuous reading device, such as a pressure gauge, to indicate that air is moving correctly. Users of older hoods without continuous reading devices should attach a strip of tissue or yarn to the bottom of the vertical sliding sash. The user must ensure the hood and baffles are not blocked by equipment and bottles, as air velocity through the face may be decreased. DEHS staff will measure the average face velocity of each fume hood annually with a velometer or a thermoanemometer. A record of monitoring results will be made.

If biological safety cabinets are used for Biosafety Level 2 work, including handling human cells, they must be certified annually by an outside contractor. A list of contractors is available on the Biosafety section of the DEHS website. It is the responsibility of the department to schedule and pay for the contractor to perform annual certification. (Not Currently at UMR)

Eye washes must be flushed weekly by the user. This will ensure that the eye wash is working, and that the water is clean, should emergency use become necessary. The user should post a log near the eye wash to document that it is being flushed every week. These logs are considered equipment maintenance records and therefore, should be kept for 1 year. An eyewash record template is available through the DEHS website. The user should also coordinate with Facilities Management to ensure that emergency showers and eye washes are tested annually. Facilities Management will document their testing on separate tags.

Fire extinguishers will be checked annually by a University contractor. The user is responsible for checking regularly to ensure that other protective equipment is functioning properly. Environmental Health and Safety staff can assist with these evaluations, should assistance be necessary.

General laboratory conditions must be monitored periodically by the users. A generic laboratory audit form is included in Appendix E (p.157), and may be tailored for use by individual laboratories. The departmental Research Safety Officer or the University's Chemical Hygiene Officer may also use this form for spot-checks of the laboratories.
2. Acceptable Operating Range

The acceptable operating range for fume hoods is 80 to 150 linear feet per minute, at the designated sash opening (usually 18 inches). If, during the annual check, a hood is operating outside of this range, DEHS staff may request that you check to ensure the baffles are adjusted properly, and that the exhaust slots are not blocked by bottles and equipment. If these adjustments do not help, DEHS staff will report the deficiency to the appropriate Facilities Management zone office for servicing.

3. Maintenance

During maintenance of fume hoods, laboratories must clean out and if necessary, decontaminate the fume hood and restrict use of chemicals to ensure the safety of maintenance personnel.

4. Training

Training in the appropriate use and care of fume hood systems, showers, eyewashes and other safety equipment must be included in the initial and update training described in Section 5.

5. New Systems

When new ventilation systems, such as variable air volume exhaust, are installed in University facilities, specific policies for their use will be developed by the Department of Environmental Health and Safety and employees will be promptly trained on use of the new equipment.
Chapter 5 - Employee Information and Training

All laboratory researchers and their supervisors (Principal Investigators included) must be trained according to the requirements of the Laboratory Safety Standard. Colleges and non-academic departments that engage in the laboratory use of hazardous chemical, physical or biological agents are responsible for identifying such employees. The employees must be informed about their roles and responsibilities as outlined in this standard, as well as hazards associated with their work and how to work safely and mitigate those hazards.

DEHS provides web-based training modules on the basic information and training topics described below on the ‘Training’ page of the DEHS website. At a minimum, new laboratory employees should complete the modules “Introduction to Research Safety”, “Chemical Safety”, and “Chemical Waste Management”.

In addition, each laboratory supervisor is responsible for ensuring that laboratory employees are provided with training about the specific hazards present in their laboratory work area, and methods to control such hazards. Such training must be provided at the time of an employee's initial assignment to a work area and prior to assignments involving new potential exposures, and must be documented. Refresher training must be provided at least annually.

Volunteers conducting research in University laboratories, in addition to completing the training described below must complete the Volunteers and Visitor’s Laboratory Use Agreement which can be accessed at www.d.umn.edu/ehso/safety/volunteers.doc. If the volunteer is a minor, a parent or guardian must also sign the agreement. Because laboratories may contain hazardous chemicals, a minor who is paid to work in a research laboratory must obtain an exemption from the Minnesota Child Labor Act. An overview of this law is available on the web (http://www.dli.mn.gov/LS/Pdf/childlbr.pdf), as are Child Labor Exemption Applications (http://www.doli.state.mn.us/ls/Exemptions.asp) which should be completed by a parent, guardian or school official and filed with the Minnesota Department of Labor and Industry.

1. Information

It is essential that laboratory employees have access to information on the hazards of chemicals and procedures for working safely. Supervisors must ensure that laboratory employees are informed about and have access to the following information sources:

The contents of the OSHA Laboratory Safety Standard

"Occupational Exposure to Hazardous Chemicals in Laboratories" and its appendices (29 CFR 1910.1450). A copy of this federal standard can be found in Appendix A (p.38) of this Laboratory Safety Plan.
The University of Minnesota Laboratory Safety Plan

This generic LSP is available to all employees on the Department of Environmental Health and Safety's web site (http://www.dehs.umn.edu/ressafety_rsp.htm). Individual department Laboratory Safety Plans are available within those departments.

The Permissible Exposure Limits (PELs)

PELs for OSHA regulated substances can be found at http://www.dehs.umn.edu/ressafety_rsp_lte.htm. Also included at this site are the ACGIH Threshold Limit Value (TLV) list, a list of OSHA health hazard definitions, lists of "select carcinogens" and reproductive toxins, and chemicals having a high degree of acute toxicity.

Signs and symptoms associated with exposures to hazardous chemicals.

Laboratory Chemical Safety Summaries (LCSSs) are included on pages 235-413 of the 1995 edition of Prudent Practices (Prudent Practices in the Laboratory: Handling and Disposal of Chemicals). LCSSs are similar to Material Safety Data Sheets (MSDS), but are tailored to the hazards of laboratory use of those chemicals. The LCSSs include toxicity information, and signs and symptoms of exposure to the chemicals.

Material Safety Data Sheets (MSDSs)

MSDSs are available online through links from the Department of Environmental Health and Safety's web site. Hard copies of MSDS for many laboratory chemicals are also available from DEHS or departmental safety offices. Individual researchers are encouraged to keep hard copies in an easily accessible location for materials that are used in large quantities, which are used frequently, or which are particularly toxic.

Information on chemical waste disposal and spill response

The University of Minnesota guidebook, Hazardous Chemical Waste Management 5th edition provides detailed information on proper waste handling procedures.

2. Training

Employee training programs will include, at a minimum, the following subjects:

Methods of detecting the presence of hazardous chemicals;

Methods include visual observation, odor, real-time air monitoring, time-weighted air sampling, etc.

Basic toxicological principles;

Principles include toxicity, hazard, exposure, routes of entry, acute and chronic effects, dose-response relationship, LD50, threshold limit values and permissible exposure limits, exposure time, and health hazards related to classes of chemicals.
Prudent laboratory practices;

Prudent laboratory practices include general techniques designed to reduce personal exposure and to control physical hazards, as well as specific protective mechanisms and warning systems used in individual laboratories. Appropriate use of fume hoods is to be specifically addressed. As noted in Chapter 2, the text Prudent Practices in the Laboratory: Handling and Disposal of Chemicals (National Research Council, 1995) describes general procedures to be followed in U of MN laboratories.

Description of available chemical information;

Container labels, Material Safety Data Sheets, etc.

Emergency response actions appropriate to individual laboratories;

Lists of emergency phone numbers, location of fire extinguishers, deluge showers, eyewashes, etc.

Applicable details of the departmental Laboratory Safety Plan;

Details should include general and laboratory-specific Standard Operating Procedures.

An introduction to the Hazardous Chemical Waste Management guidebook.

3. Updates

Update training is required for all laboratory researchers and supervisors / principal investigators (PI's) at least annually. Departmental Research Safety Officers (RSOs) are responsible for coordinating and tracking updated training. Often, RSOs may arrange for departmental-wide update-training sessions, focusing on results of laboratory audits, and highlight issues that may need improvement. Videos from DEHS’s library may be borrowed to supplement these training sessions. Individual PI’s may conduct research-group-specific safety reviews to supplement or even stand in place of departmental update sessions. Documentation (paper or electronic) of all safety training must be maintained according to the requirements outlined in Chapter 10 of this Lab Safety Plan.
‘High hazard’ research is that which due to the nature of the hazard, or the quantity of the material, or the potential for exposure poses higher than usual risk to the worker. Such research may require formal review and approval by a researcher’s departmental safety committee, perhaps with involvement of DEHS personnel. High hazard research could include gases or chemicals listed in Tables 1-5 of this Laboratory Safety Plan, or certain biological or physical agents. RSOs should conduct laboratory audits and consult with Principal Investigators to identify research programs which may fall into this ‘high hazard’ category.

PI’s whose research is identified as ‘high hazard’ should provide copies of their SOPs to the RSO and their department’s safety committee for review and approval. The committee should respond with any comments or requests for changes in a timely manner, and keep a written record of approvals within the department.
Chapter 7 - Medical Consultation and Examination

1. Employees Who Work With Hazardous Substances

All employees who work with hazardous substances will have an opportunity to receive medical attention, including any follow-up visits that the examining physician determines to be necessary, under the following circumstances:

Signs or symptoms of exposure

Whenever an employee develops signs or symptoms associated with a hazardous substance or organism to which the employee may have been exposed in the laboratory, the employee will be provided an opportunity to receive an appropriate medical examination.

Exposure monitoring

Where exposure monitoring reveals an exposure level routinely above the action level (or in the absence of an action level, the PEL) for an OSHA regulated substance for which there are exposure monitoring and medical surveillance requirements, medical surveillance will be established for the affected employee as prescribed by the particular standard.

Exposure incident

Whenever an event takes place in the work area such as a spill, leak, explosion or other occurrence resulting in the likelihood of a hazardous exposure, the affected employee will be provided an opportunity for a medical consultation. Such consultation will be for the purpose of determining the need for a medical examination.

Physical Injury

Whenever an employee is physically hurt or injured on the job, the affected employee will be provided an opportunity for a medical consultation and/or examination. Physical injuries include but are not limited to cuts, burns, punctures and sprains.

Contact the Chemical Hygiene Officer whenever the need for medical consultation or examination occurs, or when there is uncertainty as to whether any of the above criteria have been met.
2. Medical Examinations and Consultations

In the event of a life-threatening illness or injury, dial 911 and request an ambulance. Employees with urgent, but non-life-threatening, illnesses or injuries should go to the nearest medical clinic such as Methodist Hospital. If off-hours medical attention is required, the employee should be taken to the emergency room at St. Mary’s Hospital or Olmsted Medical Center. All medical examinations and consultations will be performed by or under the direct supervision of a licensed physician and will be provided without cost to the employee, without loss of pay and at a reasonable time and place.

3. Workers' Compensation Procedures and Forms

It is very important that even minor job-related injuries or illness are reported. These statistics help the Department of Environmental Health and Safety track trends that may indicate occupational hazards that need evaluation. To report an illness or injury, please contact Andrea Wilson at 507-258-8099 or wils1236@r.umn.edu. University of Minnesota Policy for Reporting Workers' Compensation Related Injuries is also available on the web at http://policy.umn.edu/Policies/hr/Benefits/WORKERSCOMP.html

This policy explains the procedures and provides the necessary reporting forms. As long as the illness or injury is not life threatening, the supervisor should provide the employee with:

- a brochure describing Workers' Compensation Information for the University of Minnesota;
- a completed Employers' Authorization for Care form; and
- a Work Status Report for the physician to complete and return to the supervisor.

Within 24 hours, the supervisor should complete:

- a State of Minnesota First Report of Injury form;
- a U of MN Employee Incident Report form; and
- a U of MN Supervisor Incident Investigation Report.

Within 24 hours, supervisors must fax the State form to Sedgwick Claims Management Services at (952) 826-3785, and the U of MN forms to the University of Minnesota Workers' Compensation Department (612)-627-1855.
4. Information Provided to Physician

The employee's supervisor or department will collect and transmit the following information to the examining physician:

- The identity of the hazardous substance(s) to which the employee may have been exposed;
- A description of the conditions under which the exposure occurred including quantitative exposure data, if available; and
- A description of the signs and symptoms of exposure that the employee is experiencing, if any.

5. Information Provided to the University of Minnesota Rochester

Supervisors should request that the examining physician provide them with a written report including the following:

- Any recommendation for further medical follow-up;
- The results of the medical examination and any associated tests;
- Any medical condition which may be revealed in the course of the examination which may place the employee at increased risk as a result of exposure to a hazardous chemical found in the workplace; and
- A statement that the employee has been informed by the physician of the results of the consultation or medical examination and any medical condition that may require further examination or treatment.

The written opinion will not reveal specific findings of diagnoses unrelated to occupational exposure.
Chapter 8 - Personnel

The following individuals and groups have responsibilities for implementation of various aspects of the University of Minnesota Rochester's Laboratory Safety Plan.

Chemical Hygiene Officer

The University of Minnesota Chemical Hygiene Officer is Dawn C. Errede, Department of Environmental Health and Safety. Ms. Errede is a Certified Industrial Hygienist (CIH) and chemical hygiene specialist with an M.S. in Environmental Health. Address: W-140 Boynton Health Service. Phone: 612-626-2330.

College or Departmental Research Safety Officer

The research safety officer for the University of Minnesota Rochester-Center for Learning Innovation is William Simmons. The specific duties of each safety officer will be determined at the college or departmental level. The duties of this RSO are included in Appendix G (p.161).

College or Departmental Safety Committee

The designation of a safety committee to assist the safety officer in his/her required duties is strongly encouraged. The Members of the UMR Lab Safety Committee (2011-2012) are:

- Dr. Rajeev Muthyala, Design Based Faculty Representative
- Marian Aanerud, Student Based Faculty Representative
- Dr. Chris DeZutter, Student Based Faculty Representative
- Dr. Peter Larsen, Student Based Faculty Representative
- Dr. Andrew Petzold, Student Based Faculty Representative
- William Simmons, Research Safety Officer
- Jenny Casper, CLI Administrative Director
- Gail Sauter, Assistant Vice Chancellor for Finance and Operations
- Dawn Errede, University Chemical Hygiene Officer (ad hoc member)
Department of Environmental Health and Safety

The Department of Environmental Health and Safety offers assistance in a wide range of health and safety issues. Staff phone numbers are included in Appendix H (p.162). Address: W-140 Boynton. Phone: 612-626-6002.

Occupational Medicine Program

The University of Minnesota Boynton Health Service provides occupational medicine services for the Research Occupational Health Program (ROHP) and the Respiratory Protection Program. For appointments, call the Boynton main appointment line at 612-625-3222 and ask to see the Occupational Physician. Non hospital employee chemical exposures should go through the Methodist Hospital urgent care.
Chapter 9 - Additional Employee Protection For Work with Particularly Hazardous Substances

Additional employee protection will be considered for work with particularly hazardous substances. These include select carcinogens, reproductive toxins and substances that have a high degree of acute toxicity (see http://www.dehs.umn.edu/ressafety_rsp_lte.htm). Pages 90-93 of the 1995 edition of Prudent Practices provides detailed recommendations for work with particularly hazardous substances. These pages may be accessed from DEHS's web site at www.dehs.umn.edu. Laboratory supervisors and principal investigators are responsible for assuring that laboratory procedures involving particularly hazardous chemicals have been evaluated for the level of employee protection required. Specific consideration will be given to the need for inclusion of the following provisions:

1. Planning;
2. Establishment of a designated area;
3. Access control
4. Special precautions such as:
   - use of containment devices such as fume hoods or glove boxes;
   - use of personal protective equipment;
   - isolation of contaminated equipment;
   - practicing good laboratory hygiene; and
   - prudent transportation of very toxic chemicals.
5. Planning for accidents and spills; and
6. Special storage and waste disposal practices.
Chapter 10 - Record Keeping, Review and Update of Laboratory Safety Plan

1. Record Keeping

Exposure evaluation

Any records of exposure evaluation carried out by individual departments (including continuous monitoring systems) will be kept within the department and also sent to the Department of Environmental Health and Safety. Results of exposure evaluations carried out by DEHS will be kept by DEHS and sent to the affected department. Raw data will be kept for one year and summary data for the term of employment plus 30 years.

Medical consultation and examination

Results of medical consultations and examinations will be kept by the Boynton Health Service for a length of time specified by the appropriate medical records standard. This time will be at least the term of employment plus 30 years as required by OSHA.

Training

Historically, individual employee training has been recorded on form BA 725A (see http://www.dehs.umn.edu/ressafety_rsp.htm) and kept in the individual's department or college for five years. More recently, web-based training and many in-person training sessions for employees are tracked electronically in the university's PeopleSoft system. The records must include the name and title of the trainer, the trainee, the date and the content of training. Training records for laboratory volunteers must also be maintained for at least five years. Hard copy and/or electronic forms must be available in the event of an audit by the University Audit Department or state or county regulators.

Fume hood monitoring

Data on annual fume hood monitoring will be kept in the Department of Environmental Health and Safety. Fume hood monitoring data are considered maintenance records and as such the raw data will be kept for one year and summary data for 5 years.

Eyewash Records

Eyewash user logs should be kept on file for 1 year, because they are considered maintenance records.
Laboratory audits and reports

Research Safety Officers must coordinate and/or conduct formal audits of laboratories in their sphere of responsibility at least annually. A checklist is available in Appendix E (p.157), and a template report form is available in Appendix K (p.178). Checklists and reports should be kept for at least 5 years.

Accident investigation reports

Research Safety Officers work with PIs and researchers to complete the Accident Investigation Form in Appendix I (p.169). Reports should be kept for at least 5 years.

2. Review and Update of Laboratory Safety Plan

On an annual basis, this Laboratory Safety Plan will be reviewed and evaluated for effectiveness by the Department of Environmental Health and Safety and updated as necessary. Any changes in the Laboratory Safety Plan will be transmitted to college and departmental research safety officers, who are responsible for carrying out a similar review and modification of their plans, and submitting a revised copy to the Chemical Hygiene Officer.

Table 1 - Poisonous Gases (Not Currently at UMR)

The gases on this list are either on the Department of Transportation's Category 1 list, or the Linde Specialty Gases Company's Group 6 – Very Poisonous list. These chemicals are highly toxic gases at ambient temperature and pressure. They have an extremely high potential for causing significant harm if not adequately controlled.

<table>
<thead>
<tr>
<th>Arsine</th>
<th>Boron trichloride</th>
<th>Chlorine pentafluoride</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chlorine trifluoride</td>
<td>Cyanogen</td>
<td>Cyanogen chloride</td>
</tr>
<tr>
<td>Diborane</td>
<td>Dinitrogen tetroxide</td>
<td>Fluorine</td>
</tr>
<tr>
<td>Germane</td>
<td>Hydrogen selenide</td>
<td>Nitric oxide</td>
</tr>
<tr>
<td>Nitrogen dioxide</td>
<td>Nitrogen trioxide</td>
<td>Nitrosyl chloride</td>
</tr>
<tr>
<td>Oxygen difluoride</td>
<td>Phosgene</td>
<td>Phosphine</td>
</tr>
<tr>
<td>Phosphorus pentafluoride</td>
<td>Selenium hexafluoride</td>
<td>Stibine</td>
</tr>
<tr>
<td>Sulfur tetrafluoride</td>
<td>Tellurium Hexafluoride</td>
<td>Tetraethylthiopyrophosphate</td>
</tr>
<tr>
<td>Tetraethylpyrophosphate</td>
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</tbody>
</table>

Guidance: Departments may choose to add other chemicals to the above list. For example, sulfur-containing compounds such as mercaptans can cause significant odor problems when used in the laboratory. Pre-approval of the conditions under which they can be used may prevent odor complaints.
Table 2 - Shock Sensitive Chemicals

The classes of chemicals listed below may explode when subjected to shock or friction. Therefore users must have appropriate laboratory equipment, information, knowledge and training to use these compounds safely.

- Acetylenic compounds, especially polyacetylenes, haloacetylenes, and heavy metal salts of acetylenes (copper, silver, and mercury salts are particularly sensitive)
- Acyl nitrates
- Alkyl nitrates, particularly polyl nitrates such as nitrocellulose and nitroglycerine
- Alkyl and acyl nitrites
- Amminemetal oxosalts: metal compounds with coordinated ammonia, hydrazine, or similar nitrogenous donors and ionic perchlorate, nitrate, permanganate, or other oxidizing group
- Azides, including metal, nonmetal, and organic azides
- Chlorite salts of metals, such as AgClO2 and Hg(ClO2)2
- Diazo compounds such as CH2N2
- Diazonium salts, when dry
- Fulminates such as mercury fulminate (Hg(CNO)2)
- Hydrogen peroxide (which becomes increasingly treacherous as the concentration rises above 30%, forming explosive mixtures with organic materials and decomposing violently in the presence of traces of transition metals)
- N-Halogen compounds such as difluoroamino compounds and halogen azides
- N-Nitro compounds such as N-nitromethylamine, nitrourea, nitroguanidine, and nitric amide
- Oxo salts of nitrogenous bases: perchlorates, dichromates, nitrates, iodates, chlorites, chlorates, and permanganates of ammonia, amines, hydroxylamine, guanidine, etc.
- Perchlorate salts (which can form when perchloric acid mists dry in fume hoods or associated duct work. Most metal, nonmetal, and amine perchlorates can be detonated and may undergo violent reaction in contact with combustible materials)
- Peroxides and hydperoxides, organic
- Peroxides (solid) that crystallize from or are left from evaporation of peroxidizable solvents (see the following Section 3)
- Peroxides, transition-metal salts
- Picrates, especially salts of transition and heavy metals, such as Ni, Pb, Hg, Cu, and Zn
- Polynitroalkyl compounds such as tetranitromethane and dinitroacetonitrile
- Polynitroaromatic compounds especially polynitrohydrocarbons, phenols, and amines (e.g., dinitrotoluene, trinitrotoluene, and picric acid)

Note: Perchloric acid must be used only in specially-designed perchloric acid fume hoods that have built-in wash down systems to remove shock-sensitive deposits. Before purchasing this acid, laboratory supervisors must arrange for use of an approved perchloric acid hood. Please see the Perchloric Acid Fact Sheet for more information.
Table 3 - Pyrophoric Chemicals

The classes of chemicals listed below will readily oxidize and ignite spontaneously in air. Therefore, users must demonstrate to the department that they have the appropriate laboratory equipment, information, knowledge and training to use these compounds safely. Please see the Pyrophoric Chemicals Fact Sheet for further information.

- Grignard reagents, RMgX
- Metal alkyls and aryls, such as RLi, RNa, R3Al, R2Zn
- Metal carboxyls such as Ni(CO)4, Fe(CO)5, Co2(CO)8
- Alkali metals such as Na, K
- Metal powders, such as Al, Co, Fe, Mg, Mn, Pd, Pt, Ti, Sn, Zn, Zr
- Metal hydrides such as NaH, LiAlH4
- Nonmetal hydrides, such as B2H6 and other boranes, PH3, AsH3
- Nonmetal alkyls, such as R3B, R3P, R3As
- Phosphorus (white)

Table 4 - Peroxide-Forming Chemicals

The chemicals listed below can form explosive peroxide crystals on exposure to air, and therefore require special handling procedures after the container is opened. Some of the chemicals form peroxides that are violently explosive in concentrated solution or as solids, and therefore should never be evaporated to dryness. Others are polymerizable unsaturated compounds and can initiate a runaway, explosive polymerization reaction. All peroxidizable compounds should be stored away from heat and light. They should be protected from physical damage and ignition sources. A warning label should be affixed to all peroxidizable materials to indicate the date of receipt and the date the container was first opened. Due to these special handling requirements, users must have the appropriate laboratory equipment, information, knowledge and training to use these compounds safely.

A. Severe Peroxide Hazard with Exposure to Air (discard within 3 months from opening)
- diisopropyl ether (isopropyl ether)
- divinylacetylene (DVA)
- vinylidene chloride (1,1-dichloroethylene)
- potassium metal
- sodium amide (sodamide)
- potassium amide
B. Peroxide Hazard on Concentration
Do not distill or evaporate without first testing for the presence of peroxides (discard or test for peroxides after 6 months)

- acetaldehyde diethyl acetal (acetal)
- cumene (isopropylbenzene)
- cyclohexene
- cyclopentene
- decalin (decahydronaphthalene)
- diacetylene (butadiene)
- dicyclopentadiene
- diethyl ether (ether)
- diethylene glycol dimethyl ether (diglyme)
- dioxane
- ethylene glycol dimethyl ether (glyme)
- ethylene glycol ether acetates
- ethylene glycol monoethers (cellosolves)
- furan
- methylacetylene
- methylcyclopentane
- methyl isobutyl ketone
- tetrahydrofuran (THF)
- tetralin (tetrahydronaphthalene)
- vinyl ethers

C. Hazard of Rapid Polymerization Initiated by Internally-Formed Peroxides

Liquids (discard or test for peroxides after 6 months)

- Chloroprene (2-chloro-1, 3-butadiene)
- vinyl acetate
- styrene
- vinylpyridine

Gases (discard after 12 months)

- butadiene
- vinylacetylene (MVA)
- tetrafluoroethylene (TFE)
- vinyl chloride
Table 5 - Carcinogens, Reproductive Toxins
Or Highly Toxic Chemicals

The chemicals listed below are extremely hazardous. Workers must have knowledge of the dangers of these chemicals prior to use, and documentation of training in safe working procedures.

Biologically active compounds

- protease inhibitors (e.g. PMSF, Aprotin, Pepstatin A, Leopeptin);
- protein synthesis inhibitors (e.g. cycloheximide, Puromycin);
- transcriptional inhibitors (e.g. α-amanitin and actinomycin D);
- DNA synthesis inhibitors (e.g. hydroxyurea, nucleotide analogs (i.e.
- dideoxy nucleotides), actinomycin D, acidicolin);
- phosphatase inhibitors (e.g. okadaic acid);
- respiratory chain inhibitors (e.g. sodium azide);
- kinase inhibitors (e.g. NaF);
- mitogenic inhibitors (e.g. colcemid); and
- mitogenic compounds (e.g. concanavalin A).
- Castor bean (Ricinus communis) lectin: Ricin A, Ricin B, RCA toxins
- Diisopropyl fluorophosphate: highly toxic cholinesterase inhibitor; the antidote, atropine sulfate and 2-PAM (2-pyridinedialdoxime methiodide) must be readily available
- Jaquirity bean lectin (Abrus precatorius)
- N-methyl-N'-nitro-N-nitrosoguanidine: carcinogen (this chemical forms explosive compounds upon degradation)
- Phalloidin from Amanita Phalloides: used for staining actin filaments
- Retinoids: potential human teratogens
- Streptozotocin: potential human carcinogen (See SOP Template example)
- Urethane (ethyl carbamate): an anesthetic agent, potent carcinogen and strong teratogen, volatile at room temperature
Appendix A

29 CFR 1910.1450 - Occupational Exposure to Hazardous Chemicals in Laboratories

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(a) Scope and application.

1. This section shall apply to all employers engaged in the laboratory use of hazardous chemicals as defined below.

2. Where this section applies, it shall supersede, for laboratories, the requirements of all other OSHA health standards in 29 CFR part 1910, subpart Z, except as follows:

   i. For any OSHA health standard, only the requirement to limit employee exposure to the specific permissible exposure limit shall apply for laboratories, unless that particular standard states otherwise or unless the conditions of paragraph (a)(2)(iii) of this section apply.

   ii. Prohibition of eye and skin contact where specified by any OSHA health standard shall be observed.

   iii. Where the action level (or in the absence of an action level, the permissible exposure limit) is routinely exceeded for an OSHA regulated substance with exposure monitoring and medical surveillance requirements paragraphs (d) and (g)(1)(ii) of this section shall apply.

3. This section shall not apply to:
i. Uses of hazardous chemicals which do not meet the definition of laboratory use, and in such cases, the employer shall comply with the relevant standard in 29 CFR part 1910, subpart Z, even if such use occurs in a laboratory.

ii. Laboratory uses of hazardous chemicals which provide no potential for employee exposure. Examples of such conditions might include:

   A. Procedures using chemically-impregnated test media such as Dip-and-Read tests where a reagent strip is dipped into the specimen to be tested and the results are interpreted by comparing the color reaction to a color chart supplied by the manufacturer of the test strip; and

   B. Commercially prepared kits such as those used in performing pregnancy tests in which all of the reagents needed to conduct the test are contained in the kit.

4. (b) Definitions

5. "Action level" means a concentration designated in 29 CFR part 1910 for a specific substance, calculated as an eight (8)-hour time-weighted average, which initiates certain required activities such as exposure monitoring and medical surveillance.

6. "Assistant Secretary" means the Assistant Secretary of Labor for Occupational Safety and Health, U.S. Department of Labor, or designee. "Carcinogen" (see "select carcinogen").

7. "Chemical Hygiene Officer" means an employee who is designated by the employer, and who is qualified by training or experience, to provide technical guidance in the development and implementation of the provisions of the Chemical Hygiene Plan. This definition is not intended to place limitations on the position description or job classification that the designated individual shall hold within the employer's organizational structure.

8. "Chemical Hygiene Plan" means a written program developed and implemented by the employer which sets forth procedures, equipment, personal protective equipment and work practices that (i) are capable of protecting employees from the health hazards presented by hazardous chemicals used in that particular workplace and (ii) meets the requirements of paragraph (e) of this section. "Combustible liquid" means any liquid having a flashpoint at or above 100° F (37.8° C), but below 200° F (93.3° C), except any mixture having components with flashpoints of 200° F (93.3° C), or higher, the total volume of which make up 99 percent or more of the total volume of the mixture.

9. "Compressed gas” means: (i) A gas or mixture of gases having, in a container, an absolute pressure exceeding 40 psi at 70° F (21.1° C); or (ii) A gas or mixture of gases having, in a container, an absolute pressure exceeding 104 psi at 130° F (54.4° C)
regardless of the pressure at 70° F (21.1° C); or (iii) a liquid having a vapor pressure exceeding 40 psi at 100° F (37.8° C) as determined by ASTM D-323-72.

10. "Designated area" means an area which may be used for work with "select carcinogens, "reproductive toxins or substances which have a high degree of acute toxicity. A designated area may be the entire laboratory, such as a laboratory hood.

11. "Emergency" means any occurrence such as, but not limited to, equipment failure, rupture of containers or failure of control equipment which results in an uncontrolled release of a hazardous chemical into the workplace.

12. "Employee" means an individual employed in a laboratory workplace whom may be exposed to hazardous chemicals in the course of his or her assignments.

13. "Explosive" means a chemical that causes a sudden, almost instantaneous release of pressure, gas, and heat when subjected to sudden shock, pressure, or high temperature.

"Flammable" means a chemical that falls into one of the following categories:

i. "Aerosol, flammable" means an aerosol that, when tested by the method described in 16 CFR 1500.45, yields a flame protection exceeding 18 inches at full valve opening, or a flashback (a flame extending back to the valve) at any degree of valve opening;

ii. "Gas, flammable" means: (A) A gas that, at ambient temperature and pressure, forms a flammable mixture with air at a concentration of 13 percent by volume or less; or (B) a gas that, at ambient temperature and pressure, forms a range of flammable mixtures with air wider than 12 percent by volume, regardless of the lower limit.

iii. "Liquid, flammable" means any liquid having a flashpoint below 100° F (37.8° C), except any mixture having components with flashpoints of 100° C or higher, the total of which make up 99 percent or more of the total volume of the mixture.

iv. "Solid, flammable" means a solid, other than a blasting agent or explosive as defined in 1910.109(a), that is liable to cause fire through friction, absorption of moisture, spontaneous chemical change, or retained heat from manufacturing or processing, or which can be ignited readily and when ignited burns so vigorously and persistently as to create a serious hazard. A chemical shall be considered to be a flammable solid if, when tested by the method described in 16 CFR 1500.44, it ignites and burns with a self-sustained flame at a rate greater than one-tenth of an inch per second along its major axis.

"Flashpoint" means the minimum temperature at which a liquid gives off a vapor in sufficient concentration to ignite when tested as follows:

i. Tagliabue Closed Tester (See American National Standard Method of Test for Flash Point by Tag Closed Tester, Z11.24 - 1979 (ASTM D 56-79)) - for liquids with a viscosity of less than 45 Saybolt Universal Seconds at 100° F (37.8° C), that do not contain suspended solids and do not have a tendency to form a surface film under test.
ii. Pensky-Martens Closed Tester (See American National Standard Method of Test for Flashpoint by Pensky-Martens Closed Tester, Z11.7 - 1979 (ASTM D 93-79)) - for liquids with a viscosity equal to or greater than 45 SUS at 100° F (37.8° C ), or that contain suspended solids, or that have a tendency to form a surface film under test.

iii. Setaflash Closed Tester (see American National Standard Method of test for Flash Point by Setaflash Closed Tester (ASTMD 3278-78)). Organic peroxides, which undergo auto-accelerating thermal decomposition, are excluded from any of the flashpoint determination methods specified above.

"Hazardous chemical" means a chemical for which there is statistically significant evidence based on at least one study conducted in accordance with established scientific principles that acute or chronic health effects may occur in exposed employees. The term "health hazard" includes chemicals which are carcinogens, toxic or highly toxic agents, reproductive toxins, irritants, corrosives, sensitizers, hepatotoxins, nephrotoxins, neurotoxins, and agents which act on the hematopoietic systems and agents which damage the lungs, skin, eyes, or mucous membranes. Appendices A and B of the Hazard Communication Standard (29 CFR 1910.1200) provide further guidance in defining the scope of health hazards and determining whether or not a chemical is to be considered hazardous for purposes of this standard.

"Laboratory" means a facility where the "laboratory use of hazardous chemicals" occurs. It is a workplace where relatively small quantities of hazardous chemicals are used on a non-production basis.

"Laboratory scale" means work with substances in which the containers used for reactions, transfers, and other handling of substances is designed to be easily and safely manipulated by one person.

"Laboratory scale" excludes those workplaces whose function is to produce commercial quantities of materials. "Laboratory-type hood" means a device located in a laboratory, enclosure on five sides with a movable sash or fixed partial enclosed on the remaining side; constructed and maintained to draw air from the laboratory and to prevent or minimize the escape of air contaminants into the laboratory; and allows chemical manipulations to be conducted in the enclosure without insertion of any portion of the employee's body other than hands and arms. Walk-in hoods with adjustable sashes meet the above definition provided that the sashes are adjusted during use so that the airflow and the exhaust of air contaminants are not compromised and employees do not work inside the enclosure during the release of airborne hazardous chemicals.

"Laboratory use of hazardous chemicals" means handling or use of such chemicals in which all of the following conditions are met:

i. Chemical manipulations are carried out on a "laboratory scale;"

ii. Multiple chemical procedures or chemicals are used;
iii. The procedures involved are not part of a production process, nor in any way simulate a production process; and (iv) "Protective laboratory practices and equipment" are available and in common use to minimize the potential for employee exposure to hazardous chemicals.

"Medical consultation" means a consultation which takes place between an employee and a licensed physician for the purpose of determining what medical examinations or procedures, if any, are appropriate in cases where a significant exposure to a hazardous chemical may have taken place.

"Organic peroxide" means an organic compound that contains the bivalent -O-O- structure and which may be considered to be a structural derivative of hydrogen peroxide where one or both of the hydrogen atoms has been replaced by an organic radical.

"Oxidizer" means a chemical other than a blasting agent or explosive as defined in 1910.109(a), that initiates or promotes combustion in other materials, thereby causing fire either of itself or through the release of oxygen or other gases.

"Physical hazard" means a chemical for which there is scientifically valid evidence that it is a combustible liquid, a compressed gas, explosive, flammable, an organic peroxide, an oxidizer pyrophoric, unstable (reactive) or water-reactive.

"Protective laboratory practices and equipment" means those laboratory procedures, practices and equipment accepted by laboratory health and safety experts as effective, or that the employer can show to be effective, in minimizing the potential for employee exposure to hazardous chemicals.

"Reproductive toxins" means chemicals which affect the reproductive capabilities including chromosomal damage (mutations) and effects on fetuses (teratogenesis).

"Select carcinogen" means any substance which meets one of the following criteria:

i. It is regulated by OSHA as a carcinogen; or

ii. It is listed under the category, "known to be carcinogens," in the Annual Report on Carcinogens published by the National Toxicology Program (NTP)(latest edition); or

iii. It is listed under Group 1 ("carcinogenic to humans") by the International Agency for research on Cancer Monographs (IARC)(latest editions); or

iv. It is listed in either Group 2A or 2B by IARC or under the category, "reasonably anticipated to be carcinogens" by NTP, and causes statistically significant tumor incidence in experimental animals in accordance with any of the following criteria: (A) After inhalation exposure of 6 - 7 hours per day, 5 days per week, for a significant portion of a lifetime to dosages of less than 10 mg/m(3); (B) after repeated skin
application of less than 300 (mg/kg of body weight) per week; or (C) after oral dosages of less than 50 mg/kg of body weight per day.

"Unstable (reactive)" means a chemical which is the pure state, or as produced or transported, will vigorously polymerize, decompose, condense, or will become self-reactive under conditions of shocks, pressure or temperature. "Water-reactive" means a chemical that reacts with water to release a gas that is either flammable or presents a health hazard.

(c) Permissible exposure limits.
For laboratory uses of OSHA regulated substances, the employer shall assure that laboratory employees' exposures to such substances do not exceed the permissible exposure limits specified in 29 CFR part 1910, subpart Z.

(d) Employee exposure determination
1. Initial monitoring. The employer shall measure the employee's exposure to any substance regulated by a standard which requires monitoring if there is reason to believe that exposure levels for that substance routinely exceed the action level (or in the absence of an action level, the PEL).

2. Periodic monitoring. If the initial monitoring prescribed by paragraph (d)(1) of this section discloses employee exposure over the action level (or in the absence of an action level, the PEL), the employer shall immediately comply with the exposure monitoring provisions of the relevant standard.

3. Termination of monitoring. Monitoring may be terminated in accordance with the relevant standard.

4. Employee notification of monitoring results. The employer shall, within 15 working days after the receipt of any monitoring results, notify the employee of these results in writing either individually or by posting results in an appropriate location that is accessible to employees.

(e) Chemical Hygiene Plan
“General” (Appendix A of this section is non-mandatory but provides guidance to assist employers in the development of the Chemical Hygiene Plan).

1. Where hazardous chemicals as defined by this standard are used in the workplace, the employer shall develop and carry out the provisions of a written Chemical Hygiene Plan which is:
   i. Capable of protecting employees from health hazards associated with hazardous chemicals in that laboratory and
   ii. Capable of keeping exposures below the limits specified in paragraph (c) of this section.
2. The Chemical Hygiene Plan shall be readily available to employees, employee representatives and, upon request, to the Assistant Secretary.

3. The Chemical Hygiene Plan shall include each of the following elements and shall indicate specific measures that the employer will take to ensure laboratory employee protection;

   i. Standard operating procedures relevant to safety and health considerations to be followed when laboratory work involves the use of hazardous chemicals;

   ii. Criteria that the employer will use to determine and implement control measures to reduce employee exposure to hazardous chemicals including engineering controls, the use of personal protective equipment and hygiene practices; particular attention shall be given to the selection of control measures for chemicals that are known to be extremely hazardous;

   iii. A requirement that fume hoods and other protective equipment are functioning properly and specific measures that shall be taken to ensure proper and adequate performance of such equipment;

   iv. Provisions for employee information and training as prescribed in paragraph (f) of this section;

   v. The circumstances under which a particular laboratory operation, procedure or activity shall require prior approval from the employer or the employer's designee before implementation;

   vi. Provisions for medical consultation and medical examinations in accordance with paragraph (g) of this section;

   vii. Designation of personnel responsible for implementation of the Chemical Hygiene Plan including the assignment of a Chemical Hygiene Officer, and, if appropriate, establishment of a Chemical Hygiene Committee; and

   viii. Provisions for additional employee protection for work with particularly hazardous substances. These include "select carcinogens, "reproductive toxins and substances which have a high degree of acute toxicity. Specific consideration shall be given to the following provisions which shall be included where appropriate:

       A. Establishment of a designated area;

       B. Use of containment devices such as fume hoods or glove boxes;

       C. Procedures for safe removal of contaminated waste; and
D. Decontamination procedures.

4. The employer shall review and evaluate the effectiveness of the Chemical Hygiene Plan at least annually and update it as necessary.

(f) Employee information and training.

1. The employer shall provide employees with information and training to ensure that they are apprised of the hazards of chemicals present in their work area.

2. Such information shall be provided at the time of an employee's initial assignment to a work area where hazardous chemicals are present and prior to assignments involving new exposure situations. The frequency of refresher information and training shall be determined by the employer.

3. Information. Employees shall be informed of:
   i. The contents of this standard and its appendices which shall be made available to employees;
   ii. the location and availability of the employer's Chemical Hygiene Plan;
   iii. The permissible exposure limits for OSHA regulated substances or recommended exposure limits for other hazardous chemicals where there is no applicable OSHA standard;
   iv. Signs and symptoms associated with exposures to hazardous chemicals used in the laboratory; and
   v. The location and availability of known reference material on the hazards, safe handling, storage and disposal of hazardous chemicals found in the laboratory including, but not limited to, Material Safety Data Sheets received from the chemical supplier.

4. Training
   i. Employee training shall include:
      A. Methods and observations that may be used to detect the presence or release of a hazardous chemical (such as monitoring conducted by the employer, continuous monitoring devices, visual appearance or odor of hazardous chemicals when being released, etc.);
      B. The physical and health hazards of chemicals in the work area; and
C. The measures employees can take to protect themselves from these hazards, including specific procedures the employer has implemented to protect employees from exposure to hazardous chemicals, such as appropriate work practices, emergency procedures, and personal protective equipment to be used.

ii. The employee shall be trained on the applicable details of the employer's written Chemical Hygiene Plan.

(g) Medical consultation and medical examinations.

1. The employer shall provide all employees who work with hazardous chemicals an opportunity to receive medical attention, including any follow-up examinations which the examining physician determines to be necessary, under the following circumstances:

i. Whenever an employee develops signs or symptoms associated with a hazardous chemical to which the employee may have been exposed in the laboratory, the employee shall be provided an opportunity to receive an appropriate medical examination.

ii. Where exposure monitoring reveals an exposure level routinely above the action level (or in the absence of an action level, the PEL) for an OSHA regulated substance for which there are exposure monitoring and medical surveillance requirements, medical surveillance shall be established for the affected employee as prescribed by the particular standard.

iii. Whenever an event takes place in the work area such as a spill, leak, explosion or other occurrence resulting in the likelihood of a hazardous exposure, the affected employee shall be provided an opportunity for a medical consultation. Such consultation shall be for the purpose of determining the need for a medical examination.

2. All medical examinations and consultations shall be performed by or under the direct supervision of a licensed physician and shall be provided without cost to the employee, without loss of pay and at a reasonable time and place.

3. Information provided to the physician. The employer shall provide the following information to the physician:

i. The identity of the hazardous chemical(s) to which the employee may have been exposed;

ii. A description of the conditions under which the exposure occurred including quantitative exposure data, if available; and
iii. A description of the signs and symptoms of exposure that the employee is experiencing, if any.

4. Physician's written opinion.

   i. For examination or consultation required under this standard, the employer shall obtain a written opinion from the examining physician which shall include the following:

      A. Any recommendation for further medical follow-up;

      B. The results of the medical examination and any associated tests;

      C. Any medical condition which may be revealed in the course of the examination which may place the employee at increased risk as a result of exposure to a hazardous workplace; and

      D. A statement that the employee has been informed by the physician of the results of the consultation or medical examination and any medical condition that may require further examination or treatment.

   ii. The written opinion shall not reveal specific findings of diagnoses unrelated to occupational exposure.

(h) Hazard identification.

1. With respect to labels and material safety data sheets:

   i. Employers shall ensure that labels on incoming containers of hazardous chemicals are not removed or defaced.

   ii. Employers shall maintain any material safety data sheets that are received with incoming shipments of hazardous chemicals, and ensure that they are readily accessible to laboratory employees.

2. The following provisions shall apply to chemical substances developed in the laboratory:

   i. If the composition of the chemical substance which is produced exclusively for the laboratory's use is known, the employer shall determine if it is a hazardous chemical as defined in paragraph (b) of this section. If the chemical is determined to be hazardous, the employer shall provide appropriate training as required under paragraph (f) of this section.

   ii. If the chemical produced is a byproduct whose composition is not known, the employer shall assume that the substance is hazardous and shall implement paragraph (e) of this section.
iii. If the chemical substance is produced for another user outside of the laboratory, the employer shall comply with the Hazard Communication Standard (29 CFR 1910.120) including the requirements for preparation of material safety data sheets and labeling.

(i) Use of respirators.
Where the use of respirators is necessary to maintain exposure below permissible exposure limits, the employer shall provide, at no cost to the employee, the proper respiratory equipment. Respirators shall be selected and used in accordance with the requirements of 29 CFR 1910.134.

(j) Recordkeeping.
1. The employer shall establish and maintain for each employee an accurate record of any measurements taken to monitor employee exposures and any medical consultation and examinations including tests or written opinions required by this standard.

2. The employer shall assure that such records are kept, transferred, and made available in accordance with 29 CFR 1910.20.

(k) Dates
1. Effective date. This section shall become effective May 1, 1990.

2. Start-up dates.
   i. Employers shall have developed and implemented a written Chemical Hygiene Plan no later than January 31, 1991.

   ii. Paragraph (a)(2) of this section shall not take effect until the employer has developed and implemented a written Chemical Hygiene Plan.
Appendix B

Other Standards & Guidelines

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*Compounds with individual standards generally have action limits (usually set at half the TLV), air monitoring requirements, and medical monitoring requirements. Please refer to the actual standard for details on any of these compounds.

Copies of these standards, policies and programs are available from the Department of Environmental Health and Safety. Call 612-626-2330 for further information.
Limits to Exposure to Toxic & Hazardous Substances

List of Definitions

ACGIH TLVs
The American Conference of Governmental Industrial Hygienists (ACGIH) publishes Threshold Limit Values (TLVs). The TLVs are airborne concentrations of substances to which nearly all workers may be repeatedly exposed, day after day, without adverse health effects. The TLVs are recommended guidelines that are revised as new toxicity information becomes available. The air concentrations expressed either as parts per million, or milligrams per cubic meter of air. There are various types of TLVs:

- TWA (Time-Weighted Average): average exposure concentration for a conventional 8-hour workday and 40 hour work week.
- STEL (Short Term Exposure Limit): a 15-minute average exposure concentration which should not result in irritation, chronic or irreversible tissue damage, or narcosis. STEL supplements the TWA.
- C (Ceiling Limit): an exposure concentration that should not be exceeded during any part of the working exposure.
- Skin: a '+' in the 'Skin' column refers to the potential for significant exposure through the cutaneous route. In these cases, appropriate measures must be taken to prevent skin and eye contact with the chemical.

California List
A '+' in any of the columns under California’s Proposition 65 List indicates that the chemical may have adverse effects on the:

- MREP - male reproductive system;
- FREP - female reproductive system; or
- DTOX - fetal development.

Cancer EPA
The Environmental Protection Agency (EPA) has six categories for confirmed and suspected carcinogens:

- Category A - substances that are human carcinogens;
- Category B1 - substances that show limited evidence of carcinogenicity in humans;
- Category B2 - substances that show sufficient evidence of carcinogenicity in animals with inadequate or lacking evidence in humans;
• Category C - substances that show limited evidence of carcinogenicity in animals and inadequate or lack of human data;

• Category D - substances that are not classifiable as a human carcinogen; and

• Category E - substances that show no carcinogenicity for humans.

**Cancer CAL 65**
California's Proposition 65 List also designates chemicals as carcinogens. Those known to the state to cause cancer are designated in this column with a ‘+’.

**Cancer IARC**
The International Agency for Research on Cancer (IARC) has four categories for confirmed and suspected carcinogens:

• Category 1 - substances for which sufficient evidence exists to establish a causal relationship between the chemical and human cancer;

• Category 2A - substances for which there is at least limited evidence of human carcinogenicity;

• Category 2B - substances for which there is sufficient evidence for carcinogenicity in animals but inadequate data for human; and

• Category 3 - substances that cannot be classified as to human carcinogenicity.

**Cancer NTP**
The National Toxicology Program (NTP) listing of carcinogens contains two categories:

• Category 1 - substances that are known to be human carcinogens; and

• Category 2 - substances that may reasonably be anticipated to be human carcinogens.

**Cancer OSHA**
An 'X' under the OSHA column denotes an OSHA-regulated carcinogen.

**Cancer TLV**
A notation under this heading indicates whether a chemical is a confirmed human carcinogen (A1) or a suspected human carcinogen (A2).

**CAS #**
Chemical Abstracts Service number.

**IDLH**
A chemical that is Immediately Dangerous to Life and Health, as published by the National Institute for Occupational Safety and Health (NIOSH) as of 3/1/95.

**NFPA 704**
National Fire Protection Association section # 704. This section defines a system for rating the
flammability (Fire/red), toxicity (Health/blue) and reactivity (React/yellow) of various chemicals. Chemical labels with colored diamond areas can be purchased which can be numbered using the NFPA 704 Hazard Rating System, with '0' considered nonhazardous and '4' extremely hazardous. The white section uses letters or symbols to denote special hazards.

**ODOR**  
A chemical's odor threshold - the point or range where most people will detect the odor of a particular chemical.

**ORAL RAT**  
The oral rat LD50 - the dose that's lethal for 50% of a group of test rats through oral administration. The lower the LD50, the more toxic the material. Compounds with an oral rat LD50 of less than 50 mg/kg (highly toxic) will have a 'yes' in this column.

**OSHA TLV**  
The federal Occupational Safety and Health Administration publishes TLVs that, unlike the ACGIH guidelines, are enforceable by law.

**RESP**  
The type of respiratory protection that is necessary to address a spill of a particular compound. Use of a nondisposable negative pressure respirator requires a physical exam and fit test before use. Filter and respirator codes are defined below:

- AM - ammonia filter
- AG - acid gas filter
- DFM - dust fume mist filter
- (F) - full face mask
- HE - high efficiency particulate air (HEPA) filter
- OV - organic vapor filter
- SA - supplied air mask
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Working with Chemicals

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5.A INTRODUCTION

Prudent execution of experiments requires not only sound judgment and an accurate assessment of the risks involved in laboratory work, but also the selection of appropriate work practices to reduce risk and protect the health and safety of the laboratory workers as well as the public and the environment. Chapter 3 provides specific guidelines to enable laboratory workers to evaluate the hazards and assess the risks associated with laboratory chemicals, equipment, and operations. Chapter 4 demonstrates how to control those risks when managing the inventory of chemicals in the laboratory. How the protocols outlined in Chapter 3 are put to use in the execution of a carefully planned experiment is the subject of Chapter 5.

Chapter 5 presents general guidelines for laboratory work with hazardous chemicals rather than specific standard operating procedures for individual substances. Hundreds of thousands of different chemicals are encountered in the research conducted in laboratories, and the specific health hazards associated with most of these compounds are generally not known. Also, laboratory work frequently generates new substances of unknown properties and unknown toxicity. Consequently, the only prudent course is for laboratory personnel to conduct their work under conditions that minimize the risks due to both known and unknown hazardous substances. The general work practices outlined in this chapter are designed to achieve this purpose.

Specifically, section 5.C describes basic prudent practices that should be employed in all laboratory work with chemicals. These guidelines are the standard operating procedures for all work conducted in laboratories where hazardous chemicals are stored or are in use.

In section 5.D, additional special procedures are presented for work with highly toxic substances. How to determine when these additional procedures are necessary is discussed in detail in Chapter 3, section 3.C. Section 5.E gives detailed special procedures for work with chemicals that pose risks due to biohazards and radioactivity; section 5.F, flammability; and section 5.G, reactivity and explosibility. Special considerations for work with compressed gases are the subject of section 5.H.

Chapter 6 provides precautionary methods for handling laboratory equipment commonly used in conjunction with hazardous chemicals. Chapters 3, 5, and 6 should all be consulted before working with hazardous chemicals.

Four fundamental principles underlie all of the work practices discussed in this chapter:

- **Plan ahead.** Determine the potential hazards associated with an experiment before beginning it.

- **Minimize exposure to chemicals.** Do not allow laboratory chemicals to come in contact with skin. Use laboratory hoods and other ventilation devices to prevent exposure to airborne substances whenever possible.

- **Do not underestimate risks.** Assume that any mixture of chemicals will be more toxic than its most toxic component. Treat all new compounds and substances of unknown toxicity as toxic substances.
• **Be prepared for accidents.** Before beginning an experiment, know what specific action to take in the event of the accidental release of any hazardous substance. Know the location of all safety equipment and the nearest fire alarm and telephone, and know what telephone numbers to call and whom to notify in the event of an emergency. Be prepared to provide basic emergency treatment. Keep your co-workers informed of your activities so that they can respond appropriately.

**5.B Prudent Planning**

The risk associated with an experiment should be determined before the laboratory work begins. The hypothetical question that should be posed before an experiment is, "What would happen if...?" For the possible contingencies, preparations should be made to take the appropriate emergency actions. The worker should know the location of emergency equipment and how to use it. He or she should be familiar with emergency procedures and should know how to obtain help in an emergency. Any special safety precautions that may be required should be addressed before the experiment is begun. The consequences of loss of electrical power or water pressure should also be considered.

The physical and health hazards associated with chemicals should be determined before working with them. This determination may involve consulting literature references, Laboratory Chemical Safety Summaries (LCSSs), Material Safety Data Sheets (MSDSs), or other reference materials (see also Chapter 3, section 3.B) and may require discussions with the laboratory supervisor and consultants such as safety and industrial hygiene officers. Every step of the waste minimization and removal processes should be checked against federal, state, and local regulations. Production of mixed chemical-radioactive-biological waste (see Chapter 7, section 7.C.1.3) should not be considered without discussions with environmental health and safety experts.

Many of the general practices applicable to working with hazardous chemicals are given elsewhere in this volume (as discussed in Chapter 2). The reader is referred to Chapter 4, section 4.C, for detailed instructions on the transport of chemicals; Chapter 4, section 4.E on storage; Chapter 6 for information on use and maintenance of equipment and glassware; and Chapter 7 for information on disposal of chemicals.

**5.C GENERAL PROCEDURES FOR WORKING WITH HAZARDOUS CHEMICALS**

**5.C.1 Personal Behavior**

Professional standards of personal behavior are required in any laboratory:

- Avoid distracting or startling other workers.
• Do not allow practical jokes and horseplay at any time.

• Use laboratory equipment only for its designated purpose.

• Do not allow visitors, including children and pets, in laboratories where hazardous substances are stored or are in use or hazardous activities are in progress.

• If children are permitted in laboratories, for example, as part of an educational or classroom activity, ensure that they are under the direct supervision of qualified adults.

• Make sure that teaching materials and publicity photographs show people wearing appropriate safety gear, in particular, eye protection.

5.C.2 Minimizing Exposure to Chemicals

Precautions should be taken to avoid exposure by the principal routes, that is, contact with skin and eyes, inhalation, and ingestion, which are discussed in detail in Chapter 3, section 3.C.

5.C.2.1 Avoiding Eye Injury

Eye protection should be required for all personnel and visitors in all locations where chemicals are stored or used. Eye protection is required whether or not one is actually performing a chemical operation. Visitor safety glasses should be made available at the entrances to all laboratories.

Researchers should assess the risks associated with an experiment and use the appropriate level of eye protection:

• Safety glasses with side shields provide the minimum protection acceptable for regular use. Safety glasses must meet the American National Standards Institute (ANSI) standard Z87.1-1989, Standard for Occupational and Educational Eye and Face Protection, which specifies a minimum lens thickness, certain impact resistance requirements, and so on.

• Safety splash goggles or face shields should be worn when carrying out operations in which there is any danger from splashing chemicals or flying particles. These thin shields do not provide protection from projectiles, however.

• Goggles are preferred over regular safety glasses to protect against hazards such as projectiles, as well as when working with glassware under reduced or elevated pressures (e.g., sealed tube reactions), when handling potentially
explosive compounds (particularly during distillations), and when employing glassware in high-temperature operations.

- Because goggles offer little protection to the face and neck, full-face shields should be worn when conducting particularly hazardous laboratory operations. In addition, glassblowing and the use of laser or ultraviolet light sources require special glasses or goggles.

Ordinary prescription glasses do not provide adequate protection against injury. Prescription safety glasses and goggles can be obtained.

Contact lenses offer no protection against eye injury and cannot be substituted for safety glasses and goggles. It is best not to wear contact lenses when carrying out operations where chemical vapors are present or a chemical splash to the eyes or chemical dust is possible because contact lenses can increase the degree of harm and can interfere with first aid and eye-flushing procedures. If an individual must wear contact lenses for medical reasons, then safety glasses with side shields or tight-fitting safety goggles must be worn over the contact lenses.

5.C.2.2 Avoiding Ingestion of Hazardous Chemicals

Eating, drinking, smoking, gum chewing, applying cosmetics, and taking medicine in laboratories where hazardous chemicals are used should be strictly prohibited. Food, beverages, cups, and other drinking and eating utensils should not be stored in areas where hazardous chemicals are handled or stored. Glassware used for laboratory operations should never be used to prepare or consume food or beverages. Laboratory refrigerators, ice chests, cold rooms, ovens, and so forth should not be used for food storage or preparation. Laboratory water sources and deionized laboratory water should not be used for drinking water.

Laboratory chemicals should never be tasted. A pipet bulb or aspirator should be used to pipet chemicals or to start a siphon; pipetting should never be done by mouth. Hands should be washed with soap and water immediately after working with any laboratory chemicals, even if gloves have been worn.

5.C.2.3 Avoiding Inhalation of Hazardous Chemicals

Toxic chemicals or compounds of unknown toxicity should never be smelled. Procedures involving volatile toxic substances and operations involving solid or liquid toxic substances that may result in the generation of aerosols should be conducted in a laboratory hood. Dusts should be recognized as potentially contaminated and hazardous. Hoods should not be used for disposal of hazardous volatile materials by evaporation. Such materials should be treated as chemical waste and disposed of in appropriate containers in accord with institutional procedures.

The following general rules should be followed when using laboratory hoods:

- For work involving hazardous substances, use only hoods that have been evaluated for adequate face velocity and proper operation. Hood operation should be inspected regularly, and the inspection certified in a visible location.
- Keep reactions and hazardous chemicals at least 6 inches behind the plane of the hood sash.

- Never put your head inside an operating laboratory hood to check an experiment. The plane of the sash is the barrier between contaminated and uncontaminated air.

- On hoods where sashes open vertically, work with the hood sash in the lowest possible position. On hoods where sashes open horizontally, position one of the doors to act as a shield in the event of an accident in the hood. When the hood is not in use, keep the sash closed to maintain laboratory airflow.

- Keep hoods clean and clear; do not clutter with bottles or equipment. If there is a grill along the bottom slot or a baffle in the back of the hood, clean them regularly so they do not become clogged with papers and dirt. Allow only materials actively in use to remain in the hood. Following this rule will provide optimal containment and reduce the risk of extraneous chemicals being involved in any fire or explosion. Support any equipment that needs to remain in hoods on racks or feet to provide airflow under the equipment.

- Report suspected hood malfunctions promptly to the appropriate office, and make sure they are corrected. Post the name of the individual responsible for use of the hood in a visible location. Clean hoods before maintenance personnel work on them.

(See Chapter 8, section 8.C, for more information on hoods.)

5.C.2.4 Avoiding Injection of Hazardous Chemicals

Solutions of chemicals are often transferred in syringes, which for many uses are fitted with sharp needles. The risk of inadvertent injection is significant, and vigilance is required to avoid that accident. Needles must be properly disposed of in “sharps” containers. Use special care when handling solutions of chemicals in hypodermic syringes.

5.C.2.5 Minimizing Skin Contact

Wear gloves whenever handling hazardous chemicals, sharp-edged objects, very hot or very cold materials, toxic chemicals, and substances of unknown toxicity. The following general guidelines apply to the selection and use of protective gloves:

- Wear gloves of a material known to be resistant to permeation by the substances in use. Wearing the wrong type of glove can be more hazardous than wearing no gloves at all, because if a chemical seeps through, the glove can hold it in prolonged contact with the wearer’s hand.

- Inspect gloves for small holes or tears before use.
• Wash gloves appropriately before removing them. (Note: some gloves, e.g., leather and polyvinyl alcohol, are water-permeable.)

• In order to prevent the unintentional spread of hazardous substances, remove gloves before handling objects such as doorknobs, telephones, pens, and computer keyboards.

• Replace gloves periodically, depending on the frequency of use and their permeation and degradation characteristics relative to the substances handled.

(For more information, see OSHA Personal Protective Equipment Standard (29 CFR 1910.132-138) regarding hand protection.)

5.C.2.6 Clothing and Protective Apparel

Long hair and loose clothing or jewelry must be confined when working in the laboratory. Unrestrained long hair, loose or torn clothing, and jewelry can dip into chemicals or become ensnared in equipment and moving machinery. Clothing and hair can catch fire. Sandals and open-toed shoes should never be worn in a laboratory in which hazardous chemicals are in use.

It is advisable to wear a laboratory coat when working with hazardous chemicals. This is particularly important if personal clothing leaves skin exposed. Apparel giving additional protection (e.g., non-permeable laboratory aprons) is required for work with certain hazardous substances. Because many synthetic fabrics are flammable and can adhere to the skin, they can increase the severity of a burn. Therefore, cotton is the preferred fabric.

5.C.3 Housekeeping

There is a definite correlation between orderliness and level of safety in the laboratory. In addition, a disorderly laboratory can hinder or endanger emergency response personnel. The following housekeeping rules should be adhered to:

• Never obstruct access to exits and emergency equipment such as fire extinguishers and safety showers.

• Clean work areas (including floors) regularly. Properly label (see Chapter 3, section 3.B.4) and store (see Chapter 4, section 4.E) all chemicals. Accumulated dust, chromatography adsorbents, and other chemicals pose respiratory hazards.

• Secure all compressed gas cylinders to walls or benches.

• Do not store chemical containers on the floor.

• Do not use floors, stairways, and hallways as storage areas.
5.C.4 Transport of Chemicals

Chemicals being transported outside the laboratory or between stockrooms and laboratories should be in break-resistant secondary containers. Secondary containers commercially available are made of rubber, metal, or plastic, with carrying handle(s), and are large enough to hold the contents of the chemical containers in the event of breakage. When transporting cylinders of compressed gases, the cylinder should always be strapped in a cylinder cart and the valve protected with a cover cap. When cylinders must be transported between floors, passengers should not be in the elevator.

5.C.5 Storage of Chemicals

The accumulation of excess chemicals can be avoided by purchasing the minimum quantities necessary for a research project. All containers of chemicals should be labeled properly. Any special hazards should be indicated on the label. For certain classes of compounds (e.g., ethers as peroxide formers), the date the container was opened should be written on the label. Peroxide formers should have the test history and date of discard written on the label as well. Only small quantities (less than 1 liter (L)) of flammable liquids should be kept at workbenches. Larger quantities should be stored in approved storage cabinets. Quantities greater than 1 L should be stored in metal or break-resistant containers. Large containers (more than 1 L) should be stored below eye level on low shelves. Hazardous chemicals and waste should never be stored on the floor.

Refrigerators used for storage of flammable chemicals must be explosion-proof, laboratory-safe units. Materials placed in refrigerators should be clearly labeled with water-resistant labels. Storage trays or secondary containers should be used to minimize the distribution of material in the event a container should leak or break. It is good practice to retain the shipping can for such secondary containers.

All chemicals should be stored with attention to incompatibilities so that if containers break in an accident, reactive materials do not mix and react violently.

(See Chapter 4, section 4.E, and Chapter 7, section 7.C.1.2, for more information.)

5.C.6 Disposal of Chemicals

Virtually every laboratory experiment generates some waste, which may include such items as used disposable lab-ware, filter media and similar materials, aqueous solutions, and hazardous chemicals. The overriding principle governing the handling of waste in prudent laboratory practice is that no activity should begin unless a plan for the disposal of nonhazardous and hazardous waste has been formulated. Application of this simple rule will ensure that the considerable regulatory requirements for waste handling are met and that unexpected difficulties,
such as the generation of a form of waste (e.g., chemical-radioactive-biological) that the institution is not prepared to deal with, are avoided.

Each category of waste has certain appropriate disposal methods. In choosing among these methods, several general principles apply, but local considerations can strongly influence the application of these rules:

- Hazardous or flammable waste solvents should be collected in an appropriate container pending transfer to the institution's central facility or satellite site for chemical waste handling or pickup by an outside disposal agency.
- Waste solvents can usually be mixed for disposal, with due regard for the compatibility of the components. Sometimes halogenated and non-halogenated wastes must be segregated for separate handling.
- The container used for the collection of liquid waste must be appropriate for its use. Glass bottles are impervious to most chemicals but present a breakage hazard, and narrow necks can cause difficulty in emptying the bottles. The use of plastic (e.g., polyethylene jerry cans) or metal (galvanized or stainless steel) safety containers for the collection of liquid waste is strongly encouraged and, indeed, required for flammable liquids.
- Galvanized steel safety cans should not be used for halogenated waste solvents because they tend to corrode and leak. Flame arresters in safety cans can easily become plugged if there is sediment and may need to be cleaned occasionally.
- Waste containers should be clearly and securely labeled as to their contents and securely capped when not in immediate use.
- Aqueous waste should be collected separately from organic solvent waste. Some laboratories may be served by a wastewater treatment facility that allows the disposal of aqueous waste to the sanitary sewer if it falls within a narrow range of acceptable waste types. Thus, solutions of nonhazardous salts or water-miscible organic materials may be acceptable in some localities. Solutions containing flammable or hazardous waste, even if water-miscible, are almost never allowed, and water-immiscible substances must never be put down the drain. Aqueous waste for non-sewer disposal should be collected in a container selected for resistance to corrosion. Glass should not be used for aqueous waste if there is danger of freezing. Depending on the requirements of the disposal facility, adjustment of the pH of aqueous waste may be required. Such adjustment requires consideration of the possible consequences of the neutralization reaction that might take place: gas evolution, heat generation, or precipitation.
• Solid chemical waste, such as reaction by-products, or contaminated filter or chromatography media, should be placed in an appropriately labeled container to await disposal or pickup. Unwanted reagents should be segregated for disposal in their original containers, if possible. If original containers are used, labels should be intact and fully legible. Every effort should be made to use, share, or recycle unwanted reagents rather than commit them to disposal. (See Chapter 4, sections 4.D and 4.E, for a discussion of labeling alternatives.)

• Nonhazardous solid waste can be disposed of in laboratory trash or segregated for recycling. Institutional policy should be consulted for these classifications.

(See Chapter 7 for further information regarding disposal, and check the appropriate LCSS to determine toxicity.)

5.C.7 Use and Maintenance of Equipment and Glassware

Good equipment maintenance is essential for safe and efficient operations. Laboratory equipment should be inspected and maintained regularly and serviced on schedules that are based on both the likelihood of and the hazards from failure. Maintenance plans should ensure that any lockout procedures cannot be violated.

Careful handling and storage procedures should be used to avoid damaging glassware. Chipped or cracked items should be discarded or repaired. Vacuum-jacketed glassware should be handled with extreme care to prevent implosions. Evacuated equipment such as Dewar flasks or vacuum desiccators should be taped or shielded. Only glassware designed for vacuum work should be used for that purpose.

Hand protection should be used when picking up broken glass. Small pieces should be swept up with a brush into a dustpan. Glassblowing operations should not be attempted unless proper annealing facilities are available. Adequate hand protection should be used when inserting glass tubing into rubber stoppers or corks or when placing rubber tubing on glass hose connections. Cuts from forcing glass tubing into stoppers or plastic tubing are the most common kind of laboratory accident and are often serious. Tubing should be fire polished or rounded and lubricated, and hands should be protected with toweling and held close together to limit movement of glass should it fracture. The use of plastic or metal connectors should be considered.

(Refer to Chapter 6 for more discussion.)

5.C.8 Handling Flammable Substances

Flammable substances present one of the most widespread hazards encountered in the laboratory. Because flammable materials are employed in so many common laboratory operations, basic prudent laboratory practice should always assume the presence of fire hazard unless a review of
the materials and operations in the laboratory verifies the absence of significant hazard. For example, simple operations with aqueous solutions in a laboratory where no flammable organic liquids are present involve no appreciable fire hazard. In all other circumstances, the risk of fire should be recognized and kept to a minimum.

For a fire to start, an ignition source, fuel, and oxidizer must be present. Prudent laboratory practice in avoiding fire is based on avoiding the presence of one of these components. The flammability and explosive characteristics of the materials being used should be known. Solvent labels, LCSSs, or other sources of information can be consulted to learn the flash point, vapor pressure, and explosive limit in air of each chemical handled. While all flammable substances should be handled prudently, the extreme flammability of some materials requires additional precautions.

To ensure that laboratory workers respond appropriately, they should be briefed on the necessary steps to take in case of a fire. The laboratory should be set up in such a way that the locations of fire alarms, pull stations, fire extinguishers, safety showers, and other emergency equipment are marked and all laboratory personnel alerted to them (see section 5.C.11 below). Exit routes in case of fire should be reviewed. Fire extinguishers in the immediate vicinity of an experiment should be appropriate to the particular fire hazards. Proper extinguishers must be used because fires can be exacerbated by use of an inappropriate extinguisher. Telephone numbers to call in case of an accident should be readily available.

(Refer to Chapter 3, section 3.B, for further information.)

5.C.9 Working with Scaled-up Reactions

Scale-up of reactions from those producing a few milligrams or grams to those producing more than 100 g of a product may represent several orders of magnitude of added risk. The attitudes, procedures, and controls applicable to large-scale laboratory reactions are fundamentally the same as those for smaller scale procedures. However, differences in heat transfer, stirring effects, times for dissolution, and effects of concentration and the fact that substantial amounts of materials are being used introduce the need for special vigilance for scaled-up work. Careful planning and consultation with experienced workers to prepare for any eventuality are essential for large-scale laboratory work.

Although it is not always possible to predict whether a scaled-up reaction has increased risk, hazards should be evaluated if the following conditions exist:

- The starting material and/or intermediates contain functional groups that have a history of being explosive-e.g., N-N, N-O, N-halogen, O-O, and O-halogen bonds-or that could explode to give a large increase in pressure.

- A reactant or product is unstable near the reaction or work-up temperature. A preliminary test consists of heating a small sample in a melting point tube.
• A reaction is delayed; that is, an induction period is required.

• Gaseous by-products are formed.

• A reaction is exothermic. What can be done to provide cooling if the reaction begins to run away?

• A reaction requires a long reflux period. What will happen if solvent is lost owing to poor condenser cooling?

• A reaction requires temperatures below 0 °C. What will happen if the reaction warms to room temperature?

In addition, thermal phenomena that produce significant effects on a larger scale may not have been detected in smaller-scale reactions and therefore could be less obvious than toxic and/or environmental hazards. Thermal analytical techniques should be used to determine whether any process modifications are necessary.

(See sections 5.D.1 and 5.G.1 and Chapter 4, section 4.B, for more information.)

5.C.10 Responsibility for Unattended Experiments and Working Alone

Generally, it is prudent to avoid working alone at the bench in a laboratory building. Individuals working in separate laboratories outside of working hours should make arrangements to check on each other periodically, or ask security guards to check on them. Experiments known to be hazardous should not be undertaken by a worker who is alone in a laboratory. Under unusually hazardous conditions, special rules may be necessary.

Laboratory operations involving hazardous substances are sometimes carried out continuously or overnight with no one present. It is the responsibility of the worker to design these experiments so as to prevent the release of hazardous substances in the event of interruptions in utility services such as electricity, cooling water, and inert gas. Laboratory lights should be left on, and signs should be posted identifying the nature of the experiment and the hazardous substances in use. If appropriate, arrangements should be made for other workers to periodically inspect the operation. Information should be posted indicating how to contact the responsible individual in the event of an emergency.

(See also Chapter 3, section 3.A.)
5.C.11 Responding to Accidents and Emergencies

5.C.11.1 General Preparation for Emergencies

All laboratory personnel should know what to do in case of an emergency. Laboratory work should not be undertaken without knowledge of the following points:

- How to report a fire, injury, chemical spill, or other emergency to summon emergency response;
- The location of emergency equipment such as safety showers and eyewashes;
- The location of fire extinguishers and spill control equipment; and
- The locations of all available exits for evacuation from the laboratory.

The above information should be available in descriptions of laboratory emergency procedures and in the institution's Chemical Hygiene Plan. Laboratory supervisors should ensure that all laboratory workers are familiar with all of this information.

Inappropriate action by individuals inadequately trained in emergency procedures can make the consequences of an emergency worse. Laboratory workers should be aware of their level of expertise with respect to use of fire extinguishers and emergency equipment, dealing with chemical spills, and dealing with injuries. They should not take actions outside the limits of their expertise but instead should rely on trained personnel.

Names and telephone numbers of responsible individuals should be posted on the laboratory door.

5.C.11.2 Handling the Accidental Release of Hazardous Substances

Experiments should always be designed so as to minimize the possibility of an accidental release of hazardous substances. Experiments should use the minimal amounts of hazardous compounds practical, and such materials should be transported properly, using break-resistant bottles or secondary containers. Personnel should be familiar with the properties (physical, chemical, and toxicological) of hazardous substances before working with them. A contingency plan to deal with the accidental release of each hazardous substance should be in place. The necessary safety equipment, protective apparel, and spill control materials should be readily available. In the event of a laboratory-scale spill, the following general guidelines for handling it should be followed in the indicated order:

1. Notify other laboratory personnel of the accident and, if necessary, evacuate the area (see section 5.C.11.3).

2. Tend to any injured or contaminated personnel and, if necessary, request help (see section 5.C.11.4).
3. Take steps to confine and limit the spill if this can be done without risk of injury or contamination (see section 5.C.11.5).

4. Clean up the spill using appropriate procedures (see section 5.C.11.6). Dispose of contaminated materials properly, according to the procedures described in Chapter 7, section 7.B.8.

(See Chapter 6, section 6.F.2, for more information on emergency procedures.)

5.C.11.3 Notification of Personnel in the Area

Other nearby workers should be alerted to the accident and the nature of the chemicals involved. In the event of the release of a highly toxic gas or volatile material, the laboratory should be evacuated and personnel posted at entrances to prevent other workers from inadvertently entering the contaminated area. In some cases (e.g., incidents involving the release of highly toxic substances and spills occurring in non-laboratory areas), it may be appropriate to activate a fire alarm to alert personnel to evacuate the entire building. The proper authorities should be called on for emergency assistance.

5.C.11.4 Treatment of Injured and Contaminated Personnel

If an individual is injured or contaminated with a hazardous substance, tending to him/her generally takes priority over implementing the spill control measures outlined in section 5.A.11.5 below. It is important to obtain medical attention as soon as possible by calling the posted number.

For spills covering small areas of skin, follow these procedures:

1. Immediately flush with flowing water for no less than 15 minutes.
2. If there is no visible burn, wash with warm water and soap, removing any jewelry to facilitate clearing of any residual materials.
3. Check the Material Safety Data Sheet (MSDS) to see if any delayed effects should be expected.
4. Seek medical attention for even minor chemical burns.
5. Do not use creams, lotions, or salves.

Take the following steps for spills on clothes:

1. Do not attempt to wipe the clothes.
2. Quickly remove all contaminated clothing, shoes, and jewelry while using the safety shower.
3. Seconds count, so do not waste time because of modesty.
4. Take care not to spread the chemical on the skin or, especially, in the eyes.

5. Use caution when removing pullover shirts or sweaters to prevent contamination of the eyes; it may be better to cut the garments off.

6. Immediately flood the affected body area with warm water for at least 15 minutes. Resume if pain returns.

7. Get medical attention as soon as possible.

8. Discard contaminated clothes or have them laundered separately from other clothing.

For splashes into the eye, take these steps:

1. Immediately flush with tepid potable water from a gently flowing source for at least 15 minutes.

2. Hold the individual's eyelids away from the eyeball, and instruct him or her to move the eye up and down and sideways to wash thoroughly behind the eyelids.

3. Use the eyewash. If one is not available, place the injured person on his or her back and pour water gently into the eyes for at least 15 minutes.

4. Follow first aid by prompt treatment by a member of a medical staff or an ophthalmologist who is acquainted with chemical injuries.

5.C.11.5 Spill Containment

Every laboratory in which hazardous substances are used should have spill control kits tailored to deal with the potential risk associated with the materials being used in the laboratory. These kits are used to confine and limit the spill if such actions can be taken without risk of injury or contamination. A specific individual should be assigned to maintain the kit. Spill control kits should be located near laboratory exits for ready access. Typical spill control kits might include these items:

- Spill control pillows. These commercially available pillows generally can be used for absorbing solvents, acids, and caustic alkalis, but not hydrofluoric acid.

- Inert absorbents such as vermiculite, clay, sand, kitty litter, and Oil Dri®. Paper is not an inert material and should not be used to clean up oxidizing agents such as nitric acid.

- Neutralizing agents for acid spills such as sodium carbonate and sodium bicarbonate.

- Neutralizing agents for alkali spills such as sodium bisulfate and citric acid.
• Large plastic scoops and other equipment such as brooms, pails, bags, and dust pans.

• Appropriate personal protective equipment, warnings, barricade tapes, and protection against slips or falls on wet floor during and after cleanup.

5.C.11.6 Spill Cleanup

Specific procedures for cleaning up spills vary depending on the location of the accident, the amount and physical properties of the spilled material, the degree and type of toxicity, and the training of the personnel involved. Outlined below are some general guidelines for handling several common spills:

• **Materials of low flammability that are not volatile or that have low toxicity.** This category of hazardous substances includes inorganic acids (e.g., sulfuric and nitric acid) and caustic bases (e.g., sodium and potassium hydroxide). For cleanup, appropriate protective apparel, including gloves, goggles, and (if necessary) shoe coverings should be worn. Absorption of the spilled material with an inert absorbent and appropriate disposal are recommended. The spilled chemicals can be neutralized with materials such as sodium bisulfate (for alkalis) and sodium carbonate or bicarbonate (for acids), absorbed on Floor-Dri® or vermiculite, scooped up, and disposed of according to the procedures detailed in Chapter 7, section 7.B.8.

• **Flammable solvents.** Fast action is crucial when a flammable solvent of relatively low toxicity is spilled. This category includes petroleum ether, pentane, diethyl ether, dimethoxyethane, and tetrahydrofuran. Other workers in the laboratory should be alerted, all flames extinguished, and any spark-producing equipment turned off. In some cases the power to the laboratory should be shut off with the circuit breaker, but the ventilation system should be kept running. The spilled solvent should be soaked up with spill absorbent or spill pillows as quickly as possible. These should be sealed in containers and disposed of properly. Non-sparking tools should be used in cleanup.

• **Highly toxic substances.** The cleanup of highly toxic substances should not be attempted alone. Other personnel should be notified of the spill, and the appropriate safety or industrial hygiene office should be contacted to obtain assistance in evaluating the hazards involved. These professionals will know how to clean up the material and may perform the operation.

5.C.11.7 Handling Leaking Gas Cylinders

Leaking gas cylinders constitute hazards that may be so serious as to require an immediate call for outside help. Workers should not apply extreme tension to close a stuck valve. Personal
protective equipment should be worn. The following guidelines cover leaks of various types of gases:

- **Flammable, inert, or oxidizing gases.** The cylinder should be moved to an isolated area, away from combustible material if the gas is flammable or an oxidizing agent, and signs should be posted that describe the hazards and state warnings. Care should be taken when moving leaking cylinders of flammable gases so that accidental ignition does not occur. If feasible, leaking cylinders should always be moved into laboratory hoods until exhausted.

- **Corrosive gases.** Corrosive gases may increase the size of the leak as they are released, and some corrosives are also oxidants, flammable, and/or toxic. The cylinder should be moved to an isolated, well-ventilated area, and suitable means used to direct the gas into an appropriate chemical neutralizer. If there is apt to be a reaction with the neutralizer that could lead to a "suck-back" into the valve (e.g., aqueous acid into an ammonia tank), a trap should be placed in the line before starting neutralization. Signs should be posted that describe the hazards and state warnings.

- **Toxic gases.** The same procedure should be followed for toxic gases as for corrosive gases, but for the protection of personnel, a special warning should be given for the added hazard of exposure. The cylinder should be moved to an isolated, well-ventilated area, and suitable means used to direct the gas into an appropriate chemical neutralizer. Signs should be posted that describe the hazards and state warnings. Appropriate personal protective equipment should be worn. (See also section 5.D.6.)

### 5.C.11.8 Handling Spills of Elemental Mercury

Mercury spills can be avoided by using supplies and equipment that do not contain mercury. However, most mercury spills do not pose a high risk. The initial response to a spill of elemental mercury should be to isolate the spill area and begin the cleanup procedure. Those doing the cleanup should wear protective gloves. The cleanup should begin with collecting the droplets. The large droplets can be consolidated by using a scraper or a piece of cardboard, and the pool of mercury removed with a pump or other appropriate equipment. A standard vacuum cleaner should never be used to pick up mercury. If a house vacuum system is used, it can be protected from the mercury by a charcoal filter in a trap. For cleaning up small mercury droplets, a special vacuum pump may be used, or the mercury may be picked up on wet toweling, which consolidates the small droplets to larger pieces, or picked up with a piece of adhesive tape. Commercial mercury spill cleanup sponges and spill control kits are available. The common practice of using sulfur should be discontinued because the practice is ineffective and the resulting waste creates a disposal problem. The mercury should be placed in a thick-wall high-density polyethylene bottle and transferred to a central depository for reclamation.
mercury spill the exposed work surfaces and floors should be decontaminated by using an appropriate decontamination kit.

5.C.11.9 Responding to Fires

Fires are one of the most common types of laboratory accidents. Accordingly, all personnel should be familiar with general guidelines (as stated below) to prevent and minimize injury and damage from fires. Hands on experience with common types of extinguishers and proper choice of extinguisher should be part of basic laboratory training.

(See also Chapter 6, section 6.F.2.)

The following should be noted:

- Preparation is essential! Make sure all laboratory personnel know the locations of all fire extinguishers in the laboratory, what types of fires they can be used for, and how to operate them correctly. Also ensure that they know the location of the nearest fire alarm pull station, safety showers, and emergency blankets.

- Even though a small fire that has just started can sometimes be extinguished with a laboratory fire extinguisher, attempt to extinguish such fires only if you are confident that you can do it successfully and quickly, and from a position in which you are always between the fire and an exit to avoid being trapped. Do not underestimate the danger from a fire, and remember that toxic gases and smoke may present additional hazards. Notify trained professionals.

- Fires in small vessels can usually be put out by covering the vessel loosely. Never pick up a flask or container of burning material.

- Extinguish small fires involving reactive metals and organometallic compounds (e.g., magnesium, sodium, potassium, and metal hydrides) with Met-L-X® or Met-L-Kyl® extinguishers or by covering with dry sand. Because these fires are very difficult to extinguish, sound the fire alarms before you attempt to extinguish the fire.

- In the event of a more serious fire, evacuate the laboratory and activate the nearest fire alarm. Upon their arrival, tell the fire department and emergency response team what hazardous substances are in the laboratory.
If a person's clothing catches fire, have him or her immediately drop to the floor and roll. Dousing with water from the safety shower can be effective. Use fire blankets only as a last resort because they tend to hold in heat and to increase the severity of burns. Remove contaminated clothing quickly, douse the person with water, and place clean, wet, cold cloth on burned areas. Wrap the injured person in a blanket to avoid shock, and get medical attention promptly.

5.D WORKING WITH SUBSTANCES OF HIGH TOXICITY

- Individuals who are working with highly toxic chemicals, as identified in Chapter 3, section 3.C, should be thoroughly familiar with the general guidelines for the safe handling of chemicals in laboratories (see section 5.C). They should also have acquired through training and experience the knowledge, skill, and discipline to carry out safe laboratory practices consistently. But these guidelines alone are not sufficient when handling substances that are known to be highly toxic and chemicals that, when combined in an experimental reaction, may generate highly toxic substances or produce new substances with the potential for high toxicity. Additional precautions are needed to set up *multiple lines of defense to minimize the risks* posed by these substances. As discussed in section 5.B, preparations for handling highly toxic substances must include sound and thorough planning of the experiment, understanding the intrinsic hazards of the substances and the risks of exposure inherent in the planned processes, selecting additional precautions that may be necessary to minimize or eliminate these risks, and reviewing all emergency procedures to ensure appropriate response to unexpected spills and accidents. Each experiment must be evaluated individually because assessment of the level of risk for work with any substance depends on how the substance will be used. Therefore, it would not be prudent for the planner to rely solely on a list of "highly toxic" chemicals to determine the level of the risk; under certain conditions, even chemicals not on these lists may become highly toxic.

- In general, the guidelines in section 5.C reflect the minimum standards for handling hazardous substances. They should become standard practice when highly toxic substances are handled in the laboratory. For example, it is always preferable to avoid working alone in laboratories. However, when highly toxic materials are being handled, it is essential that more than one person be present and that all people working in the area be familiar with the hazards of the experiments being conducted and with the appropriate emergency response.
procedures. Personal protective equipment to safeguard the hands, forearms, and face from exposure to chemicals, while desirable in most circumstances, is essential in handling highly toxic materials. Good housekeeping creates an intrinsically safer workplace and should be maintained scrupulously in areas where highly toxic substances are handled. Source reduction is always a prudent practice, but in the case of highly toxic chemicals it may mean the difference between working with toxicologically dangerous amounts of materials and working with quantities that can be handled safely with routine practice. Similarly, emergency response planning and training become very important when working with highly toxic compounds. Additional hazards from these materials (e.g., flammability and high vapor pressures) can complicate the situation, making operational safety all the more important.

5.D.1 Planning

- Careful planning needs to precede any experiment involving a highly toxic substance whenever the substance is to be used for the first time or whenever an experienced user carries out a new protocol that increases substantially the risk of exposure. Planning should include consultations with colleagues who have experience in handling the substance safely and in protocols of use. Experts in the institution's environmental health and safety program are a valuable source of information on the hazardous properties of chemicals and safe practice. They also need to be consulted for guidance regarding those chemicals that are regulated by federal, state, and local agencies or by institutional policy. Training and documentation requirements may have to be incorporated into the experiment plan.

- Effective planning is always guided by two principles: substitution of highly toxic substances with less toxic alternatives whenever appropriate and use of the smallest amount of material that is practicable for the conduct of the experiment. Other important factors to be considered in determining the need for additional safeguards are the likelihood of exposure inherent in the proposed experimental process, the toxicological and physical properties of the chemical substances being used, the concentrations and amounts involved, the duration of exposure, and known toxicological effects. It is also important to plan for careful management of the substances throughout their life cycle—from acquisition and storage through destruction or safe disposal.

5.D.2 Experiment Protocols Involving Highly Toxic Chemicals

- Experiment plans that involve the use of highly toxic substances or high-risk protocols should be considered carefully, and experienced personnel or an
appropriate source should be consulted about the risk. An experiment plan that describes the additional safeguards that will be used for all phases of the experiment from acquisition of the chemical to its final safe disposal should be in place before the experiment begins. The amounts of materials used and the names of the people involved in the laboratory work should be included in the written summary and recorded in the laboratory notebook.

- The planning process may determine that area monitoring and/or medical surveillance is necessary for ensuring the safety of the experimenters. Such a determination is likely to be made only when there is reason to believe that exposure levels for the substances planned to be used in an experiment could exceed OSHA-established regulatory action levels or similar guidelines established by other authoritative organizations. It would be prudent to review the amounts of material to be used, the toxicological properties of the substances, the opportunity for and duration of exposure, and plans for waste disposal for any experiment plans involving highly hazardous chemicals.

5.D.3 Designated Areas

Most experimental procedures involving highly toxic chemicals, including their transfer from storage containers to reaction vessels, should be confined to a designated work area in the laboratory. This area, which could be a hood or glove box, a portion of a laboratory, or the entire laboratory module, should be recognized by everyone in the laboratory or institution as a place where special precautions, laboratory skill, and safety discipline are required. Conspicuous signs should clearly indicate which areas are designated. It is not necessary to restrict the use of a designated area to the handling of highly toxic chemicals as long as laboratory personnel are aware of the nature of the substances being used and of the precautions that are necessary, and have been trained appropriately for emergency response. It may also be prudent to post relevant Laboratory Chemical Safety Summaries (LCSSs) outside the laboratory door.

The laboratory supervisor should determine which procedures need to be confined to designated areas. The general guidelines (section 5.C) for handling hazardous chemicals in laboratories may be sufficient for procedures involving low concentrations and small amounts of highly toxic chemicals, depending on the experiment, the reagents, and their toxicological and physical properties.

5.D.4 Access Control

Only persons who are directly involved in the laboratory work and who have been advised of the special precautions that may apply should have access to laboratories where highly toxic
chemicals are handled. Administrative procedures or even physical barriers may be required to prevent unauthorized personnel from entering these laboratories.

The use of locks and barricades may be appropriate to limit access to unattended areas where large amounts of highly toxic materials are being handled routinely or stored. However, it is important that locks not prevent emergency exits from the laboratory or hinder entrance for emergency response. Locks are generally more appropriate for securing storage areas and unattended laboratories than for preventing access to laboratories in which toxic chemicals are being actively used.

Some long experiments involving highly toxic compounds may require unattended operations. In such cases, securing the laboratory from access by untrained personnel is essential. These operations should also include fail-safe backup options such as shutoff devices in case a reaction overheats or pressure builds up. Additionally, equipment should include interlocks that shut down experiments by turning off devices such as heating baths or reagent pumps, or that close solenoid valves if cooling water stops flowing through an apparatus or if airflow through a fume hood becomes restricted or stops. An interlock should be constructed carefully in such a way that if a problem develops, it places the experiment in a safer mode and will not reset even if the hazardous condition is reversed. Protective devices should include alarms that indicate their activation. Security guards and untrained personnel should never be asked or allowed to check on the status of unattended experiments involving highly toxic materials. Warning signs on locked doors should list the trained laboratory workers who can be contacted in case an alarm sounds within the laboratory.

5.D.5 Special Precautions for Minimizing Exposure to Highly Toxic Chemicals

The practices listed below help build the necessary multiple lines of defense to enable laboratory work with highly toxic chemicals to be conducted safely:

1. Procedures involving highly toxic chemicals that can generate dust, vapors, or aerosols must be conducted in a hood, glove box, or other suitable containment device. Hoods should be checked for acceptable operation prior to conducting experiments with toxic chemicals. If experiments are to be ongoing over a significant period of time, the hood should be rechecked at least quarterly for integrity of flow. Hoods in continuous or long-term use with toxic materials should be equipped with flow-sensing devices that can show at a glance or by an audible signal whether they are performing adequately. When toxic chemicals are used in a glove box, it should be operated under negative pressure, and the gloves should be checked for integrity and appropriate composition before use. Any effluent from these reactions should be reactively or chemically scrubbed and/or cleaned with HEPA (high-efficiency particulate air) filters prior to discharge into the hood atmosphere. Hoods should not be used as waste disposal devices, particularly when toxic substances are involved. In order to offer maximum protection, hoods should be operated with sashes closed whenever possible, and experiments involving toxic
materials should be shielded further. Monitoring equipment might include both active and passive devices to sample laboratory working environments. (See Chapter 8, section 8.C, for detailed discussion on hoods and environmental control.)

2. When working with toxic liquids or solids, it is critical that gloves be worn to protect the hands and forearms. These gloves must be carefully selected to ensure that they are impervious to the chemicals being used and are of appropriate thickness to allow reasonable dexterity while also ensuring adequate barrier protection. Double gloves can provide a multiple line of defense and are likely to be appropriate for many situations with highly toxic chemicals. When risks from toxicity are only one facet of working with a given chemical or experimental apparatus, it is important to find a glove or combination of gloves that addresses all of the hazards present.

When using gloves, it is important to exercise proper hygiene. Reusable gloves should be washed and inspected before and after each use. Gloves that might be contaminated with toxic materials should not be removed from the immediate area (usually a hood) in which the chemicals are located. They should never be worn when handling common items such as doorknobs, elevator buttons, handles, or switches on common equipment. Other types of personal protective equipment, such as aprons of reduced permeability and disposable laboratory coats, can offer additional safeguards when working with large quantities of toxic materials.

3. Face and eye protection is also essential in preventing ingestion, inhalation, and skin absorption of toxic chemicals in the case of unexpected events. Safety glasses with side shields are a minimum standard for all laboratory work. When using toxic substances that could generate vapors, aerosols, or dusts, additional levels of protection, including full-face shields and respirators, are appropriate, depending on the degree of hazard represented. Transparent explosion shields in hoods offer additional protection from splashes. Medical supervision or surveillance may be warranted when using some toxic substances, particularly when large quantities of chemicals are involved or experiments are conducted with smaller quantities over an extended period of time. Medical certification may also be required if respirators are worn.

4. Equipment used for the handling of highly toxic chemicals should be suitably isolated from the general laboratory environment. Laboratory vacuum pumps used with these substances should be protected by high-efficiency scrubbers or HEPA filters and vented into an exhaust hood. Motor-driven vacuum pumps are recommended because they are easy to decontaminate (decontamination should be conducted in a designated hood).
5. Good laboratory hygiene should never be compromised in laboratories where highly toxic chemicals are handled. After using toxic materials the laboratory worker should wash his or her face, hands, neck, and arms. Equipment (including personal protective equipment such as gloves) that might be contaminated must never be removed from the environment reserved for handling toxic materials without complete decontamination. When possible, laboratory equipment and glassware should be chosen with an eye toward the ease of cleaning and decontamination. Mixtures that contain toxic chemicals or substances of unknown toxicity must never be smelled or tasted.

6. Transportation of very toxic chemicals from one location to another should be planned carefully, and handling of these materials outside the specially designated laboratory area should be minimized. When these materials are transported, the full complement of personal protective equipment appropriate to the chemicals in question should be worn, and the samples should be carried in unbreakable secondary containers.

**5.D.6 Preventing Accidents and Spills with Substances of High Toxicity**

Emergency response procedures must cover highly toxic substances because such procedures provide the last line of defense in working with these chemicals. Spill control and appropriate emergency response kits should be nearby, and laboratory workers should be trained in their proper use. To avoid their being contaminated or made inaccessible in an emergency, these kits should not be located within the immediate area where highly toxic substances are handled. Spill control absorbents, impermeable ground covers (to prevent the spread of contamination while conducting emergency response), warning signs, emergency barriers, first aid supplies, and antidotes should be in these kits. The contents of the kits should be validated before starting experiments. Safety showers, eyewashes, and fire extinguishers should be readily available nearby. Self-contained impermeable suits, a self-contained breathing apparatus, and cartridge respirators may also be appropriate for spill response preparedness, depending on the physical properties and toxicity of the materials being used (see section 5.C.2.3).

Experiments conducted with highly toxic chemicals should be carried out in work areas designed to contain accidental releases (see also section 5.D.3). Hood trays and other types of secondary containers should be used to contain inadvertent spills, and careful technique must be observed to minimize the potential for spills and releases.

All toxicity and emergency response information about the highly toxic chemicals being used should be readily available both before and during experimentation and should be located outside the immediate work area to ensure accessibility in emergencies. All laboratory workers who could potentially be exposed must be properly trained to participate in first aid or emergency response operations. In some cases the frequency with which highly toxic chemicals are used or the quantities involved might make formal emergency response drills warranted. Such "dry runs" may involve medical personnel as well as emergency cleanup crews.

(See also sections 5.C.11.5 and 5.C.11.6.)
5.D.7 Storage and Waste Disposal

Highly toxic chemicals should be stored in unbreakable secondary containers. If the materials are volatile or could react with moisture or air to form volatile toxic compounds, these secondary containers should be placed in a ventilated environment under negative pressure. All containers of highly toxic chemicals should be labeled clearly with chemical composition, known hazards, and warnings for handling. Chemicals that can combine to make highly toxic materials (e.g., acids and inorganic cyanides, which can generate hydrogen cyanide) should not be stored together in the same secondary container. A list of highly toxic compounds, their locations, and contingency plans for dealing with spills should be displayed prominently at any storage facility. Access to areas where highly toxic compounds are stored should be restricted to workers who are familiar with the risks they pose and who have been trained to handle these chemicals. Highly toxic chemicals that have a limited shelf life need to be tracked and monitored for deterioration in the storage facility. Those that require refrigeration should be stored in a ventilated refrigeration facility.

Procedures for disposal of highly toxic materials should be established before experiments begin, preferably before the chemicals are ordered. The procedures should address methods for decontamination of all laboratory equipment that contacts (or could contact) highly toxic chemicals. Waste should be accumulated in clearly labeled, impervious containers that are stored in unbreakable secondary containers. Volatile or reactive waste should always be covered to minimize release to the hood environment in which it is being handled.

It is the responsibility of the experimenter and the laboratory supervisor to ensure that waste is disposed of in a manner that renders it innocuous. This may involve pretreatment of the waste either before or during accumulation. In other circumstances, prudence might dictate that highly toxic compounds never be moved from an enclosed environment and might suggest in-laboratory destruction as the safest and most effective way of dealing with the waste. Regulatory requirements may have an impact on this decision (see Chapter 9). If waste cannot be rendered harmless in the laboratory, then accumulation in closed, impervious containers within secondary containment systems is prudent. The choice of methods for final disposal must ensure that these chemicals are completely destroyed or rendered harmless in some manner.

5.D.8 Multi-hazardous Materials

Some highly toxic materials present additional hazards because of their flammability (see Chapter 3, sections 3.D.1 and 3.D.4; see also section 5.F), volatility (see sections 5.E and 5.G.6), explosibility (see Chapter 3, section 3.D.3; see also section 5.G.4), or reactivity (see Chapter 3, section 3.D.2; see also section 5.G.2). These materials warrant special attention to ensure that risks are minimized and that plans to deal effectively with all potential hazards and emergency response are implemented.

(Tables 3.9 and 3.14 give information regarding incompatible chemicals and substances requiring extreme caution.)
5.E WORKING WITH BIOHAZARDOUS AND RADIOACTIVE MATERIALS

5.E.1 Biohazardous Materials

For even the most experienced laboratory worker, a careful review of the publication *Biosafety in Microbiological and Biomedical Laboratories* (U.S. DHHS, 1993) should be a prerequisite for beginning any laboratory activity involving a microorganism. It defines four levels of control that are appropriate for safe laboratory work with microorganisms that present occupational risks ranging from no risk of disease for normal healthy individuals to high individual risk of life-threatening disease, and it recommends guidelines for handling specific agents. The four levels of control, referred to as biosafety levels 1 through 4, describe microbiological practices, safety equipment, and features of laboratory facilities for the corresponding level of risk associated with handling a particular agent. The selection of a biosafety level is influenced by several characteristics of the infectious agent, the most important of which are the severity of the disease, the documented mode of transmission of the infectious agent, the availability of protective immunization or effective therapy, and the relative risk of exposure created by manipulations used in handling the agent.

Biosafety level 1 is the basic level of protection appropriate only for agents that are not known to cause disease in normal, healthy humans. Biosafety level 2 is appropriate for handling a broad spectrum of moderate-risk agents that cause human disease by ingestion or through percutaneous or mucous membrane exposure. Hepatitis B virus, human immunodeficiency virus (HIV), and salmonellae and toxoplasma spp. are representative of agents assigned to this biosafety level. Extreme precaution with needles or sharp instruments is emphasized at this level. A higher level of control may be indicated when some of these agents, especially HIV, are grown and concentrated.

Biosafety level 3 is appropriate for agents with a potential for respiratory transmission and for agents that may cause serious and potentially lethal infections. Emphasis is placed on the control of aerosols by containing all manipulations. At this level, the facility is designed to control access to the laboratory and includes a specialized ventilation system, such as a biological safety cabinet, that minimizes the release of infectious aerosols from the laboratory. The bacterium *Mycobacterium tuberculosis* is an example of an agent for which this higher level of control is appropriate. Exotic agents that pose a high individual risk of life-threatening disease by the aerosol route and for which no treatment is available are restricted to high containment laboratories that meet biosafety level 4 standards. Worker protection in these laboratories is provided by the use of physically sealed glove boxes or fully enclosed barrier suits that supply breathing air.

Several authoritative reference works are available that provide excellent guidance for the safe handling of infectious microorganisms in the laboratory, one of which is *Biosafety in the*
Laboratory—Prudent Practices for the Handling and Disposal of Infectious Materials (NRC, 1989). Standard microbiological practices described in these references are consistent with the prudent practices used for the safe handling of chemicals.

Practices that are most helpful for preventing laboratory-acquired infections are as follows:

- Wear protective gloves and a laboratory coat or gown.
- Wash hands after infectious material is handled, after gloves are removed, and before leaving the laboratory.
- Perform procedures carefully to reduce the possibility of creating splashes or aerosols.
- Contain in biological safety cabinets operations that generate aerosols.
- Use mechanical pipetting devices.
- Promptly decontaminate work surfaces after spills of infectious materials and when procedures are completed.
- Never eat, drink, smoke, handle contact lenses, apply cosmetics, or take or apply medicine in the laboratory.
- Wear eye protection.
- Take special care when using "sharps," that is, syringes, needles, Pasteur pipets, capillary tubes, scalpels, and other sharp instruments.
- Keep laboratory doors closed when experiments are in progress.
- Use secondary leak-proof containers to move or transfer cultures.
- Decontaminate infectious waste before disposal.

5.E.2 Radioactive Materials

Prudent practices for working with radioactive materials are similar to those needed to reduce the risk of exposure to toxic chemicals (section 5.C has similar information) and to biohazards:

- Know the characteristics of the radioisotopes that are being used, including half-life, types and energies of emitted radiations, the potential for exposure, how to detect contamination, and the annual limit on intake.
- Protect against exposure to airborne and ingestible radioactive materials.
- Never eat, drink, smoke, handle contact lenses, apply cosmetics, or take or apply medicine in the laboratory, and keep food, drinks, cosmetics, and tobacco products out of the laboratory entirely so that they cannot become contaminated.
• Do not pipet by mouth.
• Provide for safe disposal of waste radionuclides and their solutions.
• Use protective equipment to minimize exposures.
• Use equipment that can be manipulated remotely, as well as shielding, glove boxes, and personal protective equipment, including gloves, clothing, and respirators, as appropriate.
• Plan experiments so as to minimize exposure by reducing the time of exposure, using shielding against exposure, increasing your distance from the radiation, and paying attention to monitoring and decontamination.
• Keep an accurate inventory of radioisotopes.
• Record all receipts, transfers, and disposals of radioisotopes.
• Record surveys.
• Check workers and the work area each day that radioisotopes are used.
• Minimize radioactive waste.
• Plan procedures to use the smallest amount of radioisotope possible.
• Check waste materials for contamination before discarding.
• Place only materials with known or suspected radioactive contamination in appropriate radioactive waste containers.
• Do not generate multi-hazardous waste (combinations of radioactive, biological, and chemical waste) without first consulting with the designated radiation and chemical safety officers.

(See Chapter 7 for more information on waste and disposal.)

5.F WORKING WITH FLAMMABLE CHEMICALS

All laboratory personnel should know the properties of chemicals they are handling as well as have a basic understanding of how these properties might be affected by the variety of conditions found in the laboratory. As stated in section 5.B, Laboratory Chemical Safety Summaries (LCSSs) or other sources of information should be consulted for further information such as vapor pressure, flash point, and explosive limit in air. The use of flammable substances is common, and their properties are also discussed in Chapter 3, section 3.D.
General prudent practices include minimizing the amounts used, storing chemicals properly, keeping appropriate fire extinguishing equipment readily available, physically separating flammable materials from other operations and sources of ignition, properly grounding static sources of ignition, and using the least hazardous alternative available.

Ignition sources should be eliminated from any area where flammable substances are handled. Open flames, such as Bunsen burners, matches, and smoking tobacco, are obvious ignition sources. Gas burners should not be used as a source of heat in any laboratory where flammable substances are used. Less obvious ignition sources include gas-fired space heating or water-heating equipment and electrical equipment, such as stirring devices, motors, relays, and switches, which can all produce sparks that will ignite flammable vapors. Because the location of this equipment is often fixed, operations with flammable substances may have to be carried out elsewhere.

Low-level sources of ignition, such as hot plates, steam lines, or other hot surfaces, can even provide a sufficiently energetic ignition source for the most flammable substances in general laboratory use, such as diethyl ether and carbon disulfide (see Chapter 3, section 3.D.1.3). Flammable substances that require low-temperature storage should be stored only in refrigerators designed for that purpose. Ordinary refrigerators are a hazard because of the presence of potential ignition sources, such as switches, relays, and, possibly, sparking fan motors, and should never be used for storing chemicals. When transferring flammable liquids in metal containers, sparks from accumulated static charge must be avoided by grounding.

Fire hazards posed by water-reactive substances such as alkali metals and metal hydrides, pyrophoric substances such as metal alkyls, strong oxidizers such as perchloric acid, and flammable gases such as acetylene require procedures beyond the standard prudent practices for handling chemicals described here (see sections 5.C and 5.D) and should be researched in LCSSs or other references before work begins. In addition, emergency response to incidents involving these substances must take their special hazards into account.

### 5.F.1 Flammable Materials

The basic precautions for safe handling of flammable materials include the following:

- Handle flammable substances only in areas free of ignition sources. Besides open flames, ignition sources include electrical equipment (especially motors), static electricity, and, for some materials (e.g., carbon disulfide), even hot surfaces. Check the work area for flames or ignition sources before using a flammable substance. Before igniting a flame, check for the presence of a flammable substance.

- Never heat flammable substances with an open flame. Preferred heat sources include steam baths, water baths, oil and wax baths, salt and sand baths, heating mantles, and hot air or nitrogen baths.
• Ventilation by diluting the vapors until they are no longer flammable is one of the most effective ways to prevent the formation of flammable gaseous mixtures. Use appropriate and safe exhaust whenever appreciable quantities of flammable substances are transferred from one container to another, allowed to stand in open containers, heated in open containers, or handled in any other way. In using dilution techniques, make certain that equipment (e.g., fans) used to provide dilution is explosion proof and that sparking items are located outside the air stream.

• Keep containers of flammable substances tightly closed at all times when not in use.

• Use only refrigeration equipment certified for storage of flammable materials.

• Use the smallest quantities of flammable substances compatible with the need, and, especially when the flammable liquid must be stored in glass, purchase the smallest useful size bottle.

5.F.2 Flammable Liquids

Flammable liquids burn only when their vapor is mixed with air in the appropriate concentration. Therefore, such liquids should always be handled so as to minimize the creation of flammable vapor concentrations. Dilution of flammable vapors by ventilation is an important means of avoiding flammable concentrations. Containers of liquids should be kept closed except during transfer of contents. Transfers should be carried out only in fume hoods or in other areas where ventilation is sufficient to avoid a buildup of flammable vapor concentrations. Spillage or breakage of vessels or containers of flammable liquids or sudden eruptions from nucleation of heated liquid can result in a sudden release of vapor, which will produce an unexpected quantity of flammable vapor.

Metal lines and vessels discharging flammable liquids should be grounded properly and also grounded to discharge static electricity. For instance, when transferring flammable liquids in metal equipment avoid static-generated sparks by grounding and the use of ground straps. Development of static electricity is related closely to the level of humidity and may become a problem on very cold, dry winter days. When nonmetallic containers (especially plastic) are used, the contact should be made directly to the liquid with the grounding device rather than to the container. In the rare circumstance that static electricity cannot be avoided, all processes should be carried out as slowly as possible to give the accumulated charge time to disperse, or should be handled in an inert atmosphere.

Note that vapors of many flammable liquids are heavier than air and capable of traveling considerable distances along the floor. This possibility should be recognized, and special note should be taken of ignition sources at a lower level than that at which the substance is being used. Close attention should be given to nearby potential sources of ignition.
### 5.F.3 Flammable Gases

Leakage or escape of flammable gases can produce an explosive atmosphere in the laboratory. Acetylene, hydrogen, ammonia, hydrogen sulfide, propane, and carbon monoxide are especially hazardous. Acetylene, methane, and hydrogen have very wide flammability limits, which adds greatly to their potential fire and explosion hazard. Installation of flash arresters on hydrogen cylinders is recommended. Prior to introduction of a flammable gas into a reaction vessel, the equipment should be purged by evacuation or with an inert gas. The flush cycle should be repeated three times to reduce residual oxygen to about 1%. 

(See section 5.H for specific precautions on the use of compressed gases.)

### 5.F.4 Catalyst Ignition of Flammable Materials

Palladium or platinum on carbon, platinum oxide, Raney nickel, and other hydrogenation catalysts should be filtered carefully from hydrogenation reaction mixtures. The recovered catalyst is usually saturated with hydrogen, is highly reactive, and, thus, inflames spontaneously on exposure to air. Especially for large-scale reactions, the filter cake should not be allowed to become dry. The funnel containing the still-moist catalyst filter cake should be put into a water bath immediately after completion of the filtration. Use of a purge gas (nitrogen or argon) is strongly recommended for hydrogenation procedures so that the catalyst can then be filtered and handled under an inert atmosphere.

### 5.G WORKING WITH HIGHLY REACTIVE OR EXPLOSIVE CHEMICALS

An explosion results when a material undergoes rapid reaction that results in a violent release of energy. Such reactions can occur spontaneously or be initiated and can produce pressures, gases, and fumes that are hazardous. Highly reactive and explosive materials used in the laboratory require appropriate procedures. In this section, techniques for identifying and handling potentially explosive materials are discussed.

#### 5.G.1 Overview

Light, mechanical shock, heat, and certain catalysts can be initiators of explosive reactions. Hydrogen and chlorine react explosively in the presence of light. Examples of shock-sensitive materials include acetylides, azides, organic nitrates, nitro compounds, perchlorates, and many peroxides. Acids, bases, and other substances can catalyze the explosive polymerizations. The catalytic effect of metallic contamination can lead to explosive situations. Many metal ions can catalyze the violent decomposition of hydrogen peroxide.
Many highly reactive chemicals can polymerize vigorously, decompose, condense, and/or become self-reactive. The improper handling of these materials may result in a runaway reaction that could become violent. Careful planning is essential to avoid serious accidents. When highly reactive materials are in use, emergency equipment should be at hand. The apparatus should be assembled in such a way that if the reaction begins to run away, immediate removal of any heat source, cooling of the reaction vessel, cessation of reagent addition, and closing of laboratory hood sashes are possible. Evacuation of personnel until the reaction is under control is advisable. A heavy, transparent plastic explosion shield should be in place to provide extra protection in addition to the hood window.

Highly reactive chemicals can lead to reactions with rates that increase rapidly as the temperature increases. If the heat evolved is not dissipated, the reaction rate can increase until an explosion results. Such an event must be prevented, particularly when scaling up experiments. Sufficient cooling and surface for heat exchange should be provided to allow control of the reaction. It is also important that the concentrations of the solutions used not be excessive, especially when a reaction is being attempted or scaled up for the first time. Use of too highly concentrated reagents has led to runaway conditions and to explosions. Particular care must also be given to the rate of reagent addition versus its rate of consumption, especially if the reaction is subject to an induction period.

Large-scale reactions with organometallic reagents and reactions that produce flammables as products and/or are carried out in flammable solvents require special attention. Active metals, such as sodium, magnesium, lithium, and potassium, are a serious fire and explosion risk because of their reactivity with water, alcohols, and other compounds containing acidic OH. These materials require special storage, handling, and disposal procedures. Where active metals are present, Class D fire extinguishers that use special extinguishing materials such as a plasticized graphite-based powder or a sodium chloride-based powder (Met-L-X®) are required.

Some chemicals decompose when heated. Slow decomposition may not be noticeable on a small scale, but on a large scale with inadequate heat transfer, or if the evolved heat and gases are confined, an explosive situation can develop. The heat-initiated decomposition of some substances, such as certain peroxides, is almost instantaneous. In particular, reactions that are subject to an induction period can be dangerous because there is no initial indication of a risk, but after the induction a violent process can result.

Oxidizing agents may react violently when they come in contact with reducing materials, trace metals, and sometimes ordinary combustibles. These compounds include the halogens, oxyhalogens, and peroxyhalogens, permanganates, nitrates, chromates, and persulfates, as well as peroxides (see also section 5.G.3). Inorganic peroxides are generally considered to be stable. However, they may generate organic peroxides and hydroperoxides in contact with organic compounds, react violently with water (alkali metal peroxides), or form superoxides and ozonides (alkali metal peroxides). Perchloric acid and nitric acid are powerful oxidizing agents with organic compounds and other reducing agents. Perchlorate salts can be explosive and should be treated as potentially hazardous compounds. "Dusts"—suspensions of oxidizable particles (e.g., magnesium powder, zinc dust, carbon powder, or flowers of sulfur) in the air—constitute a powerful explosive mixture.
Scale-up of reactions can create difficulties in dissipation of heat that are not evident on a smaller scale. Evaluation of observed or suspected exothermicity can be achieved by differential thermal analysis (DTA) to identify exothermicity in open reaction systems; differential scanning calorimetry (DSC), using a specially designed sealable metal crucible, to identify exothermicity in closed reaction systems; or syringe injection calorimetry (SIC) and reactive systems screening tool (RSST) calorimetry to determine heats of reaction on a microscale and small scale. (For an expanded discussion of identifying process hazards using thermal analytical techniques, see Tuma (1991).) When it becomes apparent that an exotherm exists at a low temperature and/or a large exotherm occurs that might present a hazard, large-scale calorimetry determination of exothermic onset temperatures and drop weight testing are advisable. In situations where formal operational hazard evaluation or reliable data from any other source suggest a hazard, review or modification of the scale-up conditions by an experienced group is recommended to avoid the possibility that an individual might overlook a hazard or the most appropriate procedural changes.

Any given sample of a highly reactive material may be dangerous. Furthermore, the risk is associated not with the total energy released, but rather with the remarkably high rate of a detonation reaction. A high order explosion of even milligram quantities can drive small fragments of glass or other matter deep into the eye. It is important to use minimum amounts of hazardous materials with adequate shielding and personal protection.

Not all explosions result from chemical reactions. A dangerous, physically caused explosion can occur if a hot liquid is brought into sudden contact with a lower-boiling-point one. The instantaneous vaporization of the lower-boiling-point substance can be hazardous to personnel and destructive to equipment. The presence or inadvertent addition of water to the hot fluid of a heating bath is an example of such a hazard. Explosions can also occur when warming a cryogenic material in a closed container or over-pressurizing glassware with nitrogen (N₂) or argon when the regulator is incorrectly set. Violent physical explosions have also occurred when a collection of very hot particles is suddenly dumped into water. For this reason, dry sand should be used to catch particles during laboratory thermite reaction demonstrations.

### 5.G.2 Reactive or Explosive Compounds

Occasionally, it is necessary to handle materials that are known to be explosive or that may contain explosive impurities such as peroxides. Since explosive chemicals might be detonated by mechanical shock, elevated temperature, or chemical action with forces that release large volumes of gases, heat, and often toxic vapors, they must be treated with special care.

The proper handling of highly energetic substances without injury demands attention to the most minute detail. The unusual nature of work involving such substances requires special safety measures and handling techniques that must be understood thoroughly and followed by all persons involved. The practices listed in this section are a guide for use in any laboratory operation that might involve explosive materials.

Work with explosive (or potentially explosive) materials generally requires the use of special protective apparel (e.g., face shields, gloves, and laboratory coats) and protective devices such as
explosion shields, barriers, or even enclosed barricades or an isolated room with a blowout roof or window (see Chapter 6, sections 6.F.1 and 6.F.2). Before work with a potentially explosive material is begun, the experiment should be discussed with a supervisor or an experienced co-worker, and/or the relevant literature consulted (see Chapter 3, sections 3.B.2, 3.B.5, and 3.B.6). A risk assessment should be carried out.

Various state and federal regulations cover the transportation, storage, and use of explosives. These regulations should be consulted before explosives (and related dangerous materials) are used or generated in the laboratory. Explosive materials should be brought into the laboratory only as required and then in the smallest quantities adequate for the experiment (see Chapter 4, section 4.B). Insofar as possible, direct handling should be minimized. Explosives should be segregated from other materials that could create a serious risk to life or property should an accident occur.

5.G.2.1 Personal Protective Apparel

When explosive materials are handled, the following items of personal protective apparel are needed:

- Safety glasses that have solid side shields or goggles should be worn by all personnel, including visitors, in the laboratory.

- Full-length shields that fully protect the face and throat should be worn whenever the worker is in a hazardous or exposed position. Special care is required when operating or manipulating synthesis systems that may contain explosives (e.g., diazomethane), when bench shields are moved aside, and when handling or transporting such systems. In view of the special hazard to life that results from severing the jugular vein, extra shielding around the throat is recommended.

- Heavy leather gloves should be worn if it is necessary to reach behind a shielded area while a hazardous experiment is in progress or when handling reactive compounds or gaseous reactants. Proper planning of experiments should minimize the need for such activities.

- Laboratory coats should be worn at all times in explosives laboratories. The coat should be made of flame-resistant material and should be quickly removable. A coat can help reduce minor injuries from flying glass as well as the possibility of injury from an explosive flash.

5.G.2.2 Protective Devices

Barriers such as shields, barricades, and guards should be used to protect personnel and equipment from injury or damage from a possible explosion or fire. The barrier should completely surround the hazardous area. On benches and hoods, a 0.25-inch-thick acrylic sliding shield, which needs to be screwed together in addition to being glued, can effectively protect a worker from glass fragments resulting from a laboratory-scale detonation. The shield should be in place whenever hazardous reactions are in progress or whenever hazardous materials are being
stored temporarily. However, such shielding is not effective against metal shrapnel. The laboratory hood sash provides a safety shield only against chemical splashes or sprays, fires, and minor explosions. If more than one hazardous reaction is carried out, the reactions should be shielded from each other and separated as far as possible.

Dry boxes should be fitted with safety glass windows overlaid with 0.25-inch-thick acrylic when potentially explosive materials capable of detonation in an inert atmosphere are to be handled. This protection is adequate against most internal 5-g detonations. Protective gloves should be worn over the rubber dry box gloves to provide additional protection. Other safety devices that allow remote manipulation should be used with the gloves. Detonation of explosives from static sparks can be a considerable problem in dry boxes, so adequate grounding is essential, and an antistatic gun is recommended.

Armored hoods or barricades made with thick (1.0 inch) polyvinylbutyral resin shielding and heavy metal walls give complete protection against detonations not in excess of the acceptable 20-g limit. These hoods are designed to contain a 100-g explosion, but an arbitrary 20-g limit is usually set because of the noise level in the event of a detonation. Such hoods should be equipped with mechanical hands that enable the operator to manipulate equipment and handle adduct containers remotely. A sign, such as should be posted.

**CAUTION: NO ONE MAY ENTER AN ARMORED HOOD FOR ANY REASON DURING THE COURSE OF A HAZARDOUS OPERATION**

Miscellaneous protective devices such as both long-and short-handled tongs for holding or manipulating hazardous items at a safe distance and remote control equipment (e.g., mechanical arms, stopcock turners, lab-jack turners, remote cable controllers, and closed-circuit television monitors) should be available as required to prevent exposure of any part of the body to injury.

5.G.2.3 Evaluating Potentially Reactive Materials

Potentially reactive materials must be evaluated for their possible explosive characteristics by consulting the literature and considering their molecular structures. The presence of functional groups or compounds listed in sections 5.C.9 or 5.G.6 indicates a possible explosion hazard. New compounds can be screened for explosiveness by cautious heating and hammering of very small samples. Highly reactive chemicals should be segregated from materials that might interact with them to create a risk of explosion. Highly reactive chemicals should not be used past their expiration date.

5.G.2.4 Determining Reaction Quantities

When a possibly hazardous reaction is attempted, small quantities of reactants should be used. When handling highly reactive chemicals, it is advisable to use the smallest quantities needed for the experiment. In conventional explosives laboratories, no more than 0.1 g of product should be prepared in a single run. During the actual reaction period, no more than 0.5 g of reactants should be present in the reaction vessel. This means that the diluent, the substrate, and the energetic reactant must all be considered when determining the total explosive power of the reaction mixture. Special formal risk assessments should be established to examine operational and safety problems involved in scaling up a reaction in which an explosive substance is used or could be generated.
5.G.2.5 Conducting Reaction Operations

The most common heating devices are heating tapes and mantles and sand, water, steam, wax, silicone oil, and air (or nitrogen) baths. These should be used in such a way that if an explosion were to occur, the heating medium would be contained. Heating baths should consist of nonflammable materials. All controls for heating and stirring equipment should be operable from outside the shielded area. (See Chapter 6, section 6.C.5, for further information.)

Vacuum pumps should carry tags indicating the date of the most recent oil change. Oil should be changed once a month, or sooner if it is known that the oil has been exposed to reactive gases. All pumps should either be vented into a hood or trapped. Vent lines may be Tygon, rubber, or copper. If Tygon or rubber lines are used, they should be supported so that they do not sag, causing a trap for condensed liquids. (See Chapter 6, section 6.C.2, for details.)

When potentially explosive materials are being handled, the area should be posted with a sign such as

WARNING: VACATE THE AREA AT THE FIRST INDICATION OF [the indicator for the specific case]. STAY OUT. CALL [responsible person] AT [phone number].

When condensing explosive gases, the temperature of the bath and the effect on the reactant gas of the condensing material selected must be determined experimentally (see Chapter 6, section 6.D). Very small quantities should be used because detonations may occur. A taped and shielded Dewar flask should always be used when condensing reactants. Maximum quantity limits should be observed. A dry ice solvent bath is not recommended for reactive gases; liquid nitrogen is recommended. (See also Chapter 3, section 3.D.3.1.)

5.G.3 Organic Peroxides

Organic peroxides are a special class of compounds whose unusually low stability makes them among the most hazardous substances commonly handled in laboratories, especially as initiators for free-radical reactions. Although they are low-power explosives, they are hazardous because of their extreme sensitivity to shock, sparks, and other forms of accidental detonation. Many peroxides that are handled routinely in laboratories are far more sensitive to shock than most primary explosives (e.g., TNT), although many have been stabilized by the addition of compounds that inhibit reaction. Nevertheless, even low rates of decomposition may automatically accelerate and cause a violent explosion, especially in bulk quantities of peroxides (e.g., benzoyl peroxide). These compounds are sensitive to heat, friction, impact, and light, as well as to strong oxidizing and reducing agents. All organic peroxides are highly flammable, and fires involving bulk quantities of peroxides should be approached with extreme caution.

Precautions for handling peroxides include the following:

- Limit the quantity of peroxide to the minimum amount required. Do not return unused peroxides to the container.
• Clean up all spills immediately. Solutions of peroxides can be absorbed on vermiculite or other absorbing material and disposed of harmlessly according to institutional procedures.

• The sensitivity of most peroxides to shock and heat can be reduced by dilution with inert solvents, such as aliphatic hydrocarbons. However, do not use aromatics (such as toluene), which are known to induce the decomposition of diacyl peroxides.

• Do not use solutions of peroxides in volatile solvents under conditions in which the solvent might be vaporized because this will increase the peroxide concentration in the solution.

• Do not use metal spatulas to handle peroxides because contamination by metals can lead to explosive decomposition. Magnetic stirring bars can unintentionally introduce iron, which can initiate an explosive reaction of peroxides. Ceramic, Teflon, or wooden spatulas and stirring blades may be used if it is known that the material is not shock-sensitive.

• Do not permit smoking, open flames, and other sources of heat near peroxides. It is important to label areas that contain peroxides so that this hazard is evident.

• Avoid friction, grinding, and all forms of impact near peroxides, especially solid peroxides. Glass containers that have screw-cap lids or glass stoppers should not be used. Polyethylene bottles that have screw-cap lids may be used.

• To minimize the rate of decomposition, store peroxides at the lowest possible temperature consistent with their solubility or freezing point. Do not store liquid peroxides or solutions at or lower than the temperature at which the peroxide freezes or precipitates because peroxides in these forms are extremely sensitive to shock and heat.

• If a container of peroxide-forming material is past its expiration date, and there is a risk that peroxides may be present, open it with caution and dispose of it according to institutional procedures (see section 5.G.3.2).

• Test for the presence of peroxides if there is a reasonable likelihood of their presence and the expiration date has not passed (see section 5.G.3.1).

(Also refer to Chapter 7, section 7.D.2.5.)

5.G.3.1 Peroxide Detection Tests

The following tests can detect most (but not all) peroxy compounds, including all hydroperoxides:
- Add 1 to 3 milliliters (mL) of the liquid to be tested to an equal volume of acetic acid, add a few drops of 5% aqueous potassium iodide solution, and shake. The appearance of a yellow to brown color indicates the presence of peroxides. Alternatively, addition of 1 mL of a freshly prepared 10% solution of potassium iodide to 10 mL of an organic liquid in a 25-mL glass cylinder should produce a yellow color if peroxides are present.

- Add 0.5 mL of the liquid to be tested to a mixture of 1 mL of 10% aqueous potassium iodide solution and 0.5 mL of dilute hydrochloric acid to which has been added a few drops of starch solution just prior to the test. The appearance of a blue or blue-black color within a minute indicates the presence of peroxides.

- Peroxide test strips, which turn to an indicative color in the presence of peroxides, are available commercially. Note that these strips must be air dried until the solvent evaporates and then exposed to moisture for proper operation.

None of these tests should be applied to materials (such as metallic potassium) that may be contaminated with inorganic peroxides.

5. G. 3. 2 Disposal of Peroxides

Pure peroxides should never be disposed of directly but must be diluted before disposal. Small quantities (25 g or less) of peroxides are generally disposed of by dilution with water to a concentration of 2% or less, after which the solution is transferred to a polyethylene bottle containing an aqueous solution of a reducing agent, such as ferrous sulfate or sodium bisulfite. The material can then be handled as a waste chemical; however, it must not be mixed with other chemicals for disposal. Spilled peroxides should be absorbed on vermiculite or other absorbent as quickly as possible. The vermiculite-peroxide mixture can be burned directly or may be stirred with a suitable solvent to form a slurry that can be treated according to institutional procedures. Organic peroxides should never be flushed down the drain.

Large quantities (more than 25 g) of peroxides require special handling. Each case should be considered separately, and handling, storage, and disposal procedures should be determined by the physical and chemical properties of the particular peroxide (see also Hamstead, 1964).

Peroxides can be formed during storage of some materials in air, and a peroxide present as a contaminant in a reagent or solvent (e.g., 1,4-dioxane) can be very hazardous and change the course of a planned reaction. Especially dangerous are ether bottles that have evaporated to dryness. Excluding oxygen by storing potential peroxide-formers under an inert atmosphere (N₂ or argon) or under vacuum greatly increases their safe storage lifetime. In many instances, it is possible to purchase the chemical stored under nitrogen in septum-capped bottles. In some cases, stabilizers or inhibitors (free-radical scavengers that terminate the chain reaction) are added to the liquid to extend its storage lifetime. Because distillation of the stabilized liquid removes the stabilizer, the distillate must be stored with care and monitored for peroxide formation.
Furthermore, HPLC-grade solvents generally contain no stabilizer, and the same considerations apply to their handling.

(Also see Chapter 3, section 3.D.3.2; for disposal information, see Chapter 7, section 7.D.2.5.)

5.G.4 Explosive Gases and Liquefied Gases

A substance is more concentrated in the form of a liquefied gas than in the vapor phase and may evaporate extremely rapidly. Contact with liquid oxygen, in particular, may introduce extreme risk. Liquefied air is almost as dangerous as liquid oxygen because the nitrogen boils away, and as it does, it leaves an increasing concentration of oxygen. Other cryogenic liquids, such as nitrogen and helium, if they have been open to air, may have absorbed and condensed enough atmospheric oxygen to be very hazardous. When a liquefied gas is used in a closed system, pressure may build up, so that adequate venting is required. Relief devices are required to prevent this dangerous buildup of pressure. If the liquid is flammable (e.g., hydrogen), explosive concentrations in air may develop. Because flammability, toxicity, and pressure buildup may become serious when gases are exposed to heat, gases should be stored only in specifically designed and designated areas (see Chapter 8, section 8.E).

5.G.5 Hydrogenation Reactions

Hydrogenation reactions are often carried out under pressure with a reactive catalyst and so require special attention. Along with observation of the precautions for the handling of gas cylinders and flammable gases, additional attention must be given to carrying out hydrogenation reactions at pressures above 1 atm. The following precautions are applicable:

- Make sure that the autoclave, pressure bottle, or other apparatus is appropriate for the experiment. Most preparative hydrogenations of substances such as alkenes can be carried out safely in a commercial hydrogenation apparatus using a heterogeneous catalyst (e.g., Pt and Pd) under moderate (<80 psi H₂) pressure.

- Review the operating procedures for the apparatus, and inspect the container before each experiment. Glass reaction vessels are subject to scratches or chips that render them unsuitable for use under pressure. Never fill the vessel to capacity with the solution; filling it about half full (or less) is much safer.

- One of the most important precautions to be taken with any reaction involving hydrogen is to remove as much oxygen from the solution as possible before adding hydrogen. Failure to do this could result in an explosive oxygen-hydrogen (O₂/H₂) mixture. Normally, the oxygen in the vessel is removed by pressurizing the vessel with inert gas (N₂ or argon), followed by venting the gas. If available, vacuum can be applied to the
solution. Repeat this procedure of filling with inert gas and venting several times before the hydrogen or other high-pressure gas is introduced.

- Do not approach the rated safe pressure limit of the bottle or autoclave, with due regard to increased pressure upon heating. A limit of 75% of the rating in a high-pressure autoclave is advisable, but if this limit is exceeded accidentally, replace the rupture disk upon completion of the experiment.

- Monitor the pressure of the high-pressure device periodically as the heating proceeds to avoid too high a pressure in case of unintentional overheating.

- Purge the system of hydrogen by repeated "rinsing" with inert gas at the end of the experiment to avoid producing hydrogen-oxygen mixtures in the presence of the catalyst during work-up. Handle catalyst that has been used in the reaction with special care because it can be a source of spontaneous ignition upon contact with air.

(Also see section 5.C.)

5.G.6 Reactive or Explosive Materials Requiring Special Attention

The following list is not intended to be all-inclusive. Further guidance on reactive and explosive materials should be sought from pertinent sections of this book (see Chapter 3, sections 3.D.2 and 3.D.3) and other sources of information (note sources included in Chapter 3, section 3.B).

**Acetylenic compounds** can be explosive in mixtures of 2.5 to 80% with air. At pressures of 2 or more atmospheres, acetylene (C₂H₂) subjected to an electrical discharge or high temperature decomposes with explosive violence. Dry acetylides detonate on receiving the slightest shock.

**Acetylene must be handled in acetone solution and never stored alone in a cylinder.**

**Aluminum chloride** (AlCl₃) should be considered a potentially dangerous material. If moisture is present, there may be sufficient decomposition to form hydrogen chloride (HCl) and build up considerable pressure. If a bottle is to be opened after long storage, it should first be completely enclosed in a heavy towel.

**Ammonia** (NH₃) reacts with iodine to give nitrogen triiodide, which detonates on touch. Ammonia reacts with hypochlorites to give chlorine. Mixtures of NH₃ and organic halides sometimes react violently when heated under pressure. Ammonia is combustible. Inhalation of concentrated fumes can be fatal.

**Azides**, both organic and inorganic, and some azo compounds can be heat and shock-sensitive. Azides such as sodium azide can displace halide from chlorinated hydrocarbons such as dichloromethane to form highly explosive organic polyazides; this substitution reaction is facilitated in solvents such as dimethyl sulfoxide (DMSO).
Carbon disulfide (CS₂) is very toxic and very flammable; mixed with air, its vapors can be ignited by a steam bath or pipe, a hot plate, or a light bulb.

Chlorine (Cl₂) is toxic and may react violently with hydrogen (H₂) or with hydrocarbons when exposed to sunlight.

Chromium trioxide—pyridine complex (CrO₃ C₅H₅N) may explode if the CrO₃ concentration is too high. The complex should be prepared by addition of CrO₃ to excess C₅H₅N.

Diazomethane (CH₂N₂) and related diazo compounds should be treated with extreme caution. They are very toxic, and the pure gases and liquids explode readily even from contact with sharp edges of glass. Solutions in ether are safer from this standpoint. An ether solution of diazomethane is rendered harmless by drop wise addition of acetic acid.

Diethyl, diisopropyl, and other ethers, including tetrahydrofuran and 1,4-dioxane and particularly the branched-chain type of ethers, sometimes explode during heating or refluxing because the presence of peroxides has developed from air oxidation. Ferrous salts or sodium bisulfite can be used to decompose these peroxides, and passage over basic active alumina can remove most of the peroxidic material. In general, however, old samples of ethers should be disposed of after testing, following procedures for disposal of peroxides (see Chapter 7, section 7.D.2.5).

Dimethyl sulfoxide (DMSO), (CH₃)₂SO, decomposes violently on contact with a wide variety of active halogen compounds, such as acyl chlorides. Explosions from contact with active metal hydrides have been reported. Dimethyl sulfoxide does penetrate and carry dissolved substances through the skin membrane.

Dry benzoyl peroxide (C₆H₅CO₂)₂ is easily ignited and sensitive to shock. It decomposes spontaneously at temperatures above 50 °C. It is reported to be desensitized by addition of 20% water.

Dry ice should not be kept in a container that is not designed to withstand pressure. Containers of other substances stored over dry ice for extended periods generally absorb carbon dioxide (CO₂) unless they have been sealed with care. When such containers are removed from storage and allowed to come rapidly to room temperature, the CO₂ may develop sufficient pressure to burst the container with explosive violence. On removal of such containers from storage, the stopper should be loosened or the container itself should be wrapped in towels and kept behind a shield. Dry ice can produce serious burns, as is also true for all types of dry-ice-cooled cooling baths.

Drying agents, such as Ascarite® (sodium hydroxide-coated silica), should not be mixed with phosphorus pentoxide (P₂O₅) because the mixture may explode if it is warmed with a trace of water. Because the cobalt salts used as moisture indicators in some drying agents may be extracted by some organic solvents, the use of these drying agents should be restricted to drying gases.

Dusts that are suspensions of oxidizable particles (e.g., magnesium powder, zinc dust, carbon powder, and flowers of sulfur) in the air can constitute powerful explosive mixtures. These materials should be used with adequate ventilation and should not be exposed to ignition sources. When finely divided, some solids, including zirconium, titanium, Raney nickel, lead(such as
prepared by pyrolysis of lead tartrate), and catalysts (such as activated carbon containing active metals and hydrogen), can combust spontaneously if allowed to dry while exposed to air and should be handled wet.

**Ethylene oxide** (C\(_2\)H\(_4\)O) has been known to explode when heated in a closed vessel. Experiments using ethylene oxide under pressure should be carried out behind suitable barricades.

**Halogenated compounds**, such as chloroform (CHCl\(_3\)), carbon tetrachloride (CCl\(_4\)), and other halogenated solvents, should not be dried with sodium, potassium, or other active metal; violent explosions usually result. Many halogenated compounds are toxic. Oxidized halogen compounds—chlorates, chlorites, bromates, and iodates—and the corresponding peroxy compounds may be explosive at high temperatures.

**Hydrogen peroxide** (H\(_2\)O\(_2\)) stronger than 3% can be dangerous; in contact with the skin, it can cause severe burns. Thirty percent H\(_2\)O\(_2\) may decompose violently if contaminated with iron, copper, chromium, or other metals or their salts. Stirring bars may inadvertently bring metal into a reaction and should be used with caution.

**Liquid nitrogen-cooled traps** open to the atmosphere condense liquid air rapidly. Then, when the coolant is removed, an explosive pressure buildup occurs, usually with enough force to shatter glass equipment if the system has been closed. Hence, only sealed or evacuated equipment should be so cooled.

**Lithium aluminum hydride** (LiAlH\(_4\)) should not be used to dry methyl ethers or tetrahydrofuran; fires from reaction with damp ethers are often observed. The reaction of LiAlH\(_4\) with carbon dioxide has reportedly generated explosive products. Carbon dioxide or bicarbonate extinguishers should not be used for LiAlH\(_4\) fires; instead such fires should be smothered with sand or some other inert substance.

**Nitrates, nitro and nitroso compounds** may be explosive, especially if more than one nitro group is present. Alcohols and polyols can form highly explosive nitrate esters (e.g., nitroglycerine) from reaction with nitric acid.

**Organometallics** are hazardous because some organometallic compounds burn vigorously on contact with air or moisture. For example, solutions of t-butyl lithium can cause ignition of some organic solvents on exposure to air. The pertinent information should be obtained for a specific compound.

**Oxygen tanks** should be handled with care because serious explosions have resulted from contact between oil and high-pressure oxygen. Oil or grease should not be used on connections to an O\(_2\) cylinder or gas line carrying O\(_2\).

**Ozone** (O\(_3\)) is a highly reactive and toxic gas. It is formed by the action of ultraviolet light on oxygen (air), and, therefore, certain ultraviolet sources may require venting to the exhaust hood. Ozonides can be explosive.

**Palladium (Pd) or platinum (Pt)** on carbon, platinum oxide, Raney nickel, and other catalysts present the danger of explosion if additional catalyst is added to a flask in which an air-
flammable vapor mixture and/or hydrogen is present. The use of flammable filter paper should be avoided.

**Parr bombs** used for hydrogenations should be handled with care behind a shield, and the operator should wear goggles and a face shield.

**Perchlorates** should be avoided insofar as possible. Perchlorate salts of organic, organometallic, and inorganic cations are potentially explosive and have been set off either by heating or by shock.

Perchlorates should not be used as drying agents if there is a possibility of contact with organic compounds or of proximity to a dehydrating acid strong enough to concentrate the perchloric acid (HClO₄) (e.g., in a drying train that has a bubble counter containing sulfuric acid). Safer drying agents should be used.

Seventy percent HClO₄ can be boiled safely at approximately 200 °C, but contact of the boiling undiluted acid or the hot vapor with organic matter, or even easily oxidized inorganic matter, will lead to serious explosions. Oxidizable substances must never be allowed to contact HClO₄. This includes wooden benches or hood enclosures, which may become highly flammable after absorbing HClO₄ liquid or vapors. Beaker tongs, rather than rubber gloves, should be used when handling fuming HClO₄. Perchloric acid evaporations should be carried out in a hood that has a good draft. The hood and ventilator ducts should be washed with water frequently (weekly; but see also section 8.C.7.5) to avoid danger of spontaneous combustion or explosion if this acid is in common use. Special perchloric acid hoods are available from many manufacturers. Disassembly of such hoods must be preceded by washing of the ventilation system to remove deposited perchlorates.

**Permanganates** are explosive when treated with sulfuric acid. If both compounds are used in an absorption train, an empty trap should be placed between them and monitored for entrapment.

**Peroxides** (inorganic) should be handled carefully. When mixed with combustible materials, barium, sodium, and potassium peroxides form explosives that ignite easily.

**Phosphorus** (P) (red and white) forms explosive mixtures with oxidizing agents. White phosphorus should be stored under water because it ignites spontaneously in air. The reaction of phosphorus with aqueous hydroxides gives phosphine, which may either ignite spontaneously or explode in air.

**Phosphorus trichloride** (PCl₃) reacts with water to form phosphorous acid with HCl evolution; the phosphorous acid decomposes on heating to form phosphine, which may either ignite spontaneously or explode. Care should be taken in opening containers of PCl₃, and samples that have been exposed to moisture should not be heated without adequate shielding to protect the operator.

**Potassium** (K) is much more reactive than sodium; it ignites quickly on exposure to humid air and, therefore, should be handled under the surface of a hydrocarbon solvent such as mineral oil or toluene (see Sodium). Potassium can form explosive peroxides on contact with air. If this happens, the act of cutting a surface crust off the metal can cause a severe explosion.
**Residues from vacuum distillations** have been known to explode when the still was vented suddenly to the air before the residue was cool. Such explosions can be avoided by venting the still pot with nitrogen, by cooling it before venting, or by restoring the pressure slowly. Sudden venting may produce a shockwave that can detonate sensitive materials.

**Sodium** (Na) should be stored in a closed container under kerosene, toluene, or mineral oil. Scraps of sodium or potassium should be destroyed by reaction with \(n\)-butyl alcohol. Contact with water should be avoided because sodium reacts violently with water to form hydrogen \((H_2)\) with evolution of sufficient heat to cause ignition. Carbon dioxide, bicarbonate, and carbon tetrachloride fire extinguishers should not be used on alkali metal fires. Metals like sodium become more reactive as the surface area of the particles increases. Prudence dictates using the largest particle size consistent with the task at hand. For example, use of sodium "balls" or cubes is preferable to use of sodium "sand" for drying solvents.

**Sodium amide** (NaNH\(_2\)) can undergo oxidation on exposure to air to give sodium nitrite in a mixture that is unstable and may explode.

**Sulfuric acid** \((H_2SO_4)\) should be avoided, if possible, as a drying agent in desiccators. If it must be used, glass beads should be placed in it to help prevent splashing when the desiccator is moved. To dilute \(H_2SO_4\), the acid should be added slowly to cold water. Addition of water to the denser \(H_2SO_4\) can cause localized surface boiling and spattering on the operator.

**Trichloroethylene** \((Cl_2CCHCl)\) reacts under a variety of conditions with potassium or sodium hydroxide to form dichloroacetylene, which ignites spontaneously in air and detonates readily even at dry ice temperatures. The compound itself is highly toxic, and suitable precautions should be taken when it is used.

### 5.G.7 Chemical Hazards of Incompatible Chemicals

When transporting, storing, using, or disposing of any substance (see Chapter 4, and section 5.C), utmost care must be exercised to ensure that it cannot accidentally come into contact with an incompatible substance (see Chapter 3, section 3.D). Such contact could result in a serious explosion or the formation of substances that are highly toxic or flammable or both. Oxidizing agents and reducing agents should be separated from one another so that no contact is possible in the event of an accident. These reagents can also pose a risk upon contact with the atmosphere. Storage should be appropriate for the chemical under consideration. Glass systems that are to be evacuated should be taped to prevent danger of flying glass on implosion.
5.H WORKING WITH COMPRESSED GASES

5.H.1 Chemical Hazards of Compressed Gases

Compressed gases expose the worker to both chemical and physical hazards. Such hazards and the equipment required for the safe use of compressed gases are discussed in Chapter 6, section 6.D.

Safe storage, monitoring for leaks, and proper labeling are essential for the prudent use of compressed gases. If the gas is flammable, flash points lower than room temperature compounded by rapid diffusion throughout the laboratory present the danger of fire or explosion. Additional hazards can arise from the reactivity and toxicity of the gas, and asphyxiation can be caused by high concentrations of even inert gases such as nitrogen. An additional risk of simple asphyxiants is head injury resulting from falls following rapid loss of oxygen from the brain. Death can also occur after asphyxiation if oxygen levels remain too low to sustain life. Finally, the large amount of potential energy resulting from the compression of the gas makes a highly compressed gas cylinder a potential rocket or fragmentation bomb. On-site chemical generation of a gas should be considered as an alternative to use of a compressed gas if relatively small amounts are needed. Monitoring compressed gas inventories and disposal or return of gases not in current or likely future use are advisable to avoid the development of hazardous situations.

5.H.2 Specific Chemical Hazards of Select Gases

Workers are advised to consult the Laboratory Chemical Safety Summary (LCSS) and the Material Safety Data Sheet (MSDS) for specific gases. Certain hazardous substances that may be supplied as compressed gases are listed below:

**Boron halides** are powerful Lewis acids and hydrolyze to strong protonic acids. **Boron trichloride** (BCl\(_3\)) reacts with water to give HCl, and its fumes are corrosive, toxic, and irritating to the eyes and mucous membranes.

**Chlorine trifluoride** (ClF\(_3\)) in liquid form is corrosive and very toxic. It is a potential source of explosion and causes deep, penetrating burns on contact with the body. The effect may be delayed and progressive, as in the case of burns caused by hydrogen fluoride.

Chlorine trifluoride reacts vigorously with water and most oxidizable substances at room temperature, frequently with immediate ignition. It reacts with most metals and metal oxides at elevated temperatures. In addition, it reacts with silicon-containing compounds and thus can support the continued combustion of glass, asbestos, and other such materials. Chlorine trifluoride forms explosive mixtures with water vapor, ammonia, hydrogen, and most organic vapors. The substance resembles elemental fluorine in many of its chemical properties and handling procedures, which include precautionary steps to prevent accidents.
**Hydrogen selenide** (H₂Se) is a colorless gas with an offensive odor. It is a dangerous fire and explosion risk and reacts violently with oxidizing materials. It may flow to ignition sources. Hydrogen selenide is an irritant to eyes, mucous membranes, and pulmonary system. Acute exposures can cause symptoms such as pulmonary edema, severe bronchitis, and bronchial pneumonia. Symptoms also include gastrointestinal distress, dizziness, increased fatigue, and a metallic taste in the mouth.

**Methyl chloride** (CH₃Cl) has a slight, not unpleasant odor that is not irritating and may pass unnoticed unless a warning agent has been added. Exposure to excessive concentrations of CH₃Cl is indicated by symptoms similar to those of alcohol intoxication, that is, drowsiness, mental confusion, nausea, and possibly vomiting.

Methyl chloride may, under certain conditions, react with aluminum or magnesium to form materials that ignite or fume spontaneously with air, and contact with these metals should be avoided.

**Phosphine** (PH₃) is a spontaneously flammable, explosive, poisonous, colorless gas with the foul odor of decaying fish. The liquid can cause frostbite. Phosphine is a dangerous fire hazard and ignites in the presence of air and oxidizers. It reacts with water, acids, and halogens. If heated, it will form hydrogen phosphides, which are explosive and toxic. There may be a delay between exposure and the appearance of symptoms.

**Silane** (SiH₄) is a pyrophoric, colorless gas that ignites spontaneously in air. It is incompatible with water, bases, oxidizers, and halogens. The gas has a choking, repulsive odor.

**Silyl halides** are toxic, colorless gases with a pungent odor that are corrosive irritants to the skin, eyes, and mucous membranes. When silyl-halides are heated, toxic fumes can be emitted.
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Working with Laboratory Equipment

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6.A INTRODUCTION

Proper use of laboratory equipment is required to work safely with hazardous chemicals. Maintenance and regular inspection of laboratory equipment are an essential part of this activity. Many of the accidents that occur in the laboratory can be attributed to improper use or maintenance of laboratory equipment. This chapter discusses prudent practices for handling the apparatus often used in laboratories.

The most common equipment hazards in laboratories come from electrically powered devices, and these are followed by hazards with devices for work with compressed gases and high/low pressures and temperatures. Other physical hazards include electromagnetic radiation hazards from such equipment as lasers and radio-frequency generating devices. Seemingly ordinary hazards such as floods from water-cooled equipment, accidents with rotating equipment and machines or tools for cutting and drilling, noise extremes, slips, trips, and falls, lifting, and poor ergonomics probably account for the greatest frequency of laboratory accidents and injuries.

6.B WORKING WITH WATER-COOLED EQUIPMENT

The use of cooling water in laboratory condensers and other equipment is common laboratory practice, but can create a flooding hazard. The most common source of the problem is disconnection of the tubing supplying the water to the condenser. Hoses can pop off under irregular flows when building water pressure fluctuates or can break when the hose material has deteriorated from long-term use. Floods also result when exit hoses jump out of the sink from a strong flow pulse or sink drains are blocked by an accumulation of extraneous material. Proper use of hose clamps and maintenance of the entire cooling system or alternate use of a portable cooling bath with suction feed can resolve such problems. Plastic locking disconnects can make it easy to disconnect water lines without having to unclamp and re-clamp secured lines. Some quick disconnects also incorporate check valves, which when disconnected do not allow flow into or out of either half of the connection. This feature allows for disconnecting and reconnecting with minimal spillage of water.

6.C WORKING WITH ELECTRICALLY POWERED LABORATORY EQUIPMENT

Electrically powered laboratory equipment is used routinely for laboratory operations requiring heating, cooling, agitation or mixing, and pumping. Electrically powered equipment found in the laboratory includes fluid and vacuum pumps, lasers, power supplies, both electrophoresis and electrochemical apparatus, x-ray equipment, stirrers, hot plates, heating mantles, and, more recently, microwave ovens and ultrasonicators. Attention must be paid to both the mechanical and the electrical hazards inherent in these devices. High voltage and high power requirements
are increasingly prevalent; therefore prudent practices for handling these devices are increasingly necessary.

Electric shock is the major electrical hazard. A relatively low current of 10 milliamperes (mA) poses some danger, and 80 to 100 mA can be fatal. In addition, if improperly used, electrical equipment can serve as an ignition source for flammable or explosive vapors. Most of the risks involved can be minimized by regular, proper maintenance and a clear understanding of the correct use of the device.

### 6.C.1 General Principles

Particular caution must be exercised during installation, modification, and repair, as well as during use of the equipment. In order to ensure safe operation, all electrical equipment must be installed and maintained in accordance with the provisions of the National Electrical Code (NEC) of the National Fire Protection Association (NFPA, 1991a). Laboratory workers should also consult state and local codes and regulations, which may contain special provisions and be more stringent than the NEC and NFPA rules. All repair and calibration work on electrical equipment must be carried out by properly trained and qualified personnel. Before modification, installation, or even minor repairs of electrical equipment are carried out, the devices must be de-energized and all capacitors discharged safely. Furthermore, this de-energized and/or discharged condition must be verified before proceeding (note that OSHA Control of Hazardous Energy Standard (29 CFR 1910.147; Lock out/Tag out) applies).

It is imperative that each person participating in any experiment involving the use of electrical equipment be aware of all applicable equipment safety issues and be briefed on any potential problems. Workers can significantly reduce hazards and dangerous behavior by following some basic principles and techniques: checking and rechecking outlet receptacles (section 6.C.1.1), making certain that wiring complies with national standards and recommendations (section 6.C.1.2), and reviewing general precautions (section 6.C.1.3) and personal safety techniques (section 6.C.1.4).

#### 6.C.1.1 Outlet Receptacles

All 110-volt (V) outlet receptacles in laboratories should be of the standard design that accepts a three-
Prong-plug and provides a ground connection. Two-prong receptacles should be replaced as soon as feasible, and a separate ground wire should be added so that each receptacle is wired as shown in Figure 6.1. The ground wire should be on top so that anything falling onto the plug will not fall onto either the hot or the neutral line.

It is also possible to fit a receptacle with a ground fault circuit interrupter (GFCI), which disconnects the current if a ground fault is detected. GFCI devices are required by local electrical codes for outdoor receptacles and for selected laboratory receptacles located less than 6 feet (1.83 meters) from sinks if maintenance of a good ground connection is essential for safe operation. These devices differ in operation and purpose from fuses and circuit breakers, which are designed primarily to protect equipment and prevent electrical fires due to short circuits or other abnormally high current draw situations. Certain types of GFCIs can cause equipment shutdowns at unexpected and inappropriate times; hence, their selection and use need careful planning.

Receptacles that provide electric power for operations in hoods should be located outside the hood. This location prevents the production of electrical sparks inside the hood when a device is plugged in or disconnected, and it also allows a laboratory worker to disconnect electrical devices from outside the hood in case of an accident. Cords should not dangle outside the hood in such a way that they can accidentally be pulled out of their receptacles or tripped over. Simple, inexpensive plastic retaining strips and ties can be used to route cords safely. For fume hoods with airfoils, the electrical cords should be routed under the bottom airfoil so that the sash can be closed completely. Most airfoils can be easily removed and replaced with a screwdriver.

6.C.1.2 Wiring

Laboratory equipment plugged into a 110-V (or higher) receptacle should be fitted with a standard three-conductor line cord that provides an independent ground connection to the chassis of the apparatus (see Figure 6.2). All electrical equipment should be grounded unless it is "double-insulated." This type of equipment has a two-conductor line cord that meets national codes and standards. The use of two-pronged "cheaters" to connect equipment with three-prong grounded plugs to old-fashioned two-wire outlets should be prohibited.

The use of extension cords should be limited to temporary (less than one day) setups, if they are permitted at all. A standard three-conductor extension cord of sufficient rating for the connected equipment with an independent ground connection should be used. Electrical cables should be installed properly, even if only for temporary use, and should be kept out of aisles and other traffic areas. Overhead racks and floor channel covers should be installed if wires must pass over or under walking areas. Signal and power cables should not be intermingled in cable trays or panels. Special care is needed when installing and placing water lines (used, for example, to cool such equipment as flash lamps for lasers) so that they do not leak or produce condensation, which can dampen power cables nearby.

Equipment plugged into an electrical receptacle should include a fuse or other overload protection device to disconnect the circuit if the apparatus fails or is overloaded. This overload protection is particularly useful for equipment likely to be left on and unattended for a long time, such as variable autotransformers (e.g., Variacs and power-stats), vacuum pumps, drying ovens, stirring motors, and electronic instruments. Equipment that does not contain its own built-in
overload protection should be modified to provide such protection or replaced with equipment that provides it. Overload protection does not protect the worker from electrocution, but it does reduce the risk of fire.

6.C.1.3 General Precautions for Working with Electrical Equipment

Laboratory personnel should be certain that all electrical equipment is maintained well, properly located, and safely used. In order to do this, the following precautions should be reviewed and the necessary adjustments made prior to working in the laboratory:

- Insulate all electrical equipment properly. Visually inspect all electrical cords monthly, especially in any laboratory where flooding can occur. Keep in mind that rubber-covered cords can be eroded by organic solvents and by ozone (produced by ultraviolet lamps).

- Replace all frayed or damaged cords before any further use of the equipment is permitted. Replacement should be conducted by qualified personnel.

- Ensure the complete electrical isolation of electrical equipment and power supplies. Enclose all power supplies in a manner that makes accidental contact with power circuits impossible. In every experimental setup, including temporary ones, employ suitable barriers or enclosures to protect against accidental contact with electrical circuits.

FIGURE 6.2 Standard wiring convention for 110-V electric power to equipment.
• Equip motor-driven electrical equipment used in a laboratory where volatile flammable materials may be present (e.g., a hydrogenation room) with either non-sparking induction motors that meet Class 1, Division 2, Group C-D electrical standards (U.S. DOC, 1993) or air motors instead of series-wound motors that use carbon brushes, such as those generally used in vacuum pumps, mechanical shakers, stirring motors, magnetic stirrers, and rotary evaporators.

• Do not use variable autotransformers to control the speed of an induction motor because such operation will cause the motor to overheat and perhaps start a fire.

• Because series-wound motors cannot be modified to make them spark-free, do not use kitchen appliances (refrigerators, mixers, blenders, and so on) with such motors in laboratories where flammable materials may be present.

• When bringing ordinary electrical equipment such as vacuum cleaners and portable electric drills having series-wound motors into the laboratory for special purposes, take specific precautions to ensure that no flammable vapors are present before such equipment is used (see Chapter 5, section G).

• Locate electrical equipment so as to minimize the possibility of spills onto the equipment or flammable vapors carried into it. If water or any chemical is spilled on electrical equipment, shut off the power immediately at a main switch or circuit breaker and unplug the apparatus.

• Minimize the condensation that may enter electrical equipment if it is placed in a cold room or a large refrigerator. Cold rooms pose a particular risk in this respect because the atmosphere is frequently at a high relative humidity, and the potential for water condensation is significant.

• If electrical equipment must be placed in such areas, mount the equipment on a wall or vertical panel. This precaution will reduce, though not eliminate, the condensation problem.

• Condensation can also cause electrical equipment to overheat, smoke, or catch fire. In such a case, shut off the power to the equipment immediately at a main switch or circuit breaker and unplug the apparatus.

• To minimize the possibility of electrical shock, carefully ground the equipment using a suitable flooring material, and install ground-fault circuit interrupters (GFCIs).

• Always unplug equipment before undertaking any adjustments, modifications, or repairs (with the exception of certain instrument adjustments as indicated in section 6.C.7). When it is necessary to handle equipment that is plugged in, be
certain hands are dry and, if feasible, wear nonconductive gloves and shoes with insulated soles.

- Ensure that all workers know the location and operation of power shutoffs (i.e., main switches and circuit breaker boxes) for areas in which they work. Do not use equipment again until it has been cleaned and properly inspected.

**ACETONE SPILLED UNDER AN ELECTRONIC BALANCE**

Acetone spilled out of a reaction vessel during the addition of dry ice. It seeped underneath a nearby electronic balance and ignited. The balance was severely damaged, but the fire was extinguished before the reaction vessel broke.

All laboratories should have access to a qualified technician who can make routine repairs to existing equipment and modifications to new or existing equipment so that it will meet acceptable standards for electrical safety. The National Fire Protection Association's *National Electrical Code Handbook* (NFPA, 1993) provides guidelines.

**6.C.1.4 Personal Safety Techniques for Use with Electrical Equipment**

Each individual working with electrical equipment should be informed of basic precautionary steps that should be taken to ensure personal safety:

- Avoid contact with energized electrical circuits. Electrical equipment should be serviced only by qualified individuals.

- Before qualified individuals service electrical equipment in any way, disconnect the power source to avoid the danger of electric shock. Ensure that any capacitors are, in fact, discharged.

- Before reconnecting electrical equipment to its power source after servicing, check the equipment with a suitable tester, such as a multi-meter, to ensure that it is properly grounded.

- Do not reenergize a circuit breaker until there is assurance that the short circuit that activated it has been corrected.

- Install ground-fault circuit interrupters (GCFIs) as required by code to protect users from electric shock, particularly if an electrical device is hand-held during a laboratory operation.

- If a person is in contact with a live electrical conductor, first disconnect the power source and then remove the person from the contact and administer first aid.
6.C.1.5 Additional Safety Techniques for Equipment Using High Current or High Voltage

Unless laboratory personnel are specially trained to install or repair high-current or high-voltage equipment, such tasks should be reserved for trained electrical workers. The following reminders are included for qualified personnel.

- Always assume that a voltage potential exists within a device while servicing it, even if it is de-energized and disconnected from its power source. For example, a device may contain capacitors, which retain a potentially harmful electrical charge.

- If it is not awkward or otherwise unsafe to do so, try to work with only one hand while keeping the other hand at your side or in a pocket, away from all conducting materials. This precaution reduces the likelihood of accidents that result in current passing through the chest cavity.

- Avoid becoming grounded by staying at least 6 inches away from walls, water, and all metal materials including pipes.

- Use voltmeters and test equipment with ratings and leads sufficient to measure the highest potential voltage to be found inside the equipment being serviced.

6.C.2 Vacuum Pumps

Distillations or concentration operations that involve significant quantities of volatile substances should normally be performed with the use of a facility vacuum system, a water aspirator, or a steam aspirator-each system protected by a suitable trapping device-rather than a mechanical vacuum pump. However, the distillation of less-volatile substances, removal of final traces of solvents, and some other operations that require pressures lower than those obtainable with a water aspirator are normally performed with a mechanical vacuum pump. The suction line from the system to the vacuum pump should be fitted with a cold trap to collect volatile substances from the system and to minimize the amount of material that enters the vacuum pump and dissolves in the pump oil. A cold trap should also be used with a water aspirator to minimize contamination of discharged water. The possibility that mercury will be swept into the pump as a result of a sudden loss of vacuum can be minimized by placing a trap in the line to the pump. Vacuum pump oil contaminated with mercury must be treated as hazardous waste. (See Chapter 5, sections 5.C.11.8 and 5.D.)

The output of each pump should be vented to an air exhaust system. This procedure is essential when the pump is being used to evacuate a system containing a volatile toxic or corrosive substance. Failure to observe this precaution would result in pumping any of the substance that is not trapped into the laboratory atmosphere. It is also recommended to scrub or absorb the gases exiting the pump. Even with these precautions, however, volatile toxic or corrosive substances may accumulate in the pump oil and, thus, be discharged into the laboratory atmosphere during future pump use. This hazard can be avoided by draining and replacing the pump oil when it
becomes contaminated. The contaminated pump oil should be disposed of by following standard RCRA procedures for the safe disposal of toxic or corrosive substances. General-purpose laboratory vacuum pumps should have a record of use in order to prevent cross-contamination or reactive chemical incompatibility problems.

Belt-driven mechanical pumps with exposed belts must have protective guards. Such guards are particularly important for pumps installed on portable carts or tops of benches where laboratory workers might accidentally entangle clothing or fingers in the moving belt, but they are not necessary for enclosed pumps.

6.C.3 Refrigerators and Freezers

The potential hazards posed by laboratory refrigerators involve vapors from the contents, the possible presence of incompatible chemicals, and spillage. As general precautions, laboratory refrigerators should be placed against fire-resistant walls, should have heavy-duty cords, and preferably should be protected by their own circuit breaker. The contents of a laboratory refrigerator should be enclosed in unbreakable secondary containers. Because there is almost never a satisfactory arrangement for continuously venting the interior atmosphere of a refrigerator, any vapors escaping from vessels placed in one will accumulate in the refrigerated space and will gradually be absorbed into the surrounding insulation. Thus, the atmosphere in a refrigerator could contain an explosive mixture of air and the vapor of a flammable substance or a dangerously high concentration of the vapor of a toxic substance or both. The potential for exposure to toxic substances can be aggravated when a worker places his or her head inside a refrigerator while searching for a particular sample. The placement of potentially explosive (see Chapter 5, sections 5.C and 5.G) or highly toxic substances (see Chapter 5, sections 5.D and 5.E) in a laboratory refrigerator is strongly discouraged. If this precaution must be violated, then a clear, prominent warning sign should be placed on the outside of the refrigerator door. Storage of these types of materials in a refrigerator should be kept to a minimum and monitored regularly. As noted in Chapter 5, section 5.C, laboratory refrigerators and freezers should never be used to store food or beverages for human consumption.

AMPOULE EXPLOSION IN A REFRIGERATOR

The door to a refrigerator used for storage of chemicals in a laboratory was left open for 10 minutes while a researcher searched through chemicals. Suddenly, an ampoule stored in the door exploded, spraying the contents in all directions, including toward the researcher. Fortunately, only one other container was ruptured, and the researcher received only a cut on his face from flying glass. A review of the incident concluded that the ampoule had been sealed at a relatively low temperature. When the ampoule warmed up in the open door, pressure built up inside it, causing it to rupture.

There should be no potential sources of electrical sparks on the inside of a laboratory refrigerator where volatile or flammable chemicals are stored. Only refrigerators that have been Underwriters-approved for flammable storage by the manufacturer should be used for this
purpose. If this is not possible, all new or existing manual defrost refrigerators should be modified by

- removing the interior light and switch mounted on the door frame, if present, and
- moving the contacts of the thermostat controlling the fan and temperature outside the refrigerated compartment.

Although a prominent sign warning against the storage of flammable substances can be permanently attached to the door of an unmodified refrigerator, this alternative is less desirable than modifying the equipment by removing any spark sources from the refrigerated compartment. "Frost-free" refrigerators are not suitable for laboratory use, owing to the problems associated with attempts to modify them. Many of these refrigerators have a drain tube or hole that carries water (and any flammable material present) to an area adjacent to the compressor and, thus, present a spark hazard. The electric heaters used to defrost the freezing coils are also a potential spark hazard (see Chapter 5, section 5.G.1). To ensure its effective functioning, a freezer should be defrosted manually when ice builds up.

Uncapped containers of chemicals should never be placed in a refrigerator. Caps should provide a vapor-tight seal to prevent a spill if the container is tipped over. Aluminum foil, corks, corks wrapped with aluminum foil, and glass stoppers usually do not meet these criteria, and, therefore, their use should be discouraged. The most satisfactory temporary seals are normally screw-caps lined with either a conical polyethylene insert or a Teflon insert. The best containers for samples that are to be stored for longer periods of time are sealed, nitrogen-filled glass ampoules. At a minimum, catch pans should be used for secondary containment.

Careful labeling of samples placed in refrigerators and freezers with both the contents and the owner's name is essential. Water-soluble ink should not be used, and labels should be waterproof or covered with transparent tape. Storing samples with due consideration of chemical compatibility is important in these often small, crowded spaces.

6.C.4 Stirring and Mixing Devices

The stirring and mixing devices commonly found in laboratories include stirring motors, magnetic stirrers, shakers, small pumps for fluids, and rotary evaporators for solvent removal. These devices are typically used in laboratory operations that are performed in a hood, and it is important that they be operated in a way that precludes the generation of electrical sparks. Furthermore, it is important that, in the event of an emergency, such devices can be turned on or off from a location outside the hood. Heating baths associated with these devices (e.g., baths for rotary evaporators) should also be spark-free and controllable from outside the hood. (See sections 6.C.1 and 6.C.5; also see Chapter 5, section 5.C.7.)

Only spark-free induction motors should be used in power stirring and mixing devices or any other rotating equipment used for laboratory operations. Although the motors in most of the
Currently marketed stirring and mixing devices meet this criterion, their on-off switches and rheostat-type speed controls can produce an electrical spark any time they are adjusted, because they have exposed contacts. Many of the magnetic stirrers and rotary evaporators currently on the market have this disadvantage. An effective solution is to remove any switches located on the device and insert a switch in the cord near the plug end; because the electrical receptacle for the plug should be outside the hood, this modification ensures that the switch will also be outside the hood. The speed of an induction motor operating under a load should not be controlled by a variable autotransformer.

Because stirring and mixing devices, especially stirring motors and magnetic stirrers, are often operated for fairly long periods without constant attention, the consequences of stirrer failure, electrical overload, or blockage of the motion of the stirring impeller should be considered. It is good practice to attach a stirring impeller to the shaft of the stirring motor by using lightweight rubber tubing. If the motion of the impeller becomes impeded, the rubber can twist away from the motor shaft. If this occurs, the motor will not stall. However, this practice does not always prevent binding the impeller. Hence, it is also desirable to fit unattended stirring motors with a suitable fuse or thermal-protection device. (Also see section 6.C.1.)

6.C.5 Heating Devices

Perhaps the most common types of electrical equipment found in a laboratory are the devices used to supply the heat needed to effect a reaction or a separation. These include ovens, hot plates, heating mantles and tapes, oil baths, salt baths, sand baths, air baths, hot-tube furnaces, hot-air guns, and microwave ovens. The use of steam-heated devices rather than electrically heated devices is generally preferred whenever temperatures of 100 °C or less are required. Because they do not present shock or spark risks, they can be left unattended with assurance that their temperature will never exceed 100 °C.

A number of general precautions need to be taken when working with heating devices in the laboratory. First, new or existing variable autotransformers should be wired (or rewired) as illustrated in Figure 6.3. The actual heating element in any laboratory heating device should be enclosed in a glass, ceramic, or insulated metal case in such a fashion as to prevent a laboratory worker or any metallic conductor from accidentally touching the wire carrying the electric current. This type of construction minimizes the risk of electric shock and of accidentally producing an electrical spark near a flammable liquid or vapor (see Chapter 5, section 5.G.1). It also diminishes the possibility that a flammable liquid or vapor will come into contact with any wire whose temperature may exceed its ignition temperature. If any heating device becomes so worn or damaged that its heating element is exposed, the device should be either discarded or repaired to correct the damage before it is used again. Because many household appliances (e.g., hot plates and space heaters) do not meet this criterion, they should not be used in a
Laboratory heating devices should be used with a variable autotransformer to control the input voltage by supplying some fraction of the total line voltage, typically 110 V, to the heating element of the device. If a variable autotransformer is not wired in this manner, the switch on it may or may not disconnect both wires of the output from the 110 V line when it is switched to the off position. Also, if this wiring scheme has not been followed, and especially if the grounded three-prong plug is not used, even when the potential difference between the two output lines is only 10 V, each output line may be at a relatively high voltage (e.g., 110 V and 100 V) with respect to an electrical ground. Because these potential hazards exist, whenever a worker uses a variable autotransformer whose wiring scheme is not known, it is prudent to assume that either of the output lines carries a potential of 110 V and is capable of delivering a lethal electric shock.

The external cases of all variable autotransformers have perforations for cooling by ventilation, and some sparking may occur whenever the voltage adjustment knob is turned. Therefore, these devices should be located where water and other chemicals cannot be spilled onto them and where their movable contacts will not be exposed to flammable liquids or vapors. Variable autotransformers should be mounted on walls or vertical panels and outside of hoods; they should not simply be placed on laboratory bench tops.

Because the electrical input lines, including lines from variable transformers, to almost all laboratory heating devices have a potential of 110 V with respect to any electrical ground, these lines should always be viewed both as potential shock hazards and as potential spark hazards. Thus, any connection from these lines to a heating device should be both mechanically and electrically secure and completely covered with insulating material. Alligator clips should not be used to connect a line cord from a variable autotransformer to a heating device, especially to an oil bath or an air bath, because such connections pose a shock hazard. They also may slip off,
creating an electrical spark and, perhaps, contacting other metal parts to create an additional hazard. All connections should be made by using, preferably, a plug and receptacle combination, or wires with insulated terminals firmly secured to insulated binding posts.

Whenever an electrical heating device is used, it is essential to use either a temperature controller or a temperature-sensing device that will turn off the electric power if the temperature of the heating device exceeds some preset limit. Similar control devices are available that will turn off the electric power if the flow of cooling water through a condenser is stopped owing to the loss of water pressure or loosening of the water supply hose to a condenser. Fail-safe devices, which can be either purchased or fabricated, can prevent the more serious problems of fires or explosions that may arise if the temperature of a reaction increases significantly because of a change in line voltage, the accidental loss of reaction solvent, or loss of cooling. Fail-safe devices should be used for stills employed to purify reaction solvents, because such stills are often left unattended for significant periods of time. (See section 6.C.1 for additional information.)

6.C.5.1 Ovens

Electrically heated ovens are commonly used in the laboratory to remove water or other solvents from chemical samples and to dry laboratory glassware.

Never use laboratory ovens for human food preparation.

Laboratory ovens should be constructed such that their heating elements and their temperature controls are physically separated from their interior atmospheres. Small household ovens and similar heating devices usually do not meet these requirements and, consequently, should not be used in laboratories. With the exception of vacuum drying ovens, laboratory ovens rarely have a provision for preventing the discharge of the substances volatilized in them into the laboratory atmosphere. Thus, it should be assumed that these substances will escape into the laboratory atmosphere and may also be present in concentrations sufficient to form explosive mixtures with the air inside the oven (see Chapter 5, section 5.G). This hazard can be reduced by connecting the oven vent directly to an exhaust system.

Ovens should not be used to dry any chemical sample that has even moderate volatility and might pose a hazard because of acute or chronic toxicity unless special precautions have been taken to ensure continuous venting of the atmosphere inside the oven. Thus, most organic compounds should not be dried in a conventional unvented laboratory oven.

To avoid explosion, glassware that has been rinsed with an organic solvent should not be dried in an oven until it has been rinsed again with distilled water. Potentially explosive mixtures can be formed from volatile substances and the air inside an oven.

Bimetallic strip thermometers are preferred for monitoring oven temperatures. Mercury thermometers should not be mounted through holes in the tops of ovens so that the bulb hangs into the oven. Should a mercury thermometer be broken in an oven of any type, the oven should be closed and turned off immediately, and it should remain closed until cool. All mercury should be removed from the cold oven with the use of appropriate cleaning equipment and procedures (see Chapter 5, section 5.C.11.8) in order to avoid mercury exposure. After removal of all visible
mercury, the heated oven should be monitored in a fume hood until the mercury vapor concentration drops below the threshold limit value (TLV).

6.C.5.2 Hot Plates

Laboratory hot plates are normally used when solutions are to be heated to 100 °C or above and the inherently safer steam baths cannot be used as the source of heat. As previously noted, only hot plates that have completely enclosed heating elements should be used in laboratories. Although almost all laboratory hot plates now sold meet this criterion, many older ones pose an electrical spark hazard arising from either the on-off switch located on the hot plate, the bimetallic thermostat used to regulate the temperature, or both. Normally, these two spark sources are both located in the lower part of the hot plate in a region where any heavier-than-air and possibly flammable vapors evolved from a boiling liquid on the hot plate would tend to accumulate. In principle, these spark hazards can be alleviated by enclosing all mechanical contacts in a sealed container or by using solid-state circuitry for switching and temperature control. However, in practice, such modifications are difficult to incorporate into many of the hot plates now in use. Laboratory workers should be warned of the spark hazard associated with these hot plates. Any newly purchased hot plates should be set up in a way that avoids electrical sparks. In addition to the spark hazard, old and corroded bimetallic thermostats in these devices can eventually fuse shut and deliver full, continuous current to a hot plate. This risk can be avoided by wiring a fusible coupling into the line inside the hot plate. If the device does overheat, then the coupling will melt and interrupt the current (see Section 6.C.1).

On many brands of combined stirrer/hot plates, the controls for the stirrer and temperature control look alike. Care must be taken to distinguish their functions. A fire or explosion may occur if the temperature rather than the stirrer speed is increased inadvertently.

6.C.5.3 Heating Mantles

Heating mantles are commonly used for heating round-bottomed flasks, reaction kettles, and related reaction vessels. These mantles enclose a heating element in a series of layers of fiberglass cloth. As long as the fiberglass coating is not worn or broken, and as long as no water or other chemicals are spilled into the mantle (see section 6.C.1), heating mantles pose no shock hazard. They are normally fitted with a male plug that fits into a female receptacle on an output line from a variable autotransformer. This plug combination provides a mechanically and electrically secure connection.

Heating mantles should always be used with a variable autotransformer to control the input voltage. They must never be plugged directly into a 110-V line. Workers should be careful not to exceed the input voltage recommended by the mantle manufacturer. Higher voltages will cause it to overheat, melting the fiberglass insulation and exposing the bare heating element.

Some heating mantles are constructed by encasing the fiberglass mantle in an outer metal case that provides physical protection against damage to the fiberglass. If such metal-enclosed mantles are used, it is good practice to ground the outer metal case either by using a grounded, three-conductor cord from the variable autotransformer or by securely affixing one end of a heavy, braided conductor to the mantle case and the other end to a known electrical ground. This
practice protects the worker against an electric shock if the heating element inside the mantle shorts against the metal case.

6.C.5.4 Oil, Salt, and Sand Baths

In the use of oil, salt, and sand baths, care must be taken to avoid spilling water and other volatile substances into the baths. Such an accident can splatter hot material over a wide area and cause serious injuries.

Electrically heated oil baths are often used to heat small or irregularly shaped vessels or when a stable heat source that can be maintained at a constant temperature is desired. For temperatures below 200 °C, a saturated paraffin oil is often used; a silicone oil should be used for temperatures up to 300 °C. Care must be taken with hot oil baths not to generate smoke or have the oil burst into flames from overheating. An oil bath should always be monitored by using a thermometer or other thermal sensing device to ensure that its temperature does not exceed the flash point of the oil being used. For the same reason, oil baths left unattended should be fitted with thermal sensing devices that will turn off the electric power if the bath overheat. These baths should be heated by an enclosed heating element, such as a knife heater, a tubular immersion heater such as a Calrod®, or its equivalent. The input connection for this heating element should be a male plug that will fit a female receptacle from a variable autotransformer (e.g., Variac) output line. Alternatively, a temperature controller can be used to control the temperature of the bath precisely. Temperature controllers are now available that can provide a variety of heating and cooling options.

Oil baths must be well mixed to ensure that there are no "hot spots" around the elements that take the surrounding oil to unacceptable temperatures. This problem can be minimized by placing the thermo-regulator fairly close to the heater. Heated oil should be contained in either a metal pan or a heavy-walled porcelain dish; a Pyrex dish or beaker can break and spill hot oil if struck accidentally with a hard object. The oil bath should be mounted carefully on a stable horizontal support such as a laboratory jack that can be secured.

THERMITE REACTION EXPLOSION

An explosion injuring 27 people occurred when a thermite reaction was being demonstrated as part of a magic show at an engineering open house. The demonstration, which generated molten iron in a 2,500 to 3,000 °C reaction, was being carried out in a clay flowerpot above a beaker of water and sand to show the heat produced by the reaction when molten iron particles fall into water. Suddenly, the demonstration exploded, sending hot metal and water toward the audience. The most likely cause of the accident was thought to be a physical vapor explosion, which can occur when a very hot liquid comes into contact with a second liquid. In this case, the water may have turned to steam so rapidly that an explosion resulted. The injuries consisted of minor burns.

raised or lowered easily without danger of the bath tipping over. It is also important that equipment always be clamped high enough above a hot plate or oil bath that if the reaction begins to overheat, the heater can be lowered immediately and replaced with a cooling bath without having to readjust the clamps holding the equipment setup. A bath should never be supported on an iron ring because of the greater likelihood of accidentally tipping the bath over.
Secondary containment should be provided in the event of a spill of hot oil. Proper protective gloves should be worn when handling a hot bath.

Molten salt baths, like hot oil baths, offer the advantages of good heat transfer, commonly have a higher operating range (e.g., 200 to 425 °C), and may have a high thermal stability (e.g., 540 °C). The reaction container used in a molten salt bath must be able to withstand a very rapid heat-up to a temperature above the melting point of the salt. Care must be taken to keep salt baths dry, because they are hygroscopic, a property that can cause hazardous popping and splattering if the absorbed water vaporizes during heat-up.

6.C.5.5 Hot Air Baths and Tube Furnaces

Hot air baths can be useful heating devices. Nitrogen is preferred for reactions in which flammable materials are used. Electrically heated air baths are frequently used to heat small or irregularly shaped vessels. Because of their inherently low heat capacity, such baths normally must be heated considerably above the desired temperature (100 °C or more) of the vessel being heated. These baths should be constructed so that the heating element is completely enclosed and the connection to the air bath from the variable autotransformer is both mechanically and electrically secure. These baths can be constructed from metal, ceramic, or, less desirably, glass vessels. If a glass vessel is used, it should be wrapped thoroughly with a heat-resistant tape so that if the vessel breaks accidentally, the glass will be contained and the bare heating element will not be exposed. Fluidized sand baths are usually preferred over air baths.

Tube furnaces are often used for high-temperature reactions under reduced pressure. The proper choice of glassware or metal tubes and joints is required, and the procedures should conform to safe practice with electrical equipment and evacuated apparatus. (See also section 6.C.1 and Chapter 5, section 5.G.2.5.)

6.C.5.6 Heat Guns

Laboratory heat guns are constructed with a motor-driven fan that blows air over an electrically heated filament. They are frequently used to dry glassware or to heat the upper parts of a distillation apparatus during distillation of high-boiling materials. The heating element in a heat gun typically becomes red-hot during use and, necessarily, cannot be enclosed. Also, the on-off switches and fan motors are not usually spark-free. For these reasons, heat guns almost always pose a serious spark hazard (see Chapter 5, section 5.G.1). They should never be used near open containers of flammable liquids, in environments where appreciable concentrations of flammable vapors may be present, or in hoods used to remove flammable vapors. Household hair dryers may be substituted for laboratory heat guns only if they have three-conductor line cords or are double-insulated. Any hand-held heating device of this type that will be used in a laboratory should have ground-fault circuit interrupter (GFCI) protection to ensure against electric shock.

6.C.5.7 Microwave Ovens

To avoid exposure to microwaves, ovens should never be operated with doors open. Wires and other objects should not be placed between the sealing surface and the door on the oven's front face. The sealing surfaces must be kept absolutely clean. To avoid electrical hazards, the oven
must be grounded. If use of an extension cord is necessary, only a three-wire cord with a rating equal to or greater than that for the oven should be used. To reduce the risk of fire in the oven, samples must not be overheated. The oven must be closely watched when combustible materials are in it. Metal containers or metal-containing objects (e.g., stir bars) should not be used in the microwave, because they can cause arcing.

Generally, sealed containers should not be heated in the oven, because of the danger of explosion. If sealed containers must be used, their materials must be selected carefully and the containers properly designed. Commercially available microwave acid digestion bombs, for example, incorporate a Teflon sample cup, a self-sealing Teflon O-ring, and a compressible pressure-relief valve. The manufacturer's loading limits must not be exceeded. For such applications, the microwave oven should be properly vented using an exhaust system. Placing a large item such as an oven inside a fume hood is not recommended.

Heating a container with a loosened cap or lid poses a significant risk. Microwave ovens can heat material (e.g., solidified agar) so quickly that, even though container lids may be loosened to accommodate expansion, the lid can seat upward against the threads and containers can explode. Screw-caps must be removed from containers being microwaved. If the sterility of the contents must be preserved, screw-caps may be replaced with cotton or foam plugs.

6.C.6 Ultrasonicators, Centrifuges, and Other Electrical Equipment

6.C.6.1 Ultrasonicators

The use of high-intensity ultrasound in the chemical laboratory has grown enormously during the past decade and has a diverse set of applications. Human exposure to ultrasound with frequencies of between 16 and 100 kilohertz (kHz) can be divided into three distinct categories: airborne conduction, direct contact through a liquid coupling medium, and direct contact with a vibrating solid.

Ultrasound through airborne conduction does not appear to pose a significant health hazard to humans. However, exposure to the associated high volumes of audible sound can produce a variety of effects, including fatigue, headaches, nausea, and tinnitus. When ultrasonic equipment is operated in the laboratory, the apparatus must be enclosed in a 2-cm-thick wooden box or in a box lined with acoustically absorbing foam or tiles to substantially reduce acoustic emissions (most of which are inaudible).

Direct contact of the body with liquids or solids subjected to high-intensity ultrasound of the sort used to promote chemical reactions should be avoided. (In contrast, ultrasound used for medical diagnostic imaging is relatively benign.) Under sono-chemical conditions, cavitation is created in liquids, and it can induce high-energy chemistry in liquids and tissues. Cell death from membrane disruption can occur even at relatively low acoustic intensities. Exposure to ultrasonically vibrating solids, such as an acoustic horn, can lead to rapid frictional heating and potentially severe burns.
6.C.6.2 Centrifuges
Centrifuges should be properly installed and must be operated only by trained personnel. It is important that the load be balanced each time the centrifuge is used and the lid be closed while the rotor is in motion. The disconnect switch must be working properly to shut off the equipment when the top is opened, and the manufacturer's instructions for safe operating speeds must be followed.

For flammable and/or hazardous materials, the centrifuge should be under negative pressure to a suitable exhaust system.

6.C.6.3 Electrical Instruments
Most modern electronic instruments have a cord that contains a separate ground wire for the chassis and are supplied with a suitable fuse or other overload protection. Any existing instrument that lacks these features should be modified to incorporate them. As is true for any electrical equipment, special precautions should be taken to avoid the possibility that water or other chemicals could be spilled into these instruments.

Under most circumstances, any repairs to, adjustments to, or alterations of such instruments should be made only by a qualified individual. Laboratory workers should not undertake such adjustments unless they have received certification as well as specific training for the particular instrument to be serviced. If laboratory workers do undertake repairs, the cord should always be unplugged before any disassembly begins. However, certain adjustments can be made only when the instrument is connected to a power source. Appropriate protective measures and due diligence are required when working on energized devices. Extra precautions are particularly important for instruments that incorporate high-voltage circuitry.

Many electrical instruments, such as lasers and x-ray, E-beam, radioactive, photochemical, and electrophoresis equipment, emit potentially harmful radiation, and, therefore, special precautions must be followed when they are used. This equipment should be used and serviced only by trained personnel. (See section 6.C.1 and Chapter 5, section 5.E.)

6.C.7 Electromagnetic Radiation Hazards
Equipment found in laboratories that can produce hazardous amounts of electromagnetic radiation includes ultraviolet lamps, arc lamps, heat lamps, lasers, microwave and radio-frequency sources, and x-rays and electron beams.

6.C.7.1 Visible, Ultraviolet, and Infrared Laser Light Sources
Overexposure to direct or reflected ultraviolet light, arc lamps, and infrared sources should be minimized by sealing or enclosing sources whenever possible. Appropriately rated safety glasses, goggles, or face shields should be worn for eye protection. Long-sleeved clothing and gloves should be worn to protect arms and hands.
Control measures for the safe use of lasers have been established by the American National Standards Institute (ANSI) and presented in *Safe Use of Lasers* (ANSI Z136.1-1993), which describes the different types of laser hazards and the appropriate measures to control each type. Class IIIB and IV lasers should be operated only in posted laser-controlled areas. No one but the authorized operator of a laser system should ever enter a posted laser-controlled laboratory when the laser is in use.

### 6.C.7.2 Radio-frequency and Microwave Sources

Section 6.C.5.7 provides guidelines for the safe use of microwave ovens in the laboratory. Other devices in the laboratory can also emit harmful microwave or radio-frequency emissions. People working with these types of devices should be trained in their proper operation as well as measures to prevent exposure to harmful emissions. Shields and protective covers should be in proper position when the equipment is operating. Warning signs to protect people wearing heart pacemakers should be posted on or near these devices.

A laboratory worker removed the shield from a high-powered microwave-generating device. Fortunately, the emissions triggered the fire alarm system, prompting an evacuation of the laboratory. Had the exposure continued, the person could have suffered severe injury.

### 6.C.7.3 X-rays, E-beams, and Sealed Sources

X-rays and electron beams (E-beams) are used in a variety of laboratory equipment, mostly for analytical operations. The equipment is government-regulated. In most cases, registration and licensing are required. Personnel operating or working in the vicinity of these types of equipment should have appropriate training to minimize the risk of their being exposed to harmful ionizing radiation.

### 6.C.7.4 Miscellaneous Physical Hazards Presented by Electrically Powered Equipment

#### 6.C.7.4.1 Magnetic Fields

If an object moves into the attractive field of a strong magnet, it can become a projectile when it is pulled rapidly toward the magnet. Therefore, objects ranging from keys, scissors, knives, wrenches, and other tools to oxygen cylinders, buffing machines, and wheelchairs and other ferromagnetic objects must be excluded from the immediate vicinity of the magnet, for the sake of both safety and data quality, in the case of NMR.

Even relatively small peripheral magnetic fields can adversely affect credit cards, computer disks, and other magnetic objects, as summarized in Table 6.1. It is prudent to post warnings at the 5-gauss (G) line and to limit access to areas with more than 10 to 20 G to knowledgeable staff. People wearing heart pacemakers and other electronic or electromagnetic prosthetic devices should be kept away from strong electromagnetic sources.

Superconducting magnets use liquid nitrogen and liquid helium coolants. Thus, the precautions associated with the use of cryogenic liquids must be observed as well. (Also see section 6.E.2.)
6.C.7.4.2

**Rotating Equipment and Moving Parts**

Injuries can result from bodily contact with rotating or moving objects, including mechanical equipment, parts, and devices. The risk of injury can be reduced through improved engineering, good housekeeping, and safe work practice and personal behavior. Laboratory workers must know how to shut down equipment in the event of an emergency; must enclose or shield hazardous parts, such as belts, chains, gears, and pulleys, with appropriate guards; and must not wear loose clothing, jewelry, or unrestrained long hair around machinery.

6.C.7.4.3

**Cutting and Puncturing Tools**

Hand injuries are probably the most frequently encountered injuries in laboratories. Many of these injuries can be prevented by keeping all cutting and puncturing devices fully protected, avoiding the use of razor blades as cutting tools, and using utility knives that have a spring-loaded guard that covers the blade. Razor blades, needles, and other sharp objects or instruments should be disposed of carefully rather than simply thrown into the trash bin unprotected.

Glass cuts can be minimized by use of correct procedures (for example, that for inserting glass tubing into rubber stoppers and tubing, which is taught in introductory laboratories), through appropriate use of protective equipment, and by careful attention to manipulation.

6.C.7.4.4

**Noise Extremes**

Any laboratory operation that produces significant noise (85 decibels or greater) needs a hearing conservation program to protect employees from excessive exposure, that is, exposure to significant noise for an 8-hour average duration. An audiologist or industrial hygienist should be consulted to determine the need for such a program and to provide assistance in developing one.

6.C.7.4.5

**Slips, Trips, and Falls**

The risks of slips, trips, falls, and collisions between persons and objects can be reduced by cleaning up liquid or solid spills immediately, keeping doors and drawers closed and passageways clear of obstructions, providing step stools, ladders, and lifts to reach high areas, and walking along corridors and on stairways at a normal pace. Wet floors around ice, dry ice, or liquid nitrogen dispensers should be carpeted and paper towel dispensers made available for wiping up drops or small puddles as soon as they form.

6.C.7.4.6

**Ergonomics and Lifting**

Both standing and sitting in a static posture and making repeated motions have been shown to cause a wide variety of musculoskeletal complaints. Problems due to poor ergonomics include
eyestrain, stiff and sore back, leg discomfort, and hand and arm injuries. Each situation needs to be evaluated individually. However, personnel who spend significant time working on video display terminals should use furniture appropriate for these tasks, proper posture, and perhaps special eyeglasses. Also, people who use the same tools and/or hand motions for extended periods of time should take breaks at appropriate intervals to help prevent injuries.

Lifting injuries are one of the more common types of injuries for laboratory workers. The weight of the item to be lifted is a factor, but it is only one of several. The shape and size of an object as well as the lifting posture and the frequency of lifting are also key factors in determining the risks of lifting. The National Institute for Occupational Safety and Health (NIOSH) has developed a guide that should be consulted to help determine lifting safety (U.S. DHHS, 1994). Personnel who are at risk for lifting injuries should receive periodic training.

6.D WORKING WITH COMPRESSED GASES

6.D.1 Compressed Gas Cylinders

Precautions are necessary for handling the various types of compressed gases, the cylinders that contain them, the regulators used to control their flow, the piping used to confine them during flow, and the vessels in which they are ultimately used. Regular inventories of cylinders and checks of their integrity with prompt disposal of those no longer in use are important. (See Chapter 4, section 4.E.4, for information on storing gas cylinders, and Chapter 5, section 5.H, for discussion of the chemical hazards of gases.)

A compressed gas is defined as a material in a container with an absolute pressure greater than 276 kilo-pascals (kPa), or 40 psi (pounds per square inch) at 21 °C or an absolute pressure greater than 717 kPa (104 psi) at 54 °C, or both, or any liquid flammable material having a Reid vapor pressure greater than 276 kPa (40 psi) at 38 °C. The Department of Transportation (DOT) has established codes that specify the materials to be used for the construction and the capacities, test procedures, and service pressures of the cylinders in which compressed gases are transported. However, regardless of the pressure rating of the cylinder, the physical state of the material within it determines the pressure of the gas. For example, liquefied gases such as propane and ammonia will exert their own vapor pressure as long as any liquid remains in the cylinder and the critical temperature is not exceeded.

Prudent procedures for the use of compressed gas cylinders in the laboratory include attention to appropriate purchase, especially selecting the smallest cylinder compatible with the need, as well as proper transportation and storage, identification of contents, handling and use, and marking and return of the empty cylinder. The practice of purchasing un-returnable lecture bottles should be discouraged if that leads to accumulation of partially filled cylinders and disposal problems. Returnable cylinders should be purchased and returned as prescribed by the manufacturer.

6.D.1.1 Identification of Contents

The contents of any compressed gas cylinder should be identified clearly so as to be easily, quickly, and completely determined by any laboratory worker. Such identification should be
stenciled or stamped on the cylinder itself, or a durable label should be provided that cannot be removed from the cylinder. No compressed gas cylinder should be accepted for use that does not identify its contents legibly by name. Color coding is not a reliable means of identification; cylinder colors vary from supplier to supplier, and labels on caps have no value because many caps are interchangeable. Care in the maintenance of cylinder labels is important because unidentified compressed gas cylinders may pose a high risk and present very high disposal costs. It is good practice to provide compressed gas cylinders with tags on which the names of users and dates of use can be entered. If the labeling on a cylinder becomes unclear or an attached tag is defaced and the contents cannot be identified, the cylinder should be marked "contents unknown" and the manufacturer contacted regarding appropriate procedures.

All gas lines leading from a compressed gas supply should be labeled clearly to identify the gas, the laboratory served, and relevant emergency telephone numbers. The labels, in addition to being dated, should be color-coded to distinguish hazardous gases—that is, flammable, toxic, or corrosive substances coded with a yellow background and black letters—from inert gases, which are coded with a green background and black letters. Signs should be posted conspicuously in areas in which flammable compressed gases are stored, identifying the substances and appropriate precautions, for example:

**HYDROGEN—FLAMMABLE GAS**

**NO SMOKING—NO—OPEN FLAMES**

6.D.1.2 Handling and Use

Gas cylinders must be handled carefully to prevent accidents or damage to the cylinder. The valve protection cap should be left in place until the cylinder is secured and ready for use. Gas cylinders should not be dragged, rolled, slid, or allowed to strike each other forcefully. Cylinders should always be transported on wheeled cylinder carts with retaining straps or chains. The plastic mesh sleeves sometimes installed on cylinders by vendors are intended only to protect the paint on the cylinder and do not serve as a safety device.

Compressed gas cylinders should be secured firmly at all times. A clamp and belt or chain, securing the cylinder between "waist" and "shoulder" to a wall, are generally suitable for this purpose. In areas of seismic activity, gas cylinders should be secured both toward the top and toward the bottom. Cylinders should be individually secured; using a single restraint strap or chain around a number of cylinders is often not effective. Pressure-relief devices protecting equipment that is attached to cylinders of flammable, toxic, or otherwise hazardous gases should be vented to a safe place. (See Section 6.D.2.2.1 for details.)

Standard cylinder-valve outlet connections have been devised by the Compressed Gas Association (CGA) to prevent the mixing of incompatible gases due to an interchange of connections. The outlet threads used vary in diameter: some are internal and some are external; some are right-handed and some are left-handed. In general, right-handed threads are used for nonfuel and water-pumped gases, and left-handed threads are used for fuel and oil-pumped gases. Information on the standard equipment assemblies for use with specific compressed gases is available from the supplier. To minimize undesirable connections that may result in a hazard, only CGA standard combinations of valves and fittings should be used in compressed gas...
installations; the assembly of miscellaneous parts (even of standard approved types) should be avoided. Use of an "adapter" or cross-threading of a valve fitting should not be attempted. The threads on cylinder valves, regulators, and other fittings should be examined to ensure that they correspond to one another and are undamaged.

Cylinders should be placed so that the rotary cylinder valve handle at the top is accessible at all times. Cylinder valves should be opened slowly, and only when a proper regulator is firmly in place and the attachment has been shown to be leak-proof by an appropriate test (see Chapter 5, section 5.H). The cylinder valve should be closed as soon as the necessary amount of gas has been released. Valves should be either completely open or completely closed. Flow restrictors should be installed on gas cylinders to minimize the chance of excessive flows. The cylinder valve should never be left open when the equipment is not in use. This precaution is necessary not only for safety when the cylinder is under pressure, but also to prevent the corrosion and contamination that would result from diffusion of air and moisture into the cylinder after it has been emptied.

Most cylinders are equipped with hand-wheel valves. Those that are not should have a spindle key on the valve spindle or stem while the cylinder is in service. Only wrenches or other tools provided by the cylinder supplier should be used to remove a cylinder cap or to open a valve. In no case should a screwdriver be used to pry off a stuck cap or should pliers be used to open a cylinder valve. Some valve fittings require washers or gaskets, and the materials of construction should be checked before the regulator is fitted.

If the valve on a cylinder containing an irritating or toxic gas is being opened outside, the worker should stand upwind of the cylinder with the valve pointed downwind, away from him or herself, and should warn those working nearby in case of a possible leak. If the work is being done inside, the cylinder should be opened only in a fume hood or specially designed cylinder cabinet. A differential pressure switch with an audible alarm should be installed in any hood dedicated for use with toxic gases. In the event of hood failure, the pressure switch should activate an audible alarm warning the user of hood failure.

### 6.D.1.2.1 Preventing and Controlling Leaks

Cylinders, connections, and hoses should be checked regularly for leaks. To check for leaks, a flammable gas leak detector (for flammable gases only) or soapy water, or a 50% glycerin-water solution, is used to look for bubbles. At or below freezing temperatures, the glycerin solution should be used instead of soapy water. When the gas to be used in the procedure is a flammable oxidizing or highly toxic gas, the system should be checked first for leaks with an inert gas (helium or nitrogen) before introducing the hazardous gas.

The general procedures discussed in Chapter 5, section 5.C, can be used for relatively minor leaks, when the indicated action can be taken without exposing personnel to highly toxic substances. The leaking cylinder can be moved through populated portions of the building, if necessary, by placing a plastic bag, rubber shroud, or similar device over the top and taping it (preferably with duct tape) to the cylinder to confine the leaking gas. If there is any risk of exposure, the environmental health and safety office should be called and the area evacuated before the tank is moved.
If a leak at the cylinder valve handle cannot be remedied by tightening a valve gland or a packing nut, emergency action should be taken and the supplier should be notified. Laboratory workers should never attempt to repair a leak at the junction of the cylinder valve and the cylinder or at the safety device; rather, they should consult with the supplier for instructions.

When the nature of the leaking gas or the size of the leak constitutes a more serious hazard, a self-contained breathing apparatus and protective apparel may be required, and personnel may need to be evacuated (see Chapter 5, section 5.C.2). Cylinders leaking toxic gases always require protective equipment and evacuation of personnel. Cylinder coffins are also available to encapsulate leaking cylinders. (See Chapter 5, section 5.G, for more information.)

**SPONTANEOUS IGNITION OF HYDROGEN**

Late one evening in a chemical engineering facility, a student employee was working near a six-cylinder hydrogen gas manifold when she heard a cracking sound above her, followed by a whistling sound. She stepped away from the cylinder area to where she could see above the roof and noticed a flame on the roof above the cylinders. She immediately reported this to her supervisor, who went up on the roof and found that a rupture disk on the hydrogen manifold had ruptured. Had the disk ruptured in the daylight, the flame might not have been visible. The most likely cause of the flame was the spontaneous ignition of the hydrogen as it entered the air at high pressure. The hydrogen manifold was shut down, the rupture disk was replaced, and research was resumed.

**6.D.1.2.2**

**Pressure Regulators**

Pressure regulators are strongly recommended to reduce a high-pressure supplied gas to a desirable lower pressure and to maintain a satisfactory delivery pressure and flow level for the required operating conditions. They can be obtained to fit many operating conditions over a range of supply and delivery pressures, flow capacities, and construction materials. All regulators are of a diaphragm type and are spring-loaded or gas-loaded, depending on pressure requirements. They can be single-stage or two-stage. Under no circumstances should oil or grease be used on regulator valves or cylinder valves because these substances may be reactive with some gases (e.g., oxygen).

Each regulator is supplied with a specific CGA standard inlet connection to fit the outlet connection on the cylinder valve for the particular gas. Regulators should be checked before use to be sure they are free of foreign objects and correct for the particular gas.

Regulators for use with noncorrosive gases are usually made of brass. Special regulators made of corrosion-resistant materials can be obtained for use with such gases as ammonia, boron trifluoride, chlorine, hydrogen chloride, hydrogen sulfide, and sulfur dioxide. Because of freeze-up and corrosion problems, regulators used with carbon dioxide gas must have special internal design features and be made of special materials. Regulators used with oxidizing agents must be cleaned specially to avoid the possibility of an explosion on contact of the gas with any reducing agent or oil left from the cleaning process.
All pressure regulators should be equipped with spring-loaded pressure-relief valves (see section 6.D.2.2.1 for further information on pressure-relief devices) to protect the low-pressure side. When used on cylinders of flammable, toxic, or otherwise hazardous gases, the relief valve should be vented to a hood or other safe location. The use of internal-bleed-type regulators should be avoided. Regulators should be removed from corrosive gases immediately after use and flushed with dry air or nitrogen. Mercury bubblers should not be used.

6.D.1.2.3

Flammable Gases

It is important to keep all sources of ignition away from cylinders of flammable gases and to ensure that these cylinders will not leak. A solution of soapy water should be used to detect leaks except during freezing weather, when a 50% glycerin-water solution or its equivalent should be used. Connections to piping, regulators, and other appliances should always be kept tight to prevent leakage, and the tubing or hoses used should be kept in good condition. Regulators, hoses, and other appliances used with cylinders of flammable gases should not be interchanged with similar equipment intended for use with other gases. Cylinders should be grounded properly to prevent static electricity buildup, especially in very cold or dry environments. All cylinders containing flammable gases should be stored in a well-ventilated place. Reserve stocks of such cylinders should never be stored in the vicinity of cylinders containing oxygen, fluorine, chlorine, or other oxidizing gases. Reaction vessels should be equipped with pressure-relief devices.

6.D.1.2.4

Empty Cylinders

A cylinder should never be emptied to a pressure lower than 172 kPa (25 psi) because the residual contents may become contaminated with air if the valve is left open. Empty cylinders should never be refilled by the user. Rather, the regulator should be removed, and the valve cap should be replaced. The cylinder should be clearly marked as empty (MT) and returned to a storage area for pickup by the supplier. Empty and full cylinders should not be stored in the same place.

Cylinder discharge lines should be equipped with approved check valves to prevent inadvertent contamination of cylinders that are connected to a closed system where the possibility of flow reversal exists. Backflow is particularly troublesome in the case of gases used as reactants in a closed system. A cylinder in such a system should be shut off and removed from the system while the pressure remaining in the cylinder is still greater than the pressure in the closed system. If there is a possibility that a cylinder has become contaminated, it should be so labeled and returned to the supplier.
6.D.2 Other Equipment Used with Compressed Gases


High-pressure operations should be carried out only with equipment specifically built for this use and only by those trained especially to use this equipment. Reactions should never be carried out in, nor heat applied to, an apparatus that is a closed system unless it has been designed and tested to withstand pressure. To ensure that the equipment has been properly designed, each pressure vessel should have stamped on it, or on an attached plate, its maximum allowable working pressure, the allowable temperature at this pressure, and the material of construction. Similarly, the relief pressure and setting data should be stamped on a metal tag attached to installed pressure-relief devices, and the setting mechanisms should be sealed. Relief devices used on pressure regulators do not require these seals or numbers.

All pressure equipment should be tested or inspected periodically. The frequency of tests and/or inspections varies, depending on the type of equipment, how often it is used, and the nature of its usage. Corrosive or otherwise hazardous service requires more frequent tests and inspections. Inspection data should be stamped on or attached to the equipment.

Testing the entire assembled apparatus with soap solution and air or nitrogen pressure to the maximum allowable working pressure of the weakest section of the assembled apparatus can usually detect leaks at threaded joints, packings, and valves.

Before any pressure equipment is altered, repaired, stored, or shipped, it should be vented, and all toxic, flammable, or other hazardous material removed completely so it can be handled safely. Especially hazardous materials may require special cleaning techniques, which should be solicited from the distributor. (See section 6.E.1 for further information.)

6.D.2.2 Assembly and Operation

During the assembly of pressure equipment and piping, only appropriate components should be used, and care should be taken to avoid strains and concealed fractures resulting from the use of improper tools or excessive force. Tubing in place in a pressure apparatus should not be used to support any significant weight.

Threads that do not fit exactly should not be forced (refer to section 6.D.1.2.1). Thread connections must match; tapered pipe threads cannot be joined with parallel machine threads. Teflon tape or a suitable thread lubricant should be used when assembling the apparatus (see section 6.D.2.2.6). However, oil or lubricant must never be used on any equipment that will be used with oxygen. Parts having damaged or partly stripped threads should be rejected (also see section 6.D.2.2.5).

In assembling copper tubing installations, sharp bends should be avoided and considerable flexibility should be allowed. Copper tubing hardens and cracks on repeated bending. Many metals can become brittle in hydrogen (H₂) or corrosive gas service. Nickel alloys can generate Ni(CO)₄ in some carbon monoxide atmospheres. All tubing should be inspected frequently and replaced when necessary.
Stuffing boxes and gland joints are a likely source of trouble in pressure installations. Particular attention should be given to the proper installation and maintenance of these parts, including the proper choice of lubricant and packing material.

Experiments carried out in closed systems and involving highly reactive materials, such as those subject to rapid polymerization (e.g., dienes or unsaturated aldehydes, ketones, or alcohols) should be preceded by small-scale tests using the exact reaction materials to determine the possibility of an unexpectedly rapid reaction or unforeseen side reactions. All reactions under pressure should be shielded and should be carried out as remotely as possible, for example, with valve extensions and behind a heavy shield or with closed-circuit TV monitoring if needed.

Autoclaves and other pressure-reaction vessels should not be filled more than half full to ensure that space remains for expansion of the liquid when it is heated. Leak corrections or adjustments to the apparatus should not be made while it is pressurized; rather, the system should be depressurized before mechanical adjustments are made.

Immediately after an experiment in which low-pressure equipment connected to a source of high pressure is pressurized, the low-pressure equipment should either be disconnected entirely or left independently vented to the atmosphere. Either action will prevent the accidental buildup of excessive pressure in the low-pressure equipment due to leakage from the high-pressure side.

Vessels or equipment made partly or entirely of silver, copper, or alloys containing more than 50% copper should not be used in contact with acetylene or ammonia. Those made of metals susceptible to amalgamation (e.g., copper, brass, zinc, tin, silver, lead, and gold) should not come into contact with mercury. This includes equipment that has soldered and brazed joints.

Prominent warning signs should be placed in any area where a pressure reaction is in progress so that people entering the area will be aware of the potential risk.

6.D.2.2.1

Pressure-Relief Devices

All pressure or vacuum systems and all vessels that may be subjected to pressure or vacuum should be protected by properly installed and tested pressure-relief devices. Experiments involving highly reactive materials that might explode may also require the use of special pressure-relief devices and may need to be operated at a fraction of the permissible working pressure of the system.

Examples of pressure-relief devices include the rupture-disk type used with closed-system vessels and the spring-loaded safety valves used with vessels for transferring liquefied gases. The following precautions are advisable in the use of pressure-relief devices:

- The maximum setting of a pressure-relief device is the rated working pressure established for the vessel or for the weakest member of the pressure system at the operating temperature. The operating pressure should be less than the allowable working pressure of the system. In the case of a system protected by a spring-loaded relief device, the maximum operating pressure should be from 5 to 25% lower than the rated working pressure, depending on the type of safety
valve and the importance of leak-free operation. In the case of a system protected by a rupture-disk device, the maximum operating pressure should be about two-thirds of the rated working pressure; the exact figure is governed by the fatigue life of the disk used, the temperature, and load pulsations.

- Pressure-relief devices that may discharge toxic, corrosive, flammable, or otherwise hazardous or noxious materials should be vented in a safe and environmentally acceptable manner such as scrubbing and/or diluting with nonflammable streams.

- Shutoff valves must not be installed between pressure-relief devices and the equipment they are to protect.

- Only qualified persons should perform maintenance work on pressure-relief devices.

- Pressure-relief devices should be inspected and replaced periodically.

6.D.2.2.2

**Pressure Gauges**

- The proper choice and use of a pressure gauge involve several factors, including the flammability, compressibility, corrosivity, toxicity, temperature, and pressure range of the fluid with which it is to be used. Generally, a gauge with a range that is double the working pressure of the system should be selected.

- A pressure gauge is normally a weak point in any pressure system because its measuring element must operate in the elastic zone of the metal involved. The resulting limited factor of safety makes careful gauge selection and use mandatory and often dictates the use of accessory protective equipment. The primary element of the most commonly used gauges is a Bourdon tube, which is usually made of brass or bronze and has soft-soldered connections. More expensive gauges can be obtained that have Bourdon tubes made of steel, stainless steel, or other special metals and welded or silver-soldered connections. Accuracies vary from ±2% for less-expensive pressure gauges to ±0.1% for higher-quality gauges. A diaphragm gauge should be used with corrosive gases or liquids or with viscous fluids that would destroy a steel or bronze Bourdon tube.

- Consideration should be given to alternative methods of pressure measurement that may provide greater safety than the direct use of pressure gauges. Such methods include the use of seals or other isolating devices in pressure tap lines, indirect observation devices, and remote measurement by strain-gauge transducers with digital readouts.
6.D.2.2.3

Glass Equipment

- The use of glassware for work at high pressure should be avoided whenever possible. Glass is a brittle material subject to unexpected failures due to factors such as mechanical impact and assembly and tightening stresses. Poor annealing after glassblowing can leave severe strains. Glass equipment, such as rotameters and liquid-level gauges, incorporated in metallic pressure systems should be installed with shutoff valves at both ends to control the discharge of liquid or gaseous materials in the event of breakage. Mass flow meters are available that can replace rotameters in desired applications.

6.D.2.2.4

Plastic Equipment

- Except as noted below, the use of plastic equipment for pressure or vacuum work should be avoided unless no suitable substitute is available. These materials can fail under pressure or thermal stress.

- Tygon and similar plastic tubing have quite limited applications in pressure work. These materials can be used for hydrocarbons and most aqueous solutions at room temperature and moderate pressure. Reinforced plastic tubing that can withstand higher pressures is also available. However, loose tubing under pressure can cause physical damage by its own whipping action. Details of permissible operating conditions must be obtained from the manufacturer. Because of their very large coefficients of thermal expansion, some polymers have a tendency to expand a great deal on heating and to contract on cooling. This behavior can create a hazard in equipment subjected to very low temperatures or to alternating low and high temperatures.

6.D.2.2.5

Piping, Tubing, and Fittings

- The proper selection and assembly of components in a pressure system are critical safety factors. Considerations should include the materials used in manufacturing the components, compatibility with the materials to be under pressure, the tools used for assembly, and the reliability of the finished connections. No oil or lubricant of any kind should be used in a tubing system with oxygen because the combination produces an explosion hazard.

- All-brass and stainless steel fittings should be used with copper or brass and steel or stainless steel tubing, respectively. It is important that fittings of this type be installed
correctly. Different brands of tube fittings should not be mixed in the same apparatus assembly because construction parts are often not interchangeable.

6.D.2.2.6

Teflon Tape Applications

- Teflon tape should be used on tapered pipe thread where the seal is formed in the thread area. Tapered pipe thread is commonly found in applications where fittings are not routinely taken apart (e.g., general building piping applications).

- Teflon tape should not be used on straight thread where the seal is formed through gaskets or by other metal-to-metal contacts that are forced together when the fitting is tightened (e.g., CGA gas cylinder fittings or compression fittings). Metal-to-metal seals are machined to tolerances that seal without the need of Teflon tape or other gasket materials. If used where not needed, as on CGA fittings, Teflon tape only spreads and weakens the threaded connections and can plug up lines that it enters accidentally.

6.E WORKING WITH HIGH/Low PRESSURES AND TEMPERATURES

Work with hazardous chemicals at high/low pressures and/or high/low temperatures require planning and special precautions. For many experiments, extremes of both pressure and temperature, such as reactions at elevated temperatures and pressures and work with cryogenic liquids and high vacuum, must be managed simultaneously. Procedures at high/low pressures should be carried out with protection against explosion or implosion by appropriate equipment selection and the use of safety shields. Appropriate temperature control and interlocks should be provided so that heating or cooling baths cannot exceed the desired limits even if the equipment fails. Care must be taken to select and use glass apparatus that can safely withstand thermal expansion or contraction at the designated pressure and temperature extremes.

6.E.1 Pressure Vessels

- High-pressure operations should be performed only in special chambers equipped for this purpose. Laboratory workers should ensure that equipment for operations using pressure vessels is appropriately selected, properly labeled and installed, and protected by pressure-relief and necessary control devices. Vessels must be strong enough to withstand the stresses encountered at the intended operating pressures and temperatures. The vessel material must not corrode when it is in contact with the material(s) it contains. The material should not react with the process being studied, and
• the vessel must be of the proper size and configuration needed for the process. Reactions should never be carried out in, nor heat applied to, an apparatus that is a closed system unless it has been designed and tested to withstand pressure.

• Pressure-containing systems designed for use at elevated temperatures should have a positive temperature controller. Manual control using a simple variable autotransformer, such as a Variac, is not good practice. The use of both a back-up temperature controller capable of recording temperatures and shutting down an unattended system is strongly recommended. (See section 6.D.2 above.)

6.E.1.1 Records, Inspection, and Testing

• In some localities, adherence to national codes such as the ASME (American Society of Mechanical Engineers) Boiler and Pressure Vessel Code (ASME, 1992) is mandatory. Selection of containers, tubing, fittings, and other process equipment, along with the operational techniques and procedures, must adhere to the constraints necessary for high-pressure service. The proper selection and assembly of components in a pressure system are critical safety factors. Compatibility of materials, tools used for assembly, and the reliability of connections are all key considerations.

• Each pressure vessel in a laboratory should have a stamped number or fixed label plate that uniquely identifies it. Information such as the maximum allowable working pressure, allowable temperature at this pressure, material of construction, and burst diagram should be readily available. Information on the vessel's history should include temperature extremes it has experienced, any modifications and repairs made to the original vessel, and all inspections or test actions it has undergone. Similarly, the relieving pressure and setting data should be stamped on a metal tag attached to installed pressure-relief devices, and the setting mechanisms should be sealed. Relief devices used on pressure regulators do not require these seals or numbers.

• All pressure equipment should be tested or inspected periodically. The interval between tests or inspections is determined by the severity of the usage the equipment has received. Corrosive or otherwise hazardous service requires more frequent tests and inspections. Inspection data should be stamped on or attached to the equipment. Pressure vessels may be subjected to nondestructive inspections such as visual inspection, penetrant inspection, acoustic emissions recording, and radiography. However, hydrostatic proof tests are necessary for final acceptance. These tests should be as infrequent as possible. They should be performed before the vessel is placed in initial service, every 10 years thereafter, after a significant repair or modification, and if the vessel experiences overpressure or over-temperature.
• Testing the entire apparatus with soap solution and air or nitrogen pressure to the maximum allowable working pressure of the weakest section of the assembled apparatus can usually detect leaks at threaded joints, packing areas, and valves.

• Final assemblies should be pressure-tested and leak-tested to ensure their integrity. Laboratory workers are strongly advised to consult an expert on high-pressure work as they design, build, and operate a high-pressure process. Finally, extreme care should be exercised when disassembling pressure equipment for repair, modification, or decommissioning. Protective equipment should be worn just in case a line or vessel that is opened contains material under pressure.

6.E.1.2 Pressure Reactions in Glass Equipment

• For any reaction run on a large scale (more than 10 g total weight of reactants) or at a maximum pressure in excess of 690 kPa (100 psi), only procedures involving a suitable high-pressure autoclave or shaker vessel should be used. Whenever possible, metal reactors with glass liners should be used instead of sealed glass tubes. Fisher-Porter-type tubes with a pressure gauge and release device are preferred for pressure reactions in glass equipment. However, it is sometimes convenient to run very small-scale reactions at low pressures in a small sealed glass tube or in a thick-walled pressure bottle of the type used for catalytic hydrogenation. For any such reaction, the worker should be fully prepared for the significant possibility that the sealed vessel will burst. Removal of any gas should be prepared for by appropriate ventilation. Every precaution should be taken to prevent injury from flying glass or from corrosive or toxic reactants by using suitable shielding. Centrifuge bottles should be sealed with rubber stoppers clamped in place, wrapped with friction tape and shielded with a metal screen or wrapped with friction tape and surrounded by multiple layers of loose cloth toweling, and clamped behind a good safety shield. Some bottles are typically equipped with a head containing inlet and exhaust gas valves, a pressure gauge, and a pressure-relief valve. When corrosive materials are being used, a Teflon pressure-relief valve should be used. The preferred source of heat for such vessels is steam, because an explosion in the vicinity of an electrical heater could start a fire and an explosion in a liquid heating bath would scatter hot liquid around the area. Any reaction of this type should be carried out in a hood and labeled with signs that indicate the contents of the reaction vessel and the explosion risk.

• Glass tubes with high-pressure sealers should be no more than three-quarters full. Appropriate precautions using the proper shielding must be taken for condensing materials and sealing tubes. Vacuum work can be carried out on a Schlenck line as long as proper technique is used. The sealed glass tubes can be placed either inside pieces of brass or iron pipe capped at one end with a pipe cap or in an autoclave containing some
of the reaction solvent (to equalize the pressure inside and outside the glass tube). The
tubes can be heated with steam or in a specially constructed, electrically heated "sealed-
tube" furnace that is controlled thermostatically and located such that the force of an
explosion would be directed into a safe area. When the required heating has been
completed, the sealed tube or bottle should be allowed to cool to room temperature.
Sealed bottles and tubes of flammable materials should be wrapped with cloth toweling,
placed behind a safety shield, and then cooled slowly, first in an ice bath and then in dry
ice. After cooling, the clamps and rubber stoppers can be removed from the bottles prior
to opening. Personal protective equipment and apparel, including shields, masks, coats,
and gloves, should be used during tube-opening operations. It should be noted that NMR
tubes are often thin-walled and should only be used for pressure reactions in a special
high-pressure probe or in capillary devices.

- Newly fabricated or repaired glass equipment for pressure or vacuum work should be
  examined for flaws and strains under polarized light. Corks, rubber stoppers, and rubber
  or plastic tubing should never be relied on as relief devices for protection of glassware
  against excess pressure; a liquid seal, Bunsen tube, or equivalent positive relief device
  should be used. When glass pipe is used, only proper metal fittings should be used.

6.E.2 Liquefied Gases and Cryogenic Liquids

- Cryogenic liquids are materials with boiling points of less than -73 °C (-100 °F). Liquid
  nitrogen, helium, and argon, and slush mixtures of dry ice with isopropanol are the
  materials most commonly used in cold traps to condense volatile vapors from a system.
  In addition, oxygen, hydrogen, and helium are often used in the liquid state.

- The primary hazards of cryogenic liquids are fire or explosion, pressure buildup (either
  slowly or due to rapid conversion of the liquid to the gaseous state), embrittlement of
  structural materials, frostbite, and asphyxiation. The extreme cold of cryogenic liquids
  requires special care in their use. The vapor that boils off from a liquid can cause the
  same problems as the liquid itself.

- The fire or explosion hazard is obvious when gases such as oxygen, hydrogen, methane,
  and acetylene are used. Air enriched with oxygen can greatly increase the flammability of
  ordinary combustible materials and may even cause some noncombustible materials to
  burn readily (see Chapter 5, sections 5.G.4 and 5.G.5). Oxygen-saturated wood and
  asphalt have been known to literally explode when subjected to shock. Because oxygen
  has a higher boiling point (-183 °C) than nitrogen (-195 °C), helium (-269 °C), or
hydrogen (-252.7 °C), it can be condensed out of the atmosphere during the use of these lower-boiling-point cryogenic liquids. With the use of liquid hydrogen particularly, conditions may develop for an explosion. (See Chapter 5, sections 5.F.3 and 5.G.2, for further discussion.)

- It is advisable to furnish all cylinders and equipment containing flammable or toxic liquefied gases (not vendor-owned) with a spring-loaded pressure-relief device (not a rupture disk) because of the magnitude of the potential risk that can result from activation of a non-resetting relief device. Commercial cylinders of liquefied gases are normally supplied only with a fusible-plug type of relief device, as permitted by DOT regulations. Pressurized containers that contain cryogenic material should be protected with multiple pressure-relief devices.

- Cryogenic liquids must be stored, shipped, and handled in containers that are designed for the pressures and temperatures to which they may be subjected. Materials that are pliable under normal conditions can become brittle at low temperatures. Dewar flasks, which are used for relatively small amounts of material, should have a dust cap over the outlet to prevent atmospheric moisture from condensing and plugging the neck of the tube. Special cylinders insulated and vacuum-jacketed with pressure-relief valves and rupture devices to protect the cylinder from pressure buildup are available in capacities of 100 to 200 liters (L).

- A special risk to personnel is skin or eye contact with the cryogenic liquid. Because these liquids are prone to splash in use owing to the large volume expansion ratio when the liquid warms up, eye protection, preferably a face shield, should be worn when handling liquefied gases and other cryogenic fluids. The transfer of liquefied gases from one container to another should not be attempted for the first time without the direct supervision and instruction of someone experienced in this operation. Transfers should be done very slowly to minimize boiling and splashing.

- Unprotected parts of the body should not be in contact with non-insulated vessels or pipes that contain cryogenic liquids because extremely cold material may bond firmly to the skin and tear flesh if separation or withdrawal is attempted. Even very brief skin contact with a cryogenic liquid can cause tissue damage similar to that of frostbite or thermal burns, and prolonged contact may result in blood clots that have potentially very serious consequences. Gloves must be impervious to the fluid being handled and loose enough to be tossed off easily. A potholder may be a desirable alternative. Objects that are in contact with cryogenic liquids should also be handled with tongs or potholders. The work
area should be well ventilated. Virtually all liquid gases present the threat of poisoning, explosion, or, at a minimum, asphyxiation in a confined space. Major harmful consequences of the use of cryogenic inert gases, including asphyxiation, are due to boiling off of the liquid and pressure buildup, which can lead to violent rupture of the container or piping.

- In general, liquid hydrogen should not be transferred in an air atmosphere because oxygen from the air can condense in the liquid hydrogen, presenting a possible explosion risk. All precautions should be taken to keep liquid oxygen from organic materials; spills on oxidizable surfaces can be hazardous. Though nitrogen is inert, its liquefied form can be hazardous because of its cryogenic properties and because displacement of air oxygen in the vicinity can lead to asphyxiation followed by death with little warning. Rooms that contain appreciable quantities of liquid nitrogen (N$_2$) should be fitted with oxygen meters and alarms. Liquid nitrogen should not be stored in a closed room because the oxygen content of the room can drop to unsafe levels.

- Cylinders and other pressure vessels used for the storage and handling of liquefied gases should not be filled to more than 80% of capacity, to protect against possible thermal expansion of the contents and bursting of the vessel by hydrostatic pressure. If the possibility exists that the temperature of the cylinder may increase to above 30°C, a lower percentage (e.g., 60%) of capacity should be the limit.

6.E.2.1 Cold Traps and Cold Baths

- Cold traps should be chosen that are large enough and cold enough to collect the condensable vapors in a vacuum system. Cold traps should be checked frequently to make sure they do not become plugged with frozen material. Cold traps in a reduced-pressure system should be taped or placed in a metal can filled with vermiculite. After completion of an operation in which a cold trap has been used, the system should be vented in a safe and environmentally acceptable way. Otherwise, pressure could build up, creating a possible explosion and sucking pump oil into the system. Cold traps under continuous use, such as those used to protect inert atmosphere dry boxes, should be cooled electrically and monitored by low-temperature probes.

- Appropriate gloves and a face shield should be used to avoid contact with the skin when using cold baths. Dry gloves should be used when handling dry ice. Lowering of the head into a dry ice chest is to be avoided because carbon dioxide is heavier than air and asphyxiation can result. The preferred liquids for dry ice cooling baths are isopropyl alcohol or glycols, and the dry ice should be added slowly to the liquid portion of the cooling bath to avoid foaming. The common practice of using acetone-dry ice as a coolant should be avoided. Dry ice and liquefied gases used in refrigerant baths should
always be open to the atmosphere. They should never be used in closed systems, where they may develop uncontrolled and dangerously high pressures.

- Extreme caution should be exercised in using liquid nitrogen as a coolant for a cold trap. If such a system is opened while the cooling bath is still in contact with the trap, oxygen may condense from the atmosphere. The oxygen could then combine with any organic material in the trap to create a highly explosive mixture. Thus, a system that is connected to a liquid nitrogen trap should not be opened to the atmosphere until the trap has been removed. Also, if the system is closed after even a brief exposure to the atmosphere, some oxygen (or argon) may have already condensed. Then, when the liquid nitrogen bath is removed or when it evaporates, the condensed gases will vaporize, producing a pressure buildup and the potential for explosion. The same explosion hazard can be created if liquid nitrogen is used to cool a flammable mixture that is exposed to air.

6.E.2.2 Selection of Low-Temperature Equipment

Equipment used at low temperatures should be selected carefully. Temperature can dramatically change characteristics of materials. For example, even the impact strength of ordinary carbon steel is greatly reduced at low temperatures, and failure can occur at points of weakness, such as notches or abrupt changes in the material of construction, in cold equipment. When combinations of materials are required, it is important that the temperature dependence of their volumes be considered so that leaks, ruptures, and glass fractures can be avoided. For example, O-rings that provide a good seal at room temperature may lose resilience and fail to function on chilled equipment.

IMPROPER GLASSWARE IN A CRYOGENIC FLUID

A thin-walled Pyrex NMR sample tube containing absorbed hydrocarbons on platinum on an alumina support, which had been sealed under vacuum and annealed, was placed in a dry ice and chloroform mixture in a Dewar flask in a hood with horizontal sliding sashes. The tube exploded after approximately one minute in the bath, apparently due to thermal shock. Although the Dewar was not damaged, the researcher suffered severely irritated eyes and had to be transported to the trauma center. The researcher had been wearing glasses and a laboratory coat as personal protection, and the hood sash had been slid to the side. Face shields, goggles, gloves, and acrylic shielding were available in the laboratory but had not been used.

The 18% chromium/8% nickel stainless steels retain their impact resistance down to approximately -240 °C, the exact value depending heavily on special design considerations. The impact resistance of aluminum, copper, nickel, and many other nonferrous metals and alloys increases with decreasing temperatures. Special alloy steels should be used for liquids or gases containing hydrogen at temperatures greater than 200 °C or at pressures greater than 34.5 MPa (500 psi) because of the danger of weakening carbon steel equipment by hydrogen embrittlement.
6.E.2.3 Cryogenic Lines and Supercritical Fluids

Liquid cryogen transfer lines should be designed so that liquid cannot be trapped in any non-vented part of the system. Experiments in supercritical fluids include high pressure and should be carried out with appropriate protective systems.

6.E.3 Vacuum Work and Apparatus

Vacuum work can result in an implosion and the possible hazards of flying glass, spattering chemicals, and fire. All vacuum operations must be set up and operated with careful consideration of the potential risks.

Although a vacuum distillation apparatus may appear to provide some of its own protection in the form of heating mantles and column insulation, this is not sufficient because an implosion could scatter hot, flammable liquid. An explosion shield and a face mask should be used to protect the worker, and the procedure should be carried out in a hood.

Equipment at reduced pressure is especially prone to rapid pressure changes, which can create large pressure differences within the apparatus. Such conditions can push liquids into unwanted locations, sometimes with undesirable consequences.

Water, solvents, and corrosive gases should not be allowed to be drawn into a building vacuum system. When the potential for such a problem exists, a water aspirator with a solvent collection device and a trap with a check valve installed between the water aspirator and the apparatus, to prevent water from being drawn back into the apparatus, should be used as the vacuum source.

Mechanical vacuum pumps should be protected by cold traps, and their exhausts should be vented to an exhaust hood or to the outside of the building. If solvents or corrosive substances are inadvertently drawn into the pump, the oil should be changed before any further use. (Oil contaminated with solvents, mercury, corrosive substances, and so on, must be handled as hazardous waste.) It may be desirable to maintain a log of pump usage as a guide to length of use and potential contaminants in the pump oil. The belts and pulleys on vacuum pumps should be covered with guards. (See section 6.C.2 for a discussion of vacuum pumps.)

6.E.3.1 Glass Vessels

Although glass vessels are frequently used in low-vacuum operations, evacuated glass vessels may collapse violently, either spontaneously from strain or from an accidental blow. Therefore, pressure and vacuum operations in glass vessels should be conducted behind adequate shielding. It is advisable to check for flaws such as star cracks, scratches, and etching marks each time a vacuum apparatus is used. Only round-bottomed or thick-walled (e.g., Pyrex) evacuated reaction vessels specifically designed for operations at reduced pressure should be used. Repaired glassware is subject to thermal shock and should be avoided. Thin-walled, Erlenmeyer, or round-bottomed flasks larger than 1 L should never be evacuated.
6.E.3.2 Dewar Flasks

Dewar flasks are under high vacuum and can collapse as a result of thermal shock or a very slight mechanical shock. They should be shielded, either by a layer of fiber-reinforced friction tape or by enclosure in a wooden or metal container, to reduce the risk of flying glass in case of collapse. Metal Dewar flasks should be used whenever there is a possibility of breakage.

**IMPLODING DEWAR**

A researcher was about to prepare an ice trap in a Dewar to cool a stationary stainless steel receiver on a chemical reactor system. The researcher had positioned the Dewar on a laboratory jack stand and had raised the Dewar into position. The Dewar imploded, propelling glass shards toward the researcher, who fortunately was wearing prescription safety glasses and received only minor facial cuts. The researcher should have been wearing a full-length face shield and should have had a cover on the Dewar.

Styrofoam buckets with lids can be a safer form of short-term storage and conveyance of cryogenic liquids than glass vacuum Dewars. Although they do not insulate as well as Dewar flasks, they eliminate the danger of implosion.

6.E.3.3 Desiccators

If a glass vacuum desiccator is used, it should be made of Pyrex or similar glass, completely enclosed in a shield or wrapped with friction tape in a grid pattern that leaves the contents visible and at the same time guards against flying glass should the vessel implode. Plastic (e.g., polycarbonate) desiccators reduce the risk of implosion and may be preferable, but should also be shielded while evacuated. Solid desiccants are preferred. *An evacuated desiccator should never be carried or moved.* Care should be taken in opening the valve to avoid a shock wave into the desiccator.

6.E.3.4 Rotary Evaporators

Glass components of the rotary evaporator should be made of Pyrex or similar glass, completely enclosed in a shield to guard against flying glass should the components implode. Increase in rotation speed and application of vacuum to the flask whose solvent is to be evaporated should be gradual.

6.E.3.5 Assembly of Vacuum Apparatus

Vacuum apparatus should be assembled so as to avoid strain. Joints must be assembled so as to allow various sections of the apparatus to be moved if necessary without transmitting strain to the necks of the flasks. Heavy apparatus should be supported from below as well as by the neck. The assembler should avoid putting pressure on a vacuum line. Failure to keep the pressure below 1 atmosphere could lead to the stopcocks popping out at high velocity or to an explosion of the glass apparatus. Such increased pressure could result from warming of the contents of the trap due to failure to maintain low temperatures.

Vacuum apparatus should be placed well back onto the bench or into the hood where they will not be inadvertently hit. If the back of the vacuum setup faces the open laboratory, it should be
protected with panels of suitably heavy transparent plastic to prevent injury to nearby workers from flying glass in case of explosion.

6.F USING PERSONAL PROTECTIVE, SAFETY, AND EMERGENCY EQUIPMENT

As outlined in previous chapters, it is essential for each laboratory worker to be proactive to ensure the laboratory is a safe working environment. This attitude begins with wearing appropriate apparel and using proper eye, face, hand, and foot protection when working with hazardous chemicals. It is the responsibility of the institution to provide appropriate safety and emergency equipment for laboratory workers and for emergency personnel. (See also section 5.C.)

6.F.1 Personal Protective Equipment and Apparel

6.F.1.1 Personal Clothing

Clothing that leaves large areas of skin exposed is inappropriate in laboratories where hazardous chemicals are in use. The worker's personal clothing should be fully covering. Appropriate laboratory coats should be worn, buttoned, with the sleeves rolled down. Laboratory coats should be fire-resistant. Those fabricated of polyester are not appropriate for glassblowing or work with flammable materials. Cotton coats are inexpensive and do not burn readily. Laboratory coats or laboratory aprons made of special materials are available for high-risk activities. Laboratory coats that have been used in the laboratory should be left there to minimize the possibility of spreading chemicals to public assembly, eating, or office areas, and they should be cleaned regularly. (For more information, see the OSHA Personal Protective Equipment Standard (29 CFR 1910.132) and the OSHA Laboratory Standard (29 CFR 1910.1450).)

Unrestrained long hair and loose clothing such as neckties, baggy pants, and coats are inappropriate in a laboratory where hazardous chemicals are in use. Such items can catch fire, be dipped in chemicals, and get caught in equipment. Similarly, rings, bracelets, watches, or other jewelry that could be damaged, trap chemicals close to the skin, come in contact with electrical sources, or get caught in machinery should not be worn. Leather clothing or accessories should not be worn in situations where chemicals could be absorbed in the leather and held close to the skin.

Protective apparel should always be worn if there is a possibility that personal clothing could become contaminated with chemically hazardous material. Washable or disposable clothing worn for laboratory work with especially hazardous chemicals includes special laboratory coats and aprons, jumpsuits, special boots, shoe covers, and gauntlets, as well as splash suits. Protection from heat, moisture, cold, and/or radiation may be required in special situations. Among the factors to be considered in choosing protective apparel, in addition to the specific application, are resistance to physical hazards, flexibility and ease of movement, chemical and
thermal resistance, and ease of cleaning or disposal. Although cotton is a good material for laboratory coats, it reacts rapidly with acids. Plastic or rubber aprons can provide good protection from corrosive liquids but can be inappropriate in the event of a fire. Plastic aprons can also accumulate static electricity, and so they should not be used around flammable solvents, explosives sensitive to electrostatic discharge, or materials that can be ignited by static discharge. Disposable garments provide only limited protection from vapor or gas penetration. Disposable garments that have been used when handling carcinogenic or other highly hazardous material should be removed without exposing any individual to toxic materials and disposed of as hazardous waste. (See Chapter 5, sections 5.C.2.5 and 5.C.2.6.)

6.F.1.2 Foot Protection

Street shoes may not be appropriate in the laboratory, where both chemical and mechanical hazards may exist. Substantial shoes should be worn in areas where hazardous chemicals are in use or mechanical work is being done. Clogs, perforated shoes, sandals, and cloth shoes do not provide protection against spilled chemicals. In many cases, safety shoes are advisable. Shoe covers may be required for work with especially hazardous materials. Shoes with conductive soles are useful to prevent buildup of static charge, and insulated soles can protect against electrical shock.

6.F.1.3 Eye and Face Protection

Safety glasses with side shields that conform to ANSI standard Z87.1-1989 should be required for work with hazardous chemicals. Ordinary prescription glasses with hardened lenses do not serve as safety glasses. Contact lenses can sometimes be worn safely if appropriate eye and face protection is also worn (see, however, section 5.C.2.1). Although safety glasses can provide satisfactory protection from injury from flying particles, they do not fit tightly against the face and offer little protection against splashes or sprays of chemicals. It is appropriate for a laboratory to provide impact goggles that include splash protection (splash goggles), full-face shields that also protect the throat, and specialized eye protection (i.e., protection against ultraviolet light or laser light). Splash goggles, which have splash-proof sides to fully protect the eyes, should be worn if there is a splash hazard in any operation involving hazardous chemicals. Impact protection goggles should be worn if there is a danger of flying particles, and full-face shields with safety glasses and side shields are needed for complete face and throat protection. When there is a possibility of liquid splashes, both a face shield and splash goggles should be worn; this is especially important for work with highly corrosive liquids. Full-face shields with throat protection and safety glasses with side shields should be used when handling explosive or highly hazardous chemicals. If work in the laboratory could involve exposure to lasers, ultraviolet light, infrared light, or intense visible light, specialized eye protection should be worn. It also is appropriate for a laboratory to provide visitor safety glasses and a sign indicating that eye protection is required in laboratories where hazardous chemicals are in use.

6.F.1.4 Hand Protection

Gloves appropriate to the hazard should be used at all times. It is important that the hands and any skin that is likely to be exposed to hazardous chemicals receive special attention. Proper protective gloves should be worn when handling hazardous chemicals, toxic materials, materials of unknown toxicity, corrosive materials, rough or sharp-edged objects, and very hot or very cold
objects. Before the gloves are used, it is important that they be inspected for discoloration, punctures, or tears. A defective or improper glove can itself be a serious hazard in handling hazardous chemicals. If chemicals do penetrate glove material, they could then be held in prolonged contact with the hand and cause more serious damage than in the absence of a proper glove.

The degradation and permeation characteristics of the glove material selected must be appropriate for protection from the hazardous chemicals being handled. Glove selection guides (available from most manufacturers) should be consulted, with careful consideration given to the permeability of any material, particularly when working with organic solvents, which may be able to permeate or dissolve the glove materials. The thin latex "surgical" vinyl and nitrile gloves that are popular in many laboratories because of their composition and thin construction may not be appropriate for use with highly toxic chemicals or solvents. For example, because latex is readily permeated by carbon disulfide, a hand covered by a latex glove immersed in carbon disulfide would receive constant wetting by this toxic chemical, which would by then be absorbed through the skin. Gloves should be replaced immediately if they are contaminated or torn. The use of double gloves may be appropriate in situations involving chemicals of high or multiple hazards. Leather gloves are appropriate for handling broken glassware and inserting tubing into stoppers, where protection from chemicals is not needed. Insulated gloves should be used when working with very hot or very cold materials. With cryogenic fluids the gloves must be impervious to fluid, but loose enough to be tossed off easily. Absorbent gloves could freeze on the hand and intensify any exposure to liquefied gases. Turning up the cuffs on gloves can prevent liquids from running down the arms when hands are raised.

Gloves should be decontaminated or washed appropriately before they are taken off and should be left in the work area and not be allowed to touch any uncontaminated objects in the laboratory or any other area. Gloves should be replaced periodically, depending on the frequency of use. Regular inspection of their serviceability is important. If they cannot be cleaned, contaminated gloves should be disposed of according to institutional procedures.

Barrier creams and lotions can provide some skin protection but should never be a substitute for gloves, protective clothing, or other protective equipment. These creams should be used only to supplement the protection offered by personal equipment.

6.F.2 Safety and Emergency Equipment

Safety equipment, including spill control kits, safety shields, fire safety equipment, respirators, safety showers and eyewash fountains, and emergency equipment should be available in well-marked, highly visible locations in all chemical laboratories. Fire alarm pull stations and telephones with emergency telephone numbers clearly indicated must be readily accessible. In addition to the standard items, there may also be a need for other safety devices. It is the responsibility of the laboratory supervisor to ensure proper training and provide supplementary equipment as needed.
6.F.2.1 Spill Control Kits and Cleanup

In most cases, researchers are responsible for cleaning up their own spills. If a spill exceeds their ability or challenges their safety, they should leave the spill site and call the emergency telephone number for help. Emergency response spill cleanup personnel should be given all available information about the spill.

A spill control kit should be on hand. A typical cleanup kit may be a container on wheels that can be moved to the location of the spill and may include such items as instructions; absorbent pads; a spill absorbent mixture for liquid spills; a polyethylene scoop for dispensing spill absorbent; mixing it with the spill, and picking up the mixture; thick polyethylene bags for deposit of the mixture; and tags and ties for labeling the bags. Any kit should be used in conjunction with the personal protective equipment needed for the chemical that is to be cleaned up. Before beginning an operation that could produce a spill, the worker should locate the specialized spill control kits for that operation. (Also see Chapter 5, section 5.C.11.5.)

6.F.2.2 Safety Shields

Safety shields should be used for protection against possible explosions or splash hazards. Laboratory equipment should be shielded on all sides so that there is no line-of-sight exposure of personnel. The front sashes of conventional laboratory exhaust hoods can provide shielding. However, a portable shield should also be used when manipulations are performed, particularly with hoods that have vertical-rising doors rather than horizontal-sliding sashes.

Portable shields can be used to protect against hazards of limited severity, such as small splashes, heat, and fires. A portable shield, however, provides no protection at the sides or back of the equipment, and many such shields not sufficiently weighted for forward protection may topple toward the worker when there is a blast. A fixed shield that completely surrounds the experimental apparatus can afford protection against minor blast damage.

Polymethyl methacrylate, polycarbonate, polyvinyl chloride, and laminated safety plate glass are all satisfactory transparent shielding materials. Where combustion is possible, the shielding material should be nonflammable or slow burning; if it can withstand the working blast pressure, laminated safety plate glass may be the best material for such circumstances. When cost, transparency, high tensile strength, resistance to bending loads, impact strength, shatter resistance, and burning rate are considered, polymethyl methacrylate offers an excellent overall combination of shielding characteristics.

Polycarbonate is much stronger and self-extinguishing after ignition but is readily attacked by organic solvents.

6.F.2.3 Fire Safety Equipment

6.F.2.3.1 Fire Extinguishers

All chemical laboratories should have carbon dioxide and dry chemical fire extinguishers. Other types of extinguishers should be available if required for the work being done. The four types of extinguishers most commonly used are classified by the type of fire for which they are suitable,
as listed below. It should be noted that multipurpose class A, B, and C extinguishers are available.

- Water extinguishers are effective against burning paper and trash (class A fires). These should not be used for extinguishing electrical, liquid, or metal fires.

- Carbon dioxide extinguishers are effective against burning liquids, such as hydrocarbons or paint, and electrical fires (class B and C fires). They are recommended for fires involving computer equipment, delicate instruments, and optical systems because they do not damage such equipment. They are less effective against paper and trash fires and must not be used against metal hydride or metal fires. Care must be taken in using these extinguishers, because the force of the compressed gas can spread burning combustibles such as papers and can tip over containers of flammable liquids.

- Dry powder extinguishers, which contain ammonium phosphate or sodium bicarbonate, are effective against burning liquids and electrical fires (class B and C fires). They are less effective against paper and trash or metal fires. They are not recommended for fires involving delicate instruments or optical systems because of the cleanup problem. Computer equipment may need to be replaced if exposed to sufficient amounts of the dry powders. These extinguishers are generally used where large quantities of solvent may be present.

- Met-L-X® extinguishers and others that have special granular formulations are effective against burning metal (class D fires). Included in this category are fires involving magnesium, lithium, sodium, and potassium; alloys of reactive metals; and metal hydrides, metal alkyls, and other organometallics. These extinguishers are less effective against paper and trash, liquid, or electrical fires.

Every extinguisher should carry a label indicating what class or classes of fires it is effective against and the date last inspected. There are a number of other, more specialized types of extinguishers available for unusual fire hazard situations. Each laboratory worker should be responsible for knowing the location, operation, and limitations of the fire extinguishers in the work area. It is the responsibility of the laboratory supervisor to ensure that all workers are shown the locations of fire extinguishers and are trained in their use. After use, an extinguisher should be recharged or replaced by designated personnel.

6.F.2.3.2

Heat and Smoke Detectors

Heat sensors and/or smoke detectors may be part of the building safety equipment. If designed into the fire alarm system, they may automatically sound an alarm and call the fire department, they may trigger an automatic extinguishing system, or they may only serve as a local alarm. Because laboratory operations may generate heat or vapors, the type and location of the detectors must be carefully evaluated in order to avoid frequent false alarms.
6.F.2.3.3

Fire Hoses

Fire hoses are intended for use by trained firefighters against fires too large to be handled by extinguishers and are included as safety equipment in some structures. Water has a cooling action and is effective against fires involving paper, wood, rags, trash, and such (class A fires). Water should not be used directly on fires that involve live electrical equipment (class C fires) or chemicals such as alkali metals, metal hydrides, and metal alkyls that react vigorously with it (class D fires).

Streams of water should not be used against fires that involve oils or other water-insoluble flammable liquids (class B fires). Water will not readily extinguish such fires. Rather, it can cause the fire to spread or float to adjacent areas. These possibilities are minimized by the use of a water fog. Water fogs are used extensively by the petroleum industry because of their fire-controlling and extinguishing properties. A fog can be used safely and effectively against fires that involve oil products, as well as those involving wood, rags, rubbish, and such.

Because of the potential risks involved in using water around chemicals, laboratory workers should refrain from using fire hoses except in extreme emergencies. Otherwise, such use should be reserved for trained firefighters. Clothing fires can be extinguished by immediately dropping to the floor and rolling; however, if a safety shower is immediately available, it should be used (as noted in section 6.F.2.5).

6.F.2.3.4

Automatic Fire-Extinguishing Systems

In areas where fire potential and the risk of injury or damage are high, automatic fire-extinguishing systems are often used. These may be of the water sprinkler, foam, carbon dioxide, halon, or dry chemical type. If an automatic fire-extinguishing system is in place, laboratory workers should be informed of its presence and advised of any safety precautions required in connection with its use (e.g., evacuation before a carbon dioxide total-flood system is activated, to avoid asphyxiation).

6.F.2.4 Respiratory Protective Equipment

The primary method for the protection of laboratory personnel from airborne contaminants should be to minimize the amount of such materials entering the laboratory air. When effective engineering controls are not possible, suitable respiratory protection should be used after proper training. Respiratory protection may be needed in carrying out an experimental procedure, in dispensing or handling hazardous chemicals, in responding to a chemical spill or release in cleanup decontamination, or in hazardous waste handling.

Under Occupational Safety and Health Administration (OSHA) regulations, only equipment listed and approved by the Mine Safety and Health Administration (MSHA) and the National Institute for Occupational Safety and Health (NIOSH) may be used for respiratory protection. Also under the regulations, each site on which respiratory protective equipment is used must implement a respirator program (including training and medical certification) in compliance with

6.F.2.4.1

Types of Respirators

Several types of nonemergency respirators are available for protection in atmospheres that are not immediately dangerous to life or health but could be detrimental after prolonged or repeated exposure. Other types of respirators are available for emergency or rescue work in hazardous atmospheres from which the wearer needs protection. In either case, additional protection may be required if the airborne contaminant is of a type that could be absorbed through or irritate the skin. For example, the possibility of eye or skin irritation may require the use of a full-body suit and a full-face mask rather than a half-face mask. For some chemicals the dose from skin absorption can exceed the dose from inhalation.

The choice of the appropriate respirator to use in a given situation depends on the type of contaminant and its estimated or measured concentration, known exposure limits, and hazardous properties. The degree of protection afforded by the respirator varies with the type. Four main types of respirators are currently available:

- Chemical cartridge respirators can be used only for protection against particular individual (or classes of) vapors or gases as specified by the respirator manufacturer and cannot be used at concentrations of contaminants above that specified on the cartridge. Also, these respirators cannot be used if the oxygen content of the air is less than 19.5%, in atmospheres immediately dangerous to life, or for rescue or emergency work. These respirators function by trapping vapors and gases in a cartridge or canister that contains a sorbent material, with activated charcoal being the most common adsorbent. Because it is possible for significant breakthrough to occur at a fraction of the canister capacity, knowledge of the potential workplace exposure and length of time the respirator will be worn is important. It may be desirable to replace the cartridge after each use to ensure the maximum available exposure time for each new use. Difficulty in breathing or the detection of odors indicates plugged or exhausted filters or cartridges or concentrations of contaminants higher than the absorbing capacity of the cartridge, and the user should immediately leave the area of contamination. Chemical cartridge respirators must be checked and cleaned on a regular basis. New and used cartridges must not be stored near chemicals because they are constantly filtering the air. Cartridges should be stored in sealed containers to prevent chemical contamination.

Respirators must fit snugly on the face to be effective. Failure to achieve a good face-to-face piece seal (for example, because of glasses or facial hair) can permit contaminated air to bypass the filter and create a dangerous situation for the user. Respirators requiring a face-to-face piece seal should not be used by
those with facial hair, for whom powered air-purifying or supplied-air respirators are at times appropriate. Tests for a proper fit must be conducted prior to selection of a respirator and verified before the user enters the area of contamination.

Organic vapor cartridges cannot be used for vapors that are not readily detectable by their odor or other irritating effects or for vapors that will generate substantial heat upon reaction with the sorbent materials in the cartridge.

- Dust, fume, and mist respirators can be used only for protection against particulate, or certain classes of, dusts, fumes, and mists as specified by the manufacturer. The useful life of the filter depends on the concentration of contaminant encountered. Such particulate-removing respirators usually trap the particles in a filter composed of fibers; they are not 100% efficient in removing particles. Respirators of this type are generally disposable. Examples are surgical masks and 3M® toxic-dust and nuisance-dust masks. Some masks are NIOSH-approved for more specific purposes such as protection against simple or benign dust and fibro-genic dusts and asbestos.

- Particulate-removing respirators afford no protection against gases or vapors and may give the user a false sense of security. They are also subject to the limitations of fit.

- Supplied-air respirators supply fresh air to the face piece of the respirator at a pressure high enough to cause a slight buildup relative to atmospheric pressure. As a result, the supplied air flows outward from the mask, and contaminated air from the work environment cannot readily enter the mask. This characteristic renders face-to-face piece fit less important than with other types of respirators. Fit testing is, however, required before selection and use.

- Supplied-air respirators are effective protection against a wide range of air contaminants (gases, vapors, and particulates) and can be used where oxygen-deficient atmospheres are present. Where concentrations of air contaminants could be immediately dangerous to life, such respirators can be used provided (1) the protection factor of the respirator is not exceeded and (2) the provisions of OSHA’s Respiratory Standard (which indicates the need for a safety harness and an escape system in case of compressor failure) are not violated.
The air supply of this type of respirator must be kept free of contaminants (e.g., by use of oil filters and carbon monoxide absorbers). Most laboratory air is not suitable for use with these units. These units usually require the user to drag lengths of hose connected to the air supply, and they have a limited range.

- The self-contained breathing apparatus (SCBA) is the only type of respiratory protective equipment suitable for emergency or rescue work. Untrained personnel should not attempt to use them.

6.F.2.4.2

Procedures and Training

Each area where respirators are used should have written information available that shows the limitations, fitting methods, and inspection and cleaning procedures for each type of respirator available. Personnel who may have occasion to use respirators in their work must be thoroughly trained, before initial use and annually thereafter, in the fit testing, use, limitations, and care of such equipment. Training should include demonstrations and practice in wearing, adjusting, and properly fitting the equipment. OSHA regulations require that a worker be medically certified before beginning work in an area where a respirator must be worn (OSHA Respiratory Standard, 29 CFR 1910.134(b)(10)).

6.F.2.4.3

Inspections

Respirators for routine use should be inspected before each use by the user and periodically by the laboratory supervisor. Self-contained breathing apparatus should be inspected at least once a month and cleaned after each use.

6.F.2.5 Safety Showers and Eyewash Fountains

6.F.2.5.1

Safety Showers

Safety showers should be available in areas where chemicals are handled. They should be used for immediate first aid treatment of chemical splashes and for extinguishing clothing fires. Every laboratory worker should know where the safety showers are located in the work area and should learn how to use them. Safety showers should be tested routinely to ensure that the valve is operable and to remove any debris in the system.

The shower should be capable of drenching the subject immediately and should be large enough to accommodate more than one person if necessary. It should have a quick-opening valve requiring manual closing: a downward-pull delta bar is satisfactory if long enough, but chain pulls are not advisable because they can hit the user and be difficult to grasp in an emergency. It is preferable to have drains under safety showers to reduce the risks associated with the water.
6.F.2.5.2

**Eyewash Fountains**

Eyewash fountains should be required in research or instructional laboratories if substances used in instructional laboratories present an eye hazard or if unknown hazards may be encountered. An eyewash fountain should provide a soft stream or spray of aerated water for an extended period (15 minutes). These fountains should be located close to the safety showers so that, if necessary, the eyes can be washed while the body is showered.

6.F.2.6 Storage and Inspection of Emergency Equipment

It is often useful to establish a central location for storage of emergency equipment. Such a location should contain the following:

- self-contained breathing apparatus,
- blankets for covering the injured,
- stretchers (although it is generally best not to move a seriously injured person and to wait for qualified medical help to provide this service),
- first aid equipment (for unusual situations such as exposure to hydrofluoric acid or cyanide, where immediate first aid is required), and
- chemical spill cleanup kits and spill control equipment (e.g., spill pillows, booms, shoe covers, and a 55-gallon drum in which to collect absorbed material).

(Also consult Chapter 5, sections 5.C.11.5 and 5.C.11.6.)

Safety equipment should be inspected regularly (e.g., every 3 to 6 months) to ensure that it will function properly when needed. It is the responsibility of the laboratory supervisor or safety coordinator to establish a routine inspection system and to verify that inspection records are being kept.

Inspections of emergency equipment should be performed as follows:

- Fire extinguishers should be inspected for broken seals, damage, and low gauge pressure (depending on type of extinguisher). Proper mounting of the extinguisher and its ready accessibility should also be checked. Some types of extinguishers must be weighed annually, and periodic hydrostatic testing may be required.

- Self-contained breathing apparatus should be checked at least once a month and after each use to determine whether proper air pressure is being maintained. The examiner should look for signs of deterioration or wear of rubber parts, harness, and hardware and make certain that the apparatus is clean and free of visible contamination.
• Safety showers and eyewash fountains should be examined visually and their mechanical function should be tested. They should be purged as necessary to remove particulate matter from the water line.

6.G EMERGENCY PROCEDURES

The following emergency procedures are recommended in the event of a fire, explosion, spill, or medical or other laboratory accident. These procedures are intended to limit injuries and minimize damage if an accident should occur. Telephone numbers to call in emergencies should be posted clearly at all telephones in hazard areas.

1. Have someone call for emergency help. State clearly where the accident has occurred and its nature.

2. Ascertain the safety of the situation. Do not enter or reenter an unsafe area.

3. Render assistance to the people involved and remove them from exposure to further injury. 4. Warn personnel in adjacent areas of any potential risks to their safety.

4. Render immediate first aid; appropriate measures include washing under a safety shower, administration of CPR by trained personnel if heartbeat and/or breathing have stopped, and special first aid measures.

5. Extinguish small fires by using a portable extinguisher. Turn off nearby equipment and remove combustible materials from the area. For larger fires, contact the appropriate fire department promptly.

6. Provide emergency personnel with as much information as possible about the nature of the hazard.

In case of medical emergency, laboratory personnel should remain calm and do only what is necessary to protect life.

1. Summon medical help immediately.

2. Do not move an injured person unless he or she is in danger of further harm.

3. Keep the injured person warm. If feasible, designate one person to remain with the injured person. The injured person should be within sight, sound, or physical contact of that person at all times.
4. If clothing is on fire and a safety shower is immediately available, douse the person with water; otherwise, move the person to the floor and roll him or her around to smother the flames.

5. If harmful chemicals have been spilled on the body, remove them, usually by flooding the exposed area with sufficient running water from the safety shower, and immediately remove any contaminated clothing.

6. If a chemical has splashed into the eye, immediately wash the eyeball and the inner surface of the eyelid with plenty of water for 15 minutes. An eyewash fountain should be used if available. Forcibly hold the eye open to wash thoroughly behind the eyelids.

7. If possible, determine the identity of the chemical and inform the emergency medical personnel attending the injured person.
Appendix D

Laboratory Safety Information Sheet

Laboratory: ________________________________________________________________

Procedure Name: ________________________________

Chemical Hygiene Plan: _______ Page #s________

_____ Personal Protection:

_____ Protective Clothing: _____ Lab Coat _____ Other___________________________

_____ Gloves: Type _________________________________

_____ Eye Protection: _____ Safety Glasses _______ Safety Goggles _____________

_____ Face Protection: _____ Full Face Shield _____ Other ______________________

_____ Respiratory: _____ Mask _____ Respirator _____ Other ______________________

_____ Auditory: _____ Ear Phones/Plugs

_____ Ventilation Required:

_____ Laboratory Hood _____ Plus Safety Shield

_____ Laminar Flow Hood

_____ Special Ventilation Area _____ Glove Box _____ Other ______________________

_____ Other ________________________________
| Chemical Hazard:                                                                 |
|                                                                              |
| ____ Caustic or Corrosive Acids/Bases                                       |
| ____ Flammables                                                              |
| ____ Explosives                                                              |
| ____ Poisons                                                                 |
| ____ Carcinogens                                                             |
| ____ Mutagens/Teratogens                                                     |
| ____ Other                                                                    |

| Biological Hazards:                                                         |
|                                                                              |
| ____ Blood Product                                                           |
| ____ Infectious Agent                                                         |
| ____ Other                                                                    |

| Fire Hazard:                                                                |
|                                                                              |

| Electrical Hazard:                                                         |
|                                                                              |

| Compressed Gases:                                                          |
|                                                                              |
| ____ Toxic                                                                   |
| ____ Flammable                                                               |
Radioactive Chemicals: (See Radiation Protection Handbook)

Type of Radiation: _____ Alpha _____ Beta _____ Gamma _____ X-rays

Shielding Required _____ None _____ Plexiglas _____ Lead

Bench Protection: _____ Plastic-backed Paper _____ Tray _____ Other

Hazardous Waste: (Special Handling) (See Hazardous Chemical Management Handbook)

Blood Products

Hazardous Chemicals

Radioactive Waste

Other Hazards: ____________________________ CHP Pages #s: _______
Appendix E

LABORATORY AUDIT CHECKLIST

<table>
<thead>
<tr>
<th>Building &amp; Room Number:_______________</th>
<th>Date of Audit:______________________</th>
</tr>
</thead>
<tbody>
<tr>
<td>Department:___________________________</td>
<td></td>
</tr>
<tr>
<td>Auditors(s):________________________</td>
<td></td>
</tr>
<tr>
<td>Lab Supervisor:_______________________</td>
<td></td>
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</tbody>
</table>

1. Safety Equipment

<table>
<thead>
<tr>
<th>Working</th>
<th>Accessible</th>
<th>Last checked</th>
</tr>
</thead>
<tbody>
<tr>
<td>__________________</td>
<td>__________________</td>
<td>__________________</td>
</tr>
<tr>
<td>a. fume hoods</td>
<td>__________________</td>
<td>__________________</td>
</tr>
<tr>
<td>b. biological hoods</td>
<td>__________________</td>
<td>__________________</td>
</tr>
<tr>
<td>c. eye washes</td>
<td>__________________</td>
<td>__________________</td>
</tr>
<tr>
<td>d. showers</td>
<td>__________________</td>
<td>__________________</td>
</tr>
<tr>
<td>e. fire extinguisher(s)</td>
<td>A B C D</td>
<td>__________________</td>
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</tbody>
</table>

2. House-keeping

<table>
<thead>
<tr>
<th>Y</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. food, beverages and appliances absent from the laboratory?</td>
<td></td>
</tr>
<tr>
<td>b. food absent from chemical refrigerators and vice versa?</td>
<td></td>
</tr>
<tr>
<td>c. bench tops clean and unobstructed?</td>
<td></td>
</tr>
<tr>
<td>d. emergency numbers posted by telephone?</td>
<td></td>
</tr>
<tr>
<td>e. laboratory doors closed?</td>
<td></td>
</tr>
<tr>
<td>f. floors, aisles and exits unobstructed?</td>
<td></td>
</tr>
<tr>
<td>g. outside hallways uncluttered?</td>
<td></td>
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</tbody>
</table>

3. Chemical Storage

<table>
<thead>
<tr>
<th>Y</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. all containers appropriately labeled?</td>
<td></td>
</tr>
<tr>
<td>b. no flammables in unapproved refrigerators?</td>
<td></td>
</tr>
<tr>
<td>c. liquid chemicals equipped with secondary containment?</td>
<td></td>
</tr>
<tr>
<td>d. flammable liquids within allowable quantities?</td>
<td></td>
</tr>
<tr>
<td>e. chemicals stored appropriately (incompatibles separated)?</td>
<td></td>
</tr>
<tr>
<td>f. gas cylinders secured and stored appropriately?</td>
<td></td>
</tr>
<tr>
<td>g. empty and full cylinders separated?</td>
<td></td>
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</tbody>
</table>

4. Waste Management

<table>
<thead>
<tr>
<th>Y</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. chemical wastes tightly capped?</td>
<td></td>
</tr>
<tr>
<td>b. incompatible chemicals separated?</td>
<td></td>
</tr>
<tr>
<td>c. liquid chemicals equipped with secondary containment?</td>
<td></td>
</tr>
<tr>
<td>d. chemical wastes labeled appropriately?</td>
<td></td>
</tr>
<tr>
<td>e. weekly chemical waste inspections documented (where required)?</td>
<td></td>
</tr>
<tr>
<td>f. sharps disposed in proper containers?</td>
<td></td>
</tr>
<tr>
<td>g. special bags used for autoclaving waste?</td>
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</tbody>
</table>
h. red waste bags used for infectious waste?  

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4. Waste Management (cont.)  

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</table>
i. broken glass disposed in labeled container?  

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j. radioactive materials disposed in approved containers?  

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5. Mechanical Equipment  

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a. guards in place (fans, centrifuges, drive belts)?  

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b. belts/pulleys in good condition?  

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6. Electrical Equipment  

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a. grounded?  

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b. fitted with overload protection device?  

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c. outlets located outside of hoods?  

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d. motors intrinsically safe (where appropriate)?  

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e. cords in good condition?  

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f. current carrying parts not exposed?  

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g. GFI's on outlets within 6 feet of a sink?  

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7. Paper Work  

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a. training records available?  

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</table>
b. training records current?  

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c. training records complete (for all employees)?  

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d. Incident Report forms available (for work-related illnesses and injuries)?  

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e. MSDSs accessible?  

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f. Chemical Hygiene Plan accessible?  

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g. written laboratory-specific SOPs available?  

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h. staff knows the laboratory safety officer?  

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i. Hazardous Chemical Waste Management Guidebook accessible?  

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j. Radiation Protection Manual accessible?  

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Comments  

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Appendix F

Example Standard Operating Procedure

Title: ____________________________

PI: ____________________________ Lab Location: ____________________________

Issue Date: ____________________________ Revision Date: ____________________________

Prepared by: ____________________________ Approved by: ____________________________

Hazard Identification:

Physical-Chemical Properties

• CAS# ____________________________
• Molecular formula ____________________________
• Molecular weight ____________________________
• Form ____________________________
• Solubility ____________________________
• Volatility ____________________________
• Other ____________________________

Toxicity

• Acute effects ____________________________
• Chronic effects ____________________________
• Local effects ____________________________
• Systemic effects ____________________________

Sterigmatocystin activation
(http://www.biocentrum.dtu.dk/mycology/home/monthly_fungus/2002_01/)

Exposure Assessment:

Route

• Inhalation ____________________________
• Skin/eye absorption ____________________________
Accidental ingestion
Accidental injection

Duration
frequency
length

Control Plan:
Work in a ventilated enclosure (fume hood) equipped with spill control.
Wear nitrile gloves, goggles and labcoat.
No eating or drinking in the lab.
Wash hands and face thoroughly after lab work.

Note 1: Aflatoxin in chloroform can diffuse through latex and vinyl gloves (IARC). It is likely that sterigmatocystin solutions would behave similarly. Therefore, wear a laminated glove such as a Silvershield or a 4H for working with ST-solutions.

Note 2: To avoid dispersion of the powder due to electrostatic effects, solid ST should be handled using cotton gloves.

Experimental Procedures:

Waste Management Procedures:
ST is completely degraded by an excess of sodium hypochlorite solution (bleach) followed by addition, after dilution, of acetone to destroy potential hazardous dichloro derivatives. 200 µg of ST in 4 mL of methanol are completely degraded by treatment of 5 mL of a 5°Cl hypochlorite solution for 1 hr. Further treatment with acetone removes potential mutagenic compounds. (IARC)

Availability of chlorine is expressed as °Cl. A 1 mol/L solution of hypochlorite corresponds to 22.4°Cl. (IARC)

Collect mixture in compatible container and label as Hazardous Waste.

Spill and Accident Procedures:

References:
RTECS (Registry of Toxic Effects of Chemical Substances), 12/30/2003
Appendix G

Duties of a Departmental Research Safety Officer

The duties of a laboratory safety officer are to be determined and assigned by the department to which the employee reports. The range of duties will vary depending upon the needs of the particular department, including the hazardous materials used, the type of work being performed, and the availability of a safety committee to share in the safety officer's responsibilities. Following is a list of duties that may be assigned to a departmental laboratory safety officer.

1. Serve as liaison between employing department and Department of Environmental Health and Safety.

2. Modify University of Minnesota Generic Laboratory Safety Plan to fit department. Submit modification for approval. Perform annual review.

3. Work with department administrators and employees to implement Laboratory Safety Plan.

4. Consult with laboratory personnel regarding safety protocols for specific procedures.

5. Arrange general departmental training sessions for laboratory employees. Keep training records.

6. Carry out routine inspections of laboratories and report results to laboratory supervisors.

7. Receive reports of malfunctioning equipment. Facilitate laboratory maintenance and repair activities.

8. Assure that safety equipment is in place and is operative.

9. Know the current legal requirements regarding regulated substances.
Appendix H

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Appendix I

Principle Investigator________________________ Inciden t Date__________

ACCIDENT INVESTIGATION WORKSHEET
This report is to be filled out in the event of all laboratory fires, explosions and chemical spills, regardless of whether or not an injury occurred. Attach additional sheets as necessary. In the event of an injury, the Workers’ Compensation forms must also be completed.

1. Where (building and room #) and when (date and time) did this incident occur?

2. Briefly describe the nature of the incident (i.e. fire, explosion, spill, etc.).

3. Describe the events leading up to the incident. Include a diagram and/or description of all pertinent details such as materials used, reactions, reaction setups, etc.

4. What personal protective equipment (eye protection, gloves, safety shields, etc.) were you using? Be specific as to the type of eye protection, gloves, etc.

5. What engineering controls (fume hoods, etc.) were being used?

6. What specific laboratory safety references were consulted prior to work with the substances involved in the incident?

7. How did you respond to the incident?

8. What would you have done differently, if anything, to prevent or minimize the incident?

Sheet Completed by (print name) _____________ Date form completed__________
Appendix J

Toxic Substances Control Act (TSCA) Fact Sheet

This fact sheet is designed to provide University of Minnesota laboratories with an overview of the requirements and impacts of Toxic Substances Control Act (TSCA) with regards to new chemicals. More specific guidance and resources are available on the EPA TSCA website (http://www.epa.gov/oppt/newchems).

Overview of TSCA
The Toxic Substances Control Act (TSCA), administered by the U.S. Environmental Protection Agency (EPA), is intended to ensure that the human health and environmental effects of chemical substances are identified and properly controlled prior to placing these materials into commerce.

Chemical substances regulated by TSCA include: "Any organic or inorganic substances of a particular molecular identity including any combination of such substances occurring, in whole or in part, as a result of chemical reaction or occurring in nature and any element or uncombined radical."

Chemical substances not regulated or excluded by TSCA include:
(1) pesticides regulated by FIFRA
(2) tobacco and tobacco products regulated by ATF
(3) radioactive materials regulated by NRC
(4) foods, food additives, drugs, cosmetics or devices regulated by FDA

Laboratories engaged in research must consider the applicability of the Toxic Substances Control Act (TSCA) to their operation. Most University of Minnesota laboratory operations for which TSCA is applicable will fall under the R&D Exemption.

Research and Development (R&D) Exemption:
(1) Any chemical substance is exempted from many of the requirements of TSCA when it is:
- imported, produced or used in small quantities, and
- solely for purposes of non-commercial scientific experimentation, analysis or research, and
- under the supervision of a technically qualified individual.

(2) To maintain this exemption status, laboratories engaged in research and development must comply with the following TSCA requirements:
- Certify the TSCA status of imports of R&D substances, in writing.
- Notify receiving countries of exports of certain R&D substances, in writing.
- Document prudent laboratory practices.
- Label containers, shipping containers and shipping papers of any substance shipped for R&D purposes with language to that effect. Evaluate and communicate risks for any shipped R&D substance by preparing and shipping an MSDS and/or transfer form with the substance.
- Create and maintain records of any allegations of effects to human health or the environment potentially caused by R&D substances.
- Document and report any significant risks to human health or the environment potentially associated with R&D substances.

Note that chemical substances that do not meet this definition or laboratories that do not meet the requirements of the R&D exemption are subject to significant additional TSCA requirements. If you suspect that your operation does not meet the R&D exemption; please contact the DEHS office at 626-6002 for assistance.

To ensure that your department complies with TSCA’s regulatory requirements, each department should complete the following steps:

**Step 1: Determine TSCA’s applicability to your department**
Use the TSCA Applicability Form to evaluate each research laboratory operation and to document the results to the TSCA Coordinator. Laboratory operations should be monitored on an on-going basis for any changes that could affect your TSCA applicability. A new TSCA Applicability Form should be prepared whenever such changes take place.

**Step 2: Identify a “TSCA Coordinator” for your department**
This person may be a department’s Research Safety Officer or another technically qualified individual that will manage the department’s TSCA requirements to ensure compliance. A person who is knowledgeable in the following areas should act as TSCA Coordinator:
- How chemicals are procured and transferred (e.g. direct purchase, import from foreign country, and shipped to non-U of MN facilities, etc.)
- The type and approximate quantity of chemicals used in the department;
- The nature of the research and operations conducted in the department;
- Grant and funding applications and contracts.

**Step 3: Establish a TSCA compliance file**
TSCA is primarily an administrative, records-intensive program. TSCA files will be the first stop during an inspector’s visit. TSCA files should contain the following documents:
- TSCA Applicability Form
  * Lab Safety Plan documenting prudent practices
- Import certifications
- Export notifications
- Inter-facility shipping/transfer records
- Significant adverse effect log
- Substantial risk reports

**Step 4: Develop a process for ongoing review of TSCA applicability/compliance**
Ensure that a process is in-place to conduct ongoing applicability determination and documentation.

**Resources Available from Environmental Health and Safety**
1. TSCA Applicability Form
2. TSCA Transfer Document
3. TSCA Import Certification
4. TSCA Export Notification Chemical List
Toxic Substance Control Act - Import Certification Form

Chemical substances imported into the United States must be accompanied by a certification form indicating that the shipment is in compliance with the EPA’s Toxic Substance Control Act. The following chemical substances are being imported and sent to a laboratory researcher at the University of Minnesota, Minneapolis, MN. This shipment contains the following chemical substances:

<table>
<thead>
<tr>
<th>Chemical Name</th>
<th>Chemical Abstracts Services (CAS) Registry Number (if available)</th>
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The following certification can be made regarding this shipment (select one of the following two certifications).

- I certify that all chemical substances in this shipment comply with all applicable rules or orders under TSCA and that I am not offering a chemical substance for entry in violation of TSCA or any applicable rule or order under TSCA.

(Or)

- I certify that all chemicals in this shipment are not subject to TSCA.

(And, if applicable)

- The attached list of chemical substances will be used for research purposes only.

Please do not hesitate to contact me if you have questions concerning this import certification or require additional information concerning it. Thank you for your attention in this matter.

Name: __________________________________________ Date: ____________

Signature

Name: __________________________________________

Print

Address: _______________________________________

Title: __________________________________________

Phone: __________________________
Importation of chemical substances into the United States

All chemical substances imported directly into this country and used for research purposes must have a completed import certification accompanying it. The customs officer will look for this certification with the package's shipping papers and if it is not found will hold up the shipment or return it to the sender. Therefore it is essential for the appropriate certification statement to accompany imported materials.

In almost all cases this certification should be a "positive" certification statement worded as follows:

"I certify that all chemical substances in this shipment comply with all applicable rules or orders under TSCA and that I am not offering a chemical substance for entry in violation of TSCA or any applicable rule or order under TSCA."

It is also desirable to place the following words on the certification or the purchase order:

"This chemical substance will be used for research purposes only".

As long as you are using the imported chemical substance for research purposes and following the guidance in this document, the certification described above is applicable and factual.

For a small number of chemical substances imported into this country for research purposes a "negative" certification statement is appropriate (rather than a positive statement). The chemical substances that fall into this category include - pesticides, nuclear materials, food, food additives, drugs, cosmetics, or medical devices. The "negative" certification statement should be worded as follows:

"I certify that all chemicals in this shipment are not subject to TSCA".

A TSCA Import Certification Form should be completed and submitted with your purchase order to the foreign vendor. The vendor must be instructed to return the certification form with your shipment so the form will be available to the customs officer when it enters the country. A copy of this certification should be placed in your laboratory's TSCA record folder or binder as well.

If you are importing a chemical substance for a non-research purpose additional steps must be taken to comply with TSCA. Contact the DEHS to determine what is necessary.
Toxic Substance Control Act - Chemical Substance Transfer Form

Chemical substances imported or synthesized in the laboratory for which little or no health, safety or environmental information exists, must be accompanied by a Chemical Substance Transfer form and a Preliminary Health and Safety Information Sheet when hand carried or shipped to another laboratory. A copy of these forms must also be retained in the laboratory initiating the transfer. The following chemical substance(s) are being transferred to:

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<th>Chemical Name</th>
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These chemical substances have been imported into this country or have been synthesized in a US laboratory and little is known about the environmental, health or safety hazards associated with them. The attached Preliminary Health and Safety Information Sheet conveys whatever is known. The substance(s) listed are being provided to you with the understanding that they will be used solely for scientific experimentation, analysis, or research. Certain provision of the EPA Toxic Substance Control Act may apply to the handling of these materials. You should consult with your institution's environmental health and safety coordinator or staff to identify your institution's specific policies.

Please do not hesitate to contact me if you have questions concerning this material or require additional information concerning it.

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Transfer or shipment of newly synthesized or imported chemical substances for which limited environmental, health, or safety data exist.

The EPA requires that individuals that either import or synthesis chemical in their laboratories, or obtain them from other laboratories, maintain control over them and ensure that individuals that they distribute these substances to understand the known health, safety and environmental risks associated with the substance. Whenever transferring an imported chemical or a chemical synthesized in your laboratory (for which little or no environmental, health, or safety is available) the following procedures must be followed:

- Complete the Chemical Substance Transfer Form and Preliminary Health and Safety Information Sheet for the chemical substances to be transferred and provide both forms to the researcher receiving the substances.
- Maintain a copy of these documents in your laboratory's TSCA folder or binder.

When transferring chemical substances that have been imported or synthesized in your laboratory it is essential that the individual receiving the substance be informed that the substance can only be used for research purposes. Accompanying documents must convey whatever health, safety and environmental risks are known to be associated with the substance.

Exporting chemicals out of the United States

When certain chemical substances are exported or hand carried out of the United States, the EPA must be notified in writing. In some instances the notification is a "one time" notification and in other cases the EPA must be notified annually. If you are exporting or hand carrying a chemical to a foreign country, check the EPA Chemical Export Notification List (approximately 1,500 items) for which notification is required. This list can be found in a variety of formats and contains many common laboratory chemicals. If the chemical substance you are exporting is on the list a notification is necessary. Contact the DEHS for assistance in making the notification.

The Department of Transportation regulates the transport of chemicals and all packages of chemicals must be packed and labeled in accordance with their regulations prior to shipment. Contact the DEHS for assistance in packing the chemical substances you are shipping within or outside the United States.
Toxic Substance Control Act Applicability Form

First name: ______________________________________________

Last name: ______________________________________________

Department: ______________________________________________

Email: ________________________________________________

Work phone: ____________________________________________

Please check all statements that apply to your laboratory at the University of Minnesota Rochester and submit the form to your department’s Research Safety Officer. Your responses will be reviewed to determine if special provisions of the EPA TSCA Act may apply to your laboratory. Thanks for your assistance.

- I synthesize new chemical substances.
- I import (purchase) chemicals directly from vendors outside of the USA.
- I transfer or provide chemicals (which I previously directly imported into the US or synthesized in my lab) to other labs at U of MN and/or other US locations.
- I export (or hand carry) chemicals to locations outside of the USA (includes small quantities used in field research).
- I am not involved in any of the activities identified above.
TSCA U of MN

Do you make, import or use chemicals not listed on the TSCA inventory (new chemicals)?

Certify that TSCA is not applicable

NO

YES

Are the new chemicals used in your laboratory activities regulated by any of the following agencies or regulations?
- Food & Drug Administration (FDA)
- Nuclear Regulatory Commission (NRC)
- Bureau of Alcohol, Tobacco & Firearms (ATF)
- Federal Insecticide, Fungicide, & Rodenticide Act (FIFRA)

YES

NO

Do you import these new chemicals?

Certify that TSCA is not applicable

NO

YES

TSCA import regulations apply.

Are new chemicals used in your laboratory used in small quantities and solely for the purpose of non-commercial scientific experimentation, analysis or research?

YES

NO

Are new chemicals used by, or directly under the supervision of, a technically qualified individual?

YES

NO

Has laboratory established & documented Prudent Laboratory Practices for handling these new chemicals and for chemicals of unknown toxicity/hazard?

YES

NO

New chemicals qualify for the TSCA R&D exemption.

May not qualify for TSCA R&D Exemption. Contact DEHS at 6-6002

REQUIREMENTS FOR TSCA R&D EXEMPTION:
- Certify TSCA status of imported chemicals
- Document exports of chemicals
- Label and document all shipments of new chemicals with TSCA risk evaluation & communication
- Document allegations of adverse reactions to human health or environment
- Document and report discovery of substantial risk to human health or environment

Certify TSCA R&D Exemption

Certify TSCA import certification required. Contact DEHS at 6-6002
Appendix K

Audit Template Sample

Laboratory audit results for: xxx, Professor, Department of Research
Audit date: 3/21/07
Report date: 3/28/07
Auditor(s): Char P. Eyes

Please review this audit report with your laboratory staff and respond to Char P. Eyes within 30 days with follow-up on the action items (►).

Room xxx – Comments

✓ Fume hoods working, accessible and last checked 7/10/06.

► Researchers observed using the chemical fume hood with the sash fully open. To reduce chemical exposures, ensure all researchers lower the sash below shoulder height when working in the fume hood.

► Researchers observed using the chemical fume hood with several horizontal panels missing. To reduce chemical exposures, ensure all researchers leave no more than a 30” horizontal opening when working in the fume hood.

► Indicator light on fume hood 062 not working. Called in to Facilities Management by Char P. Eyes.

✓ Showers and eyewashes working and accessible. Equipment last checked by Facilities Management on 2/07.

► Shower accessible but clear chemicals away from eyewash activation handle.

► Unless the eyewash has no drain, users must test and flush eyewashes weekly. Keep a written log next to the eyewash with the date of testing and the initials of the tester.

✓ Fire extinguisher accessible and last checked by contractor 12/06.

✓ No food/beverage items observed in laboratory. Thank you for enforcing the no eating/drinking policy in U of MN laboratories.

► Food/beverage items observed in laboratory. Please enforce the ‘no eating/drinking’ policy in U of MN laboratories.

✓ Bench tops tidy.

✓ Emergency numbers posted by the telephone.

✓ Emergency exit unobstructed.

✓ Laboratory door to the hallway closed.

► Food fridge observed in laboratory. Either remove all chemicals from this room, or remove the food fridge. Thanks in advance for complying with the no eating/drinking policy in U of MN laboratories.

► Bench tops cluttered. To reduce potential for accidents, please tidy up.

► No telephone in laboratory
- Two bicycles observed in laboratory – aisle ways obstructed. To ensure unobstructed egress in the event of an emergency, and to comply with the U of MN’s Regents’ Traffic Ordinance, bicycles and other non-research related equipment are prohibited in laboratories. Please use bicycle racks outside the building.

- Laboratory door to the hallway open. To comply with fire codes, maintain security and air balance in the labs, please keep this door closed.

- Segregate incompatible chemicals:

- Four solvent stills located on the bench top. Still should be located inside a fume hood or replaced with purification columns.

- Chemicals stored alphabetically. To ensure incompatibles are segregated, group chemicals first by hazard class, and then alphabetize within the class.

- Flammable chemicals stored on open shelves above shoulder height. To reduce risk of breakage when moving containers, please move all hazardous chemicals into chemical storage cabinets, or at least onto shelves below shoulder height.

- Date all cans/bottles of ether, THF, dioxane, etc. when container is received, opened, and each time it is checked for peroxides. Consult the U of MN’s hazardous waste guidebook for appropriate peroxide test schedules (http://www.dehs.umn.edu/hwd/guidebook/guidebook5.html#peroxide)

- To reduce chemical exposures and the risk of fire/explosion, ensure that all pouring/refilling operations for flammable solvents are conducted inside a chemical fume hood. Grounding is also necessary.

- Segregate organic from inorganic acids

- Perchloric acid observed in laboratory. This chemical must be used only in a stainless steel fume hood equipped with a wash down system. Therefore, if this chemical is not currently being used, please manifest as hazardous waste.

- HF observed in __. Ensure antidote cream for HF (calcium gluconate gel – available from Boynton Health Service) is on hand and researchers are trained in proper response to HF exposures.

- Container not labeled. Ensure all containers are clearly labeled at all times.

- Crystals observed on cap of bottle in refrigerator. Inventory chemicals regularly, ensure bottles are clean and labels readable, and manifest old or unused chemicals as hazardous waste.

- Pare down storage of small bottles: inventory and manifest unneeded bottles through the hazardous waste system,

- Chemical freezer needs defrosting

- Liquid chemicals observed on upper shelves. Store concentrated liquid chemicals (solvents, etc.) below shoulder height, preferably in cabinets.

- Chemicals labeled, segregated and stored appropriately.

- Gas cylinders secured.

- Gases with a health hazard rating of 3 or 4 must be stored and used only in an exhausted system (fume hood or gas cabinet). Please remove the large ammonia cylinder from this laboratory.

- Gas cylinders not secured. Cylinders must be securely strapped or chained to a
1. Please use drilled caps to cover supply and waste chemicals for the HPLC system.

2. Source and waste chemicals for HPLC equipped with drilled caps.

3. Chemical wastes capped, labeled, and liquids equipped with secondary containment.

4. Two open bottles of hazardous waste observed. Please ensure all wastes are capped whenever not being filled.

5. Hazardous wastes too old (>90 days). Whether full or not, please complete packing forms for disposal.

6. Provide secondary containment for boxed hazardous waste. Trays are available from the stockroom.

7. ‘Name’ and ‘start date’ missing from some chemical labels. Please follow guidance in the U of MN’s Hazardous Waste Guidebook.

8. Hazardous waste labels smeared. Labels must be readable at all times. Protect with plastic?

9. Do not recap needles – dispose directly in sharps container.

10. Do not overstuff sharps containers – seal and dispose when ¾ full.

11. Put Pasteur pipettes in sharps container, not in broken glass bucket.

12. Belts/pulleys in good condition

13. Tubing secured tightly

14. Electrical cords and plugs in good condition

15. Cooling lines unsecured. To prevent floods, please secure tubing tightly.

16. Extension cords observed in laboratory. Please rearrange so equipment can be plugged directly into a socket. Advise Dawn Errede if additional sockets are required.

17. Guard on the pulley for the vacuum pump in the back room is missing. To prevent entanglements, please find and replace the guard.

18. Belt on vacuum pump in poor condition. Replace.

19. A cord to ___ was in poor condition. To reduce the chance for fire, please have this item repaired.

20. To reduce ignition sources within the fume hood and to promote quick and safe power disconnects in an emergency, please remove the power strip from fume hood 023. Power strips must be mounted only outside the hood.

21. The electrical outlets in this lab are not equipped with ground fault interrupters (GFIs). Please remind researchers to be very careful with any electrical equipment when working within six feet of a sink.
Appendix L  Lab Hibernation/Shut-down Template

Business As Usual Procedures

- Identify any critical equipment, research materials (chemical or biological), or processes that building monitors should be aware of such as freezers not on BSAC, temperature sensitive areas, etc.
- Prepare hibernation sign to be placed on door including lab staff contact information and above identified critical information. If no special monitoring is required indicate that on the sign.
- Verify that written lab SOPs include steps for shutting down critical equipment or processes including those that are temperature, pressure, or air sensitive – includes glove boxes and distillation equipment.
- Customize the following check list as needed for your lab – add additional procedures if needed

<table>
<thead>
<tr>
<th>Shut-down Procedures For Unoccupied Labs</th>
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<tbody>
<tr>
<td>- Shut down all experiments that need monitoring, are temperature or humidity sensitive, or could be affected by loss of electricity, water, or other services.</td>
</tr>
<tr>
<td>- Close sashes on chemical fume hoods.</td>
</tr>
<tr>
<td>- Ensure that all containers of chemical or radioactive materials and all hazardous waste containers are properly labeled, sealed, and placed in appropriate storage area.</td>
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<tr>
<td>- Ensure that water reactive chemicals are in sealed containers and stored in areas that are unlikely to become wet.</td>
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<tr>
<td>- Ensure that air reactive chemicals are properly stored.</td>
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<tr>
<td>- Ensure that all gas and vacuum valves are closed.</td>
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<tr>
<td>- Ensure that all water is turned off such as circulating water baths and water aspirators.</td>
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<tr>
<td>- Ensure that all gas tanks are secured. Close tanks and if possible remove regulators and place screw caps on tanks. NOTE: Leave inert gas flowing if it is being used to blanket reactive compounds.</td>
</tr>
<tr>
<td>- Secure all infectious material and toxins in appropriate storage units that are marked with a biohazard sticker or sign. Disinfect all potentially contaminated surfaces and properly dispose of all biohazard waste.</td>
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<tr>
<td>- Review storage of biologicals and other perishable items. Place valuable items in storage units that have backup systems or store items in duplicate locations. Review safety and other issues for the use of alternate cooling methods (e.g. liquid nitrogen, dry ice, etc.).</td>
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<tr>
<td>- Turn off biological safety cabinets and UV lights.</td>
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<tr>
<td>- If animals are used in the lab, either return animals to RAR or sacrifice animals.</td>
</tr>
<tr>
<td>- Turn off and unplug all non-essential electrical devices particularly heat-generating equipment such as hot plates, stir plates, and ovens.</td>
</tr>
<tr>
<td>- Back up all data and turn off computers. Store lab note books and computers in areas that will not be impacted by possible broken water pipes. Secure lap tops and other easy to remove electronic devices.</td>
</tr>
<tr>
<td>- If possible, elevate equipment, supplies, electrical wires, and chemicals off of the floor to protect against flooding from broken pipes.</td>
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<tr>
<td>- Ensure that all refrigerator, freezer and incubator doors are tightly closed.</td>
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<tr>
<td>- Close all doors, including cabinets, storage areas and offices. Lock all exterior lab doors.</td>
</tr>
<tr>
<td>- Post hibernation sign on door.</td>
</tr>
<tr>
<td>- Contact Environmental Health &amp; Safety, 626-6002, with any security or safety concerns.</td>
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# Hibernation Information

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<tr>
<th>P.I./Lab Supervisor:</th>
<th>Emergency Contact Info:</th>
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<tbody>
<tr>
<td>Lab Location:</td>
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<tr>
<td>Critical Equipment</td>
<td>Type of Monitoring Required</td>
</tr>
<tr>
<td>Critical Materials</td>
<td>Type of Monitoring Required</td>
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**Personal Protective Equipment or Special Procedures to Enter Lab**