The CNST NanoFab Safety Manual

Rev. 9/9/2013

The NIST Center for Nanoscale Science and Technology (CNST) is committed to making safety a core value in the NanoFab. We have established and implemented policies, procedures, training, and infrastructure designed to ensure the safe operation and use of the NanoFab by researchers ranging from nanofabrication novices to experts in the field. Our comprehensive NanoFab safety program includes:

- a detailed analysis of all hazards associated with every tool and process;
- multiple systems to mitigate and control all such hazards *before any work begins*;
- a multi-tiered safety training program;
- vigilant monitoring of all NanoFab laboratories and infrastructure, including daily inspections complemented by an extensive closed-circuit video system monitored at all times; and
- an annual facility safety inspection and assessment performed by an outside expert.

In addition to the NanoFab-wide safety activities, the safety of each proposed project is individually assessed by technical experts during the initial application review. Before working in the NanoFab, every user must complete NanoFab safety training and orientation and pass a safety exam, with annual retesting required to maintain access. A similar safety training and testing program is also required for contractors performing installation or repair work in the NanoFab.

Detailed guidance on working safely in the NanoFab can be found in the *CNST NanoFab Safety Manual*. This manual is intended as a reference and describes the rules and procedures required to work safely in the NanoFab. These rules and procedures apply equally to all users and staff, and the manual must be read and understood before beginning work in the NanoFab.

It is the responsibility of all users and staff to act in a professional, courteous, and safe manner at all times while working in the NanoFab. Anyone endangering the safety of themselves or others users will have their access privileges revoked.

Any comments or questions regarding the content of this manual should be directed to:
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1. Introduction

This safety manual was developed by the NIST Center for Nanoscale Science and Technology (CNST) for the users and staff members of the CNST NanoFab. The practices and policies contained within have been developed to be in compliance with all Federal Regulations and in accordance with OSHA Laboratory Standard, 29CFR 1910.1450, and NFPA 318, Protection of Semiconductor Fabrication Facilities. This document is a reference manual covering the basic operational policies for the safe use of the CNST NanoFab at NIST. It applies equally to all users and staff members, and governs both safety and laboratory rules. All users and staff members are expected to have read and understood these policies and procedures. This booklet, along with the mandatory safety training and written safety examination, is expected to be sufficient training and notification for the Right-to-Know regulations for Laboratory Workers. Laboratory workers are expected to have a technical level sufficient to understand everything in this booklet.

The CNST NanoFab laboratories are located at NIST in Building 215/Room D101, in the basement ("subfab") of building 215, and within the G corridor of building 216. The NanoFab is operated as a shared access facility with certified users from various levels of expertise from novice to expert. The NanoFab provides users with access to over 100, commercial-state-of-the-art tools and processes that contain a variety of hazards and that require training to operate safely. The hazards include various toxic gases and chemicals, which pose significant safety risks if handled incorrectly. This booklet documents acceptable operating procedures and conduct for use of the NanoFab laboratories. It is impossible, however, to define a policy for every conceivable situation. ***Rules and policies are no substitute for common sense***. Anyone who fails to act in a professional, safe, and responsible manner while in the NanoFab will be banned from further use of the facility at the discretion of the management.

Users' suggestions and feedback on the facility, its staff, its operation, and its equipment are welcome at all times. Please feel free to direct your suggestions to whomever you feel the most comfortable with.

2. General Lab Procedures

2.1 Access

Access to the NanoFab is only granted to certified users and NanoFab staff members who have completed the required safety training and NanoFab Orientation, and have passed the required **annual** Safety Certification Examination. The user will be granted access that will allow personal access at any time during operating hours. Use of the Facility is a privilege that can be revoked by the NanoFab Management at any time.

2.2 New User Orientation and Safety Training

NanoFab Orientation and safety training is required to gain access to any NanoFab laboratory. The orientation is typically conducted in groups of 10 or less, but can also be conducted on a scheduled individual basis. The training is done in three parts:

1. Laboratory safety training is done online and covers chemical handling, general laboratory safety, and best practices at https://asddev.nist.gov/CNST/index.cfm.
2. NanoFab Orientation is a staff-guided walking tour through the NanoFab pointing out need to know locations, safety devices, and specific NanoFab working procedures.
3. A written safety exam is required and can be taken anytime, but must be completed with a passing grade before an access badge can be obtained. Completing the examination is evidence that the user understands at least 95% of the information presented. This safety exam must be taken every year. If the exam is not completed with a passing grade or you do not take the exam, your existing access privileges will automatically be deactivated.

2.3 Cleanroom Locations (See Cleanroom layout, section 10)

- **Main Cleanroom Entrance (Bldg 215/rm.D101):** This area can be accessed by users, staff members, NIST Environmental Services, and authorized NIST Plant Personnel during normal operating conditions. The door is locked during outages, emergency procedures, and under abnormal conditions. **Do not bring chemicals, chemical waste, or other hazardous materials through the main entrance.**
- **Lockers Rooms:** The lockers and hangers are for regular users (at least one day per week). Non-frequent users, Visitors, and Students can occupy an empty locker on a daily basis, but will not receive an assigned locker unless it has been determined by the Management that a locker assignment is necessary. The locker is for your personal belongings, street clothes and shoes, coats, cell phones, valuables, wafer boxes, notes, etc. **Do not keep chemicals in lockers or in the gowning area**.
- **Gowning:** This area is a controlled environment and should only be accessed by certified users. Approved visitors can access this area when accompanied by a certified user, or a NanoFab staff member. Do not bring dirty or questionable items into this area. **Do not bring process chemicals through the gowning area, including fresh chemicals, chemical**

waste, or other hazardous materials. Use the approved chemical pass-through for transferring chemicals into the Cleanroom.

- **Cleanroom:** The Cleanroom areas can be accessed by a certified user, NanoFab staff member, Environmental Services, authorized Plant Personnel, and visitors (if authorized by the NanoFab Manager when accompanied by a certified user or NanoFab staff member). Frequent entry and exit is discouraged. The work conducted in the Cleanroom is performed with toxic gases, hazardous chemicals, and potentially dangerous equipment. Always be aware of those who are working around you. Move carefully throughout the Cleanroom so you do not disturb or interfere with work being conducted. Chemicals are periodically refreshed and are introduced into the Cleanroom by the users or NanoFab staff members. The chemicals for the Cleanroom are retrieved from the chemical storage areas (room D106) and properly transferred (see section 5.1 Chemical Handling) to the service chase(s) adjacent to the Cleanroom bay and placed into the appropriate chemical pass-through (acid or solvent).
- **Service areas:** These areas are identified by signs displaying **"Restricted Area NanoFab Staff Only"**. Users are not allowed to enter these areas unless specifically authorized by a member of the Cleanroom staff. Staff members and users are discouraged from entering the service areas from the Cleanroom unless absolutely necessary. Proper entry to the service areas is from the class 1000 hallway (use pre-gowning protocols). The service areas are hard to see from the Cleanroom and if a person is injured, it may be difficult for them to receive help. NanoFab staff members can access this area when needed. The areas under the raised floor can be accessed by NanoFab staff members and NIST physical plant personnel only. The service areas in the sub-fab can only be accessed by NanoFab staff members, and NIST plant personnel. The Liquid Nitrogen Area outside bldg. 215 can be accessed by NanoFab staff members, vendor delivery personnel, and plant personal only.

2.4 Non-Cleanroom Laboratories (See G-corridor and C02 layout, section 10)

- 216/G corridor: This area houses the advanced imaging equipment, e-beam lithography, and XRD metrology.
- 215/C02: This area houses the post processing equipment such as dicing, wire bond, die bond and CMP.

2.5 NanoFab Conduct

The NanoFab consists of several labs and a class 100 cleanroom where proper conduct and a professional attitude are required at all times. This facility is used NIST wide and many sensitive experiments with many hours of work are taking place on a regular basis. You must act in a manner that will not disrupt or disturb other researchers using the NanoFab. As a user of the NanoFab you are responsible for reporting any activities that deviate from normal behavior. The violator(s) may lose NanoFab privileges based on the discretion of the CNST management.

2.6 Hours of Operation

The normal hours of operation are 7:00 am to midnight, Monday through Friday. Usage outside of these operating hours must be authorized by the CNST NanoFab Manager (See section 4.4). Authorized users utilizing the Cleanroom outside of these operating hours must have authorization and comply with any and all responsibilities dictated by the NanoFab management.

2.7 Security Cameras

Security cameras are located throughout the Cleanroom and NanoFab laboratories and are monitored at all times by the CNST and/or the NIST Emergency Services Division. The system stores the prior 2 months of video.

2.8 User Communication

All users must supply the CNST NanoFab Management with a working email address that can be checked on a daily basis for messages relating to the NanoFab. Questions, comments, or suggestions about any safety issue, this manual, or other concern can be directed to any member of the NanoFab staff at any time.

2.9 NanoFab Governance and Appeals

The management of the CNST and NanoFab are responsible for its safe operation. Use of the NanoFab by any user is at the sole discretion of the management. On matters involving equipment usage or safety, every user must follow the direct instructions of the NanoFab staff. Both staff members and users are expected to act in a courteous and professional manner at all times. Deviations from this norm by either users or staff should be reported to the NanoFab Management immediately.

If at any time a user feels that he/she have been unfairly treated by a staff member or strongly disagree with the rules imposed by a staff member, please discuss the situation with the NanoFab Manager.

3. Equipment Use

3.1 Approved Users

Access to the NanoFab itself does not permit use of any particular instrument. The equipment in the laboratories may be used only by certified users who have also been specifically trained in its use and **approved by a member of the NanoFab Staff**. The equipment in the NanoFab is highly sophisticated and complex, and can be potentially hazardous or damaged if not used properly. Each instrument has operating instructions, restrictions, and safety rules in place to ensure the continued operation of the instrument, and proper use is strictly enforced. Failure to follow the operating procedures or rules can result in injury, damage to the equipment, and disruption of NanoFab operations. Consequently, careless or damaging use of any equipment will result in suspension of a users' privileges, either for a specific instrument or the NanoFab as a whole.

3.2 Equipment Operations

Operating procedures are presented to the user during equipment training and should be maintained by the user for future reference. Operating procedures and instructions manuals are available online at http://nanofab.cnst.nist.gov.

3.3 Equipment Problems

For the safety of the user, please report all equipment damage or malfunctions to a NanoFab staff member. **DO NOT TRY TO REPAIR THE PROBLEM YOURSELF**, this could result in injury, expensive damage, and/or extended downtime.

4. Laboratory Practices

4.1 Visitors

Visitors into the NanoFab laboratories must be authorized by the NanoFab management and escorted by a staff member or certified user. Visitors are not allowed, for any reason, to operate equipment, use chemicals, or to be left unattended. An authorized service contractor may be left unattended, but must first be authorized by the NanoFab Manager and trained by the NanoFab Safety Officer or a NanoFab staff member, and must be provided access to a contact person at all times.

4.2 User Storage

Do not store chemicals in user storage bins or lockers. All chemicals are to be stored in an approved area and the container must be labeled properly (see section 5.1).

4.3 Phones

There are phones throughout the NanoFab laboratories. Inside the Cleanroom there are 12 wall-mounted phones located near the main center hallway at the ends of the work bays. The other laboratories have phones near the lab entrance. The phones can be used for person-to-person communication, paging, and for emergencies. There are also wall mounted phones located outside of the Cleanroom at D101 and D108. All phones dial outside lines: dial 9 then the number. **For emergencies at NIST call x2222**. Personal cell phones are permitted but should be stowed safely and securely on your person.

Emergency calls: If an injury occurs, dial 2222 and provide the room number (located above the phones) and the type of injury to the emergency responder.

4.4 After-Hours Policy

The NanoFab is open Monday thru Friday from 7 am to 12 midnight. Technical staff members are available during these hours to assist active users and to respond to any safety issues that may arise.

In general, users need to schedule and conduct their work during normal operating hours in order to adhere to the NIST Laboratory Safety Policy.

Under special circumstances, the CNST NanoFab Facility Manager may allow a user to access the NanoFab during off hours on weekdays or on the weekends. Off hours access will be authorized by the CNST NanoFab Manager on a case-by-case basis for specific dates and times only.

Failure to comply with these policies for NanoFab use may result in the suspension of your NEMO account and the revocation of NanoFab access privileges.

1. **Authorization:** Users must receive prior authorization EACH time off hours lab access is needed. Authorization is approved by the CNST NanoFab Facility Manager only.

2. **Buddy system:** Any user wishing to access the Cleanroom off hours must be accompanied by another researcher who is also a facility user. Both users must be signed in.

4.5 NanoFab Shutdown

NanoFab shutdowns are regularly scheduled events and may also occur in the event of a storm, building faults, emergency, *etc*. A NanoFab staff member is responsible for containing the process gases, and properly shutting down the power to predetermined areas of the NanoFab laboratories to minimize the risk of fire or equipment damage. During a shutdown, all NanoFab laboratories will be locked and no access will be granted for any reason.

4.6 Safety Glasses/Contact Lenses

The entry PPE requirements are noted on the red border hazard door signs located at the entrance to all NanoFab labs. Safety Glasses are required at all times when working in the Cleanroom and 215/G101. There are safety glasses available to all users in the locker room. Each user can keep them in his/her storage space, but they must be returned when the user no longer intends to use the NanoFab. Visitors are required to wear safety glasses. The safety of wearing contact lenses in laboratories has been a subject of discussion for many years. The American Chemical Society has approved the wearing of contact lenses for laboratory workers, and they are permitted in the NanoFab Cleanroom, but are not a substitute for safety glasses. A second pair of contact lenses or a pair of prescription eyeglasses is recommended as a backup.

4.7 NanoFab Alarms/ Evacuation

There are numerous alarms in the NanoFab laboratories. The user must be able to identify each alarm quickly, and act accordingly. If someone cannot identify an alarm, he/she shall leave the lab immediately through the nearest exit and notify a NanoFab staff member.

Types of Alarms:

- **End of Cycle Alarm:** Some alarms signify the end of cycle on some instruments; these are usually not very loud, and may be recognized by a repetitious beep.
- **Exhaust Failure Alarm:** Only activated in the main control room. The individual NanoFab tools themselves will alarm when the tool senses loss of exhaust. Contact a NanoFab staff member.
- **Shelter In Place Alarm:** A shelter-in-place alarm is similar to a fire alarm with verbal instructions indicating it is a shelter-in -place alarm. If a shelter in place alarm occurs, proceed to the nearest shelter in place location. In the Cleanroom, shelter in place is in the men's or women's locker room. In the 216 G-corridor, shelter in place in the service galley SG-4-1 behind the labs.
- **Fire Alarms:** These are located throughout the NanoFab laboratories. They can be recognized by a flashing strobe and horn. Some of these devices provide verbal instructions, but occupants are required to leave the lab immediately — *do not stop to remove one's gown if inside the Cleanroom*. After evacuating the building,

assemble outside in the small parking lot on South Drive across the street from the Cleanroom building (215), (Occupants may be directed to an alternate location by a EMS responder or NanoFab Staff member). *Everyone is also required to leave the lab in the event that the fire alarm was sounded for a practice drill.*

- **Toxic Gas Detector Alarms:** These are identified by a loud repeating beep with the activation of the yellow flashing evacuation strobe, located in building 215 only. Please evacuate the lab immediately.
- **Power Disruption/Power Loss, HVAC Failure, Chemical Exhaust Failure:** Only activated in the main control room. The individual tools themselves will alarm when the tool senses loss of exhaust. Contact a NanoFab staff member.

Emergency Evacuation Procedure:

1. Do not stop to remove your gown if you are in the Cleanroom.
2. Contain any hazardous work in progress if possible.
3. Leave the lab through the nearest exit.
4. Avoid heading towards the Oxidation/Diffusion Furnace room (B106). This area has many of the hazardous gases being used.
5. Assemble outside in the small parking lot on South Drive across the street from the building.

4.8 Injured Person Retrieval

A person injured in the lab may require immediate attention. It may be required that safety personnel enter the Cleanroom without following the Cleanroom protocols. They are trained to retrieve or treat the person on the spot if it is required to do so.

5. Chemical Safety

5.1 Handling, Labeling and Record Keeping

Handling chemicals in the NanoFab laboratories is a common practice. Chemicals are retrieved from the chemical storage area (215/D106) and are introduced into the Cleanroom via an airlock or pass-through.

- **Transport:** Use bottle carriers when transporting bottles, *especially* glass bottles. Use the chemical cart if transporting multiple bottles. Do not transport chemicals that are incompatible with one another. Never transport acids with solvents or bases. Acids produce heat from an exothermic reaction and can ignite solvents. Acids that mix with strong bases produce violent reactions that can cause the chemicals to suddenly splash onto the user.

- **Chemical Deliveries/Receiving:** Chemicals are delivered to bldg 215, room D108. NanoFab staff members who are authorized Cispro Power Users will retrieve the chemicals, enter them into the chemical inventory database (Cispro), put a barcode sticker on the container, wipe them down, and place them into the appropriate chemical storage closets. All chemicals must be handled with chemical resistant gloves and eye protection. It is a best practice to wash hands after handling chemicals and chemical containers.

- **Pouring:** Move slowly, and hold the bottle with two hands. One hand should be firmly around the neck and the other hand should support the bottom of the bottle.

- **Labeling:** Federal regulations require all hazardous chemical containers to be properly labeled according to OHSA 1910.1200 Hazard Communication. This regulation states that the chemical hazard information for all materials must be transmitted to the end user and anyone who may be in contact with the material at anytime. Chemical bottles without the proper manufacturer hazard labels on them will require the user to fill out a complete hazard label for that material (most chemical bottles used in the Cleanroom are commercial products with proper labeling).

  For temporary containers used for processing (Petri dished, beakers, flasks, etc.) one can use the pre-printed plastic chemical ID labels in front of or near the containers for quick identification of the product by staff members or other users. If there is a unique hazard associated with the material such as incompatibility or other specific safety concern, this hazard must be identified on the ID label. For short term use (while performing an experiment or process; not for storage), one may also write the chemical hazard and contact information on a Cleanroom wipe or Cleanroom post-it and locate it in front of or near the container. ***NO CHEMICALS INCLUDING WATER SHALL BE USED IN THE NANOFAB WITHOUT PROPER HAZARD ID LABELING***.

- **Record Keeping:** All hazardous materials used or stored in the NanoFab are entered into a NIST-wide inventory software database system called Cispro. This system is accessible

by users, staff members, and emergency responders. It lists the materials by name and hazard according to the NFPA 704.

5.2 Personal Protective Equipment

Proper Personal Protective Equipment (PPE) is mandatory when using chemicals. In addition, special protective equipment is required for NanoFab staff members performing toxic gas bottle changes. Some chemicals and toxic gases require specialized PPE training, and this equipment cannot be used without proper training (i.e. SCBA, respirators, etc). The protective equipment used in the Cleanroom is listed below:

- Acid Aprons
- Nitrile examination gloves (provide minimal chemical protection; are primarily used to control human particulate contamination in the Cleanroom)
- Protective chemical armbands
- High-wrist tripolymer or nitrile gloves
- Face shield and safety glasses
- Self Contained Breathing Apparatus (SCBA-training and certification required every two years)
- Corrosive Protection Suit (Emergency Responders)

PPE Requirements:

- Acids or Bases:
  - Thick Tripolymer-Blend Gloves over Cleanroom gloves
  - Chemical apron
  - Protective Arm Sleeves
  - Face shield and sash fixed in lower position
- Solvents:
  - Thin Tripolymer-Blend Gloves over Cleanroom gloves
  - Chemical apron
  - Face shield or Sash fixed in lower position
- TMAH:
  - Protective Arm Sleeves
  - Thick Tripolymer-Blend Gloves over Cleanroom gloves
  - Chemical apron
  - Face shield or Sash fixed in lower position

PPE Certification and testing:

- *SCBA Equipment*: This equipment must be cleaned and tested every six months. This is coordinated by the NanoFab Staff who are using SCBA equipment, with NIST Fire Protection Group. This is conducted every six months to ensure the operability of the equipment.

PPE Training:

For PPE to be effective, proper use is essential, as described by the following procedures:

- *Chemical Protective Apparel*
  - Adjustable face shield: This shield is used with safety glasses. It can be adjusted to fit most head sizes. There are adjustment knobs on the straps that can be used to tighten the apparatus around the head. There are other adjustment knobs that can be used to make the face shield snug and secure. Do not use the face shield if the adjustments are too loose, it may fall off the head or obscure one's vision.
  - Chemical Gloves: Choose gloves that fit over the protective glove, which are not too loose or too tight. A glove that is too loose will not provide the required dexterity needed to use the chemical process equipment (e.g., timer buttons, tweezers, wet bench controls, etc.).
  - Toxic Gas Safety Equipment
    - **SCBA:** This equipment can only be used by trained individuals who have completed the required medical exam, and have passed fit testing and training. The certification for SCBA equipment is good for one or two years depending on the medical evaluation. The user of this equipment is required to receive ***annual training*** on Compressed Gas Safety and bottle change-outs from a certified outfit (NFPA 318) before the equipment can be used to conduct their work. The medical exam and the fit-testing can be arranged by the NanoFab Manager or by the staff member. This is conducted on the NIST Gaithersburg Campus. Contact OSHE at x5375, option 3.
    - **Toxic Gas Bottle Training:**
      - The supervisor will keep a record of a staff member's required training and maintain the schedule the staff member will be required to repeat the training.
      - The Supervisor will maintain a list of technicians performing this duty.
      - As per NFPA 318 Chapter 8, section 8.8.1 *Operators working with hazardous gases and handling hazardous compressed and liquefied gas containers shall be trained for that function.* section 8.8.2 *Training shall be provided annually.*
      - Medical evaluations, fit testing, and training for the SCBA equipment use is required every two years and the staff member who completes the medical and fit testing will be issued a certificate from the Health Unit; this certificate must be kept on record by the supervisor. The schedule for the medical and fit test must be supported by the supervisor.
      - Note the date, location, and source of the training. If a quiz or certificate was available, print it out and attach it to the Supplemental Training form.

- Sign the certification of training at the bottom of the page.
- Have your supervisor initial each line after training is completed.
- Save a copy and return the original to the Center Office.

5.3 Chemical Spills

Spill response procedures are provided in the NIST Gaithersburg Occupant Emergency Plan. These procedures apply to all chemical spills and oil spills that occur at the Gaithersburg site. Please keep the following points in mind should a spill occur:

- If a spill is found and the source is unknown:
  - Immediately clear the area and call the Fire Protection Group at x2222.
  - Report the location of the spill, name, phone number, and any relevant information about the spill and access to the spill site. Stay on the line until the dispatcher has the information needed.

If one knows the source of the spill, and is familiar with the hazards of the spilled material:

- First ensure that everyone in the area is safe.
- If it is safe to do so, remove all ignition sources.
- If one has the training and equipment, attempt to contain the spill.
- Call the Fire Protection Group x2222 and report the spill. Even if emergency response assistance is not needed, report the spill to the Fire Protection Group. The Fire Protection Group, in coordination with the Safety, Health, and Environment Division, must review each spill to ensure that it has been addressed properly. The spill clean-up materials must be properly disposed as chemical waste and the location of the spill must be cleared for occupancy.

Questions regarding spill response should be directed to the Safety, Health, and Environment Division at x5822 or x5818.

5.4 Eyewash Stations and Showers

The proper use of an eye wash station requires the user to activate the eyewash, and using the thumb and fingers, hold open the eyes, and rinse for several minutes. The user or buddy must call NIST Emergency Services at **x2222**. There are eyewash stations and showers available in the Cleanroom and the locations are listed below.

- **Eyewash stations**
  - At the ends of the chemical wet benches
  - In the class 1000 corridors immediately outside the Cleanroom proper.
- **Safety Showers**
  - In the class 1000 corridors immediately outside the Cleanroom proper.

5.5 Material Safety Data Sheets (MSDS)

Material Safety Data information is provided in hard copy format, and is located in the main entrance in 215/D101. One can also find up-to-date MSDS information on the internet at the

ChemWatch website ChemWatch Search Page or by searching the following keywords: *MSDS, Material Safety Data Sheets, chemical name or on the chemical manufacturer website*. This data provides information about a particular chemical such as its hazards, storage procedures, first aid, long-term exposure, etc. There are many online sites that provide this information for free. Chemical vendors are required to provide MSDS information when purchasing chemicals. The NIST emergency response team has this information available electronically and they have access to the NIST-wide chemical inventory through the CisPro database information online.

5.6 Approval

New chemicals that enter the Cleanroom must be authorized by the NanoFab Management and must be accompanied by their MSDS information. This requirement is intended to ensure safety and compatibility with all current chemicals and processes.

5.7 HF Safety

Hydrofluoric acid (HF) is an extremely dangerous chemical. Because it is commonly used in the Cleanroom in various concentrations, *a user may become exposed to HF even if he or she does not use it*. Therefore every user must be aware of HF safety procedures. The areas where HF is used and stored are well identified by HF Acid danger signs. Stay alert and work carefully in these areas of the Cleanroom. If one is exposed to HF follow the procedures listed below.

1. Remove contaminated clothing and/or rinse with copious amounts of water.
   - Use the sink, eyewash or safety shower.
2. Apply 2.5 % Calcium Gluconate (Calgonate) topical gel, and massage into the affected area.
   - Located at each HF processing bench
   - Additional tubes located in the refrigerators in Photobays 1 and 2.
3. Call x2222 to report the incident.
4. Fill out an incident report. (See Section 11 in this manual).

5.8 Chemical Storage

Chemicals are to be stored in the properly designated areas; see the Cleanroom layout in section 10 of this manual for the location of the chemical storage areas. Use chemicals in an approved fume hood. The Cleanroom has separate chemical fume hoods for solvents, bases/oxidizers, and acids, and the hoods are labeled accordingly. Do not store incompatible substances next to each other. If a user does not know what chemicals are incompatible, he or she must contact a Cleanroom staff member before proceeding. Never store a solvent next to an acid, because acids produce heat from an exothermic reaction. Never store chemicals in your locker. Always use secondary containment in cabinets, shelves, and other storage areas to prevent mixing of leaking or spilled containers. *When storing chemical bottles on shelves, NIST Safety protocols state they can be no higher than shoulder to eye height. As per the Cleanroom building design, the chemical shelves located in the user areas of the Cleanroom (Bays A101-A106 and Bays B101-B106) are permanently installed at 1536 mm (60.5 inches). Based on this requirment and the bulk chemical cabinet storage design, the safe chemical shelf height has been clearly defined for*

the CNST Cleanroom to be no higher than 1536 mm (60.5 inches) in all user areas and no higher than 65 inches in the bulk chemical storage area located in room 215/D106 (outside of the research Cleanroom proper).

5.9 Pregnancy

Users who may be pregnant are not restricted from using the NanoFab, but may want to discuss the situation with their personal physician or with the NIST Health Unit Physician. Some chemicals such as solvents and materials such as photoresist can be harmful to an unborn fetus.

5.10 Chemical Waste, Disposal and Neutralization/Waste Satellite Accumulation Area (SAA)

Some chemical waste generated in the Cleanroom must be stored in a properly labeled container (see appendix for proper labeling) and placed in the designated storage areas under the fume hoods and or in the labeled pass-throughs. Contact a Cleanroom staff member when the waste storage areas are full so the waste may be properly disposed of. The chemical waste bottle(s) will be placed in compatible chemical cabinets at the Waste Satellite Accumulation Area in the disposal/receiving room 215/D107. The Cleanroom staff will fill out an electronic Waste Pickup Request Form to have the waste chemicals retrieved for disposal.

Chemical Waste Neutralization:

Scope: This section describes the guidelines, procedures, and controls governing the disposal of allowable liquid chemical waste in the NanoFab Cleanroom. *THE PROCEDURES DESCRIBED IN THE SECTION **DO** **NOT** APPLY TO ANY OTHER NIST FACILITY OTHER THAN THE CNST NANOFAB CLEANROOM, WHICH IS SPECIALLY EQUIPED TO HANDLE SUCH WASTE.*

Most acid and base aqueous solutions can be safely disposed of by one of the following methods: carefully pouring them into the chemical fume hood sink drains; manually opening the drains on the tanks on the wet benches; or by aspiration where they would then be treated at the neutralizer in the SubFab prior to release. See the chemical waste information charts in this section of this manual for a detailed list of chemicals allowed for neutralization. ***Solvents such as but not limited to methanol and acetone should never be poured down the acid fume hood sink drain. Solvent fume hoods have a waste funnel installed to dispose of all non-chlorinated solvents. TMAH waste must be collected — never pour TMAH down acid drains or waste funnels.*** If you are not ***absolutely*** sure what chemical waste can be safely neutralized, contact a NanoFab staff member. The neutralizer at the CNST NanoFab is supported 24/7 by the NIST Plant Services in order to prevent depletion of the effluent treatment material and to provide continuous monitoring of the pH levels. The neutralization system is alarmed, and the Power Plant at NIST will receive the alarm 24/7 in the event of system failure or trouble. All drains in the NanoFab Cleanroom used for neutralization are labeled for this use.

Disposing of acids and bases by pouring them down the lab drains and using the neutralizer system minimizes the risk to personnel introduced by over-handling of the chemical waste.

Instructions for pouring allowed chemical waste into the acid drains for neutralization:

- Always wear the proper PPE:

1. Chemical apron;
2. Tripolymer high-wrist chemical gloves; and
3. Safety glasses and face shield.

- Run the sink water to provide a small amount of water supply to aid in draining.
- Do not release volumes greater than 750 ml at one time.
- Do not pour acids and bases down the acid drain at the same time.
- **NEVER POUR SOLVENTS DOWN THE ACID DRAIN!!!**
- Keeping the container as low as possible in the sink, slowly pour the material down the drain.
- Run the water in the sink for 2 min to 3 min after dumping to clear the drain trap.
- Rinse labware and place onto dirty dishware cart.

Wet Bench Heated Baths:

Users may aspirate acid baths as needed.

Training:

All NanoFab users must be trained by a NanoFab staff member prior to releasing any approved material into the waste disposal neutralizer drains. Contact the NanoFab Manager or a NanoFab staff member for specific details about this training.

Solid Waste:

Dispose of solvent saturated wipes in the red solvent waste containers located in the solvent hoods. Rinse acid/base saturated wipes and discard in regular trash cans.

Chemical Waste Disposal Information Chart

Chemicals	Contents	Category	Disposal
Acetic acid solutions	$C_2H_4O_2$	Other Chemical Solutions	**Collect**
SECCO ETCHANT	HF, CHROMIC ACID	Other Chemical Solutions	**Collect**
Succinic acid	butanedioic acid; historically known as spirit of amber) is a dicarboxylic acid	Other Chemical Solutions	**Collect**
Chromium etchant type 1020	Ceric Ammonium Nitrate, Nitric	Other Chemical Solutions	**Collect**
TMAH solutions	Tetramethylammonium hydroxide solution (25%)	TMAH Solutions	**Collect**
Gold etchant type TFA (KI etch)	Iodine Complex, Potassium Iodide	Potassium Iodide Solutions	Neutralizer Drain
Silver etchant type TFS	Iodine Complex, Potassium Iodide	Potassium Iodide Solutions	Neutralizer Drain
Hydrochloric acid	HCL	Hydrochloric Acid Solutions	Neutralizer Drain
Hydrofluoric acid	HF (49%)	Hydrofluoric acid Solutions	Neutralizer Drain
Buffered Oxide etches	HF and ammonium fluoride	Hydrofluoric acid Solutions	Neutralizer Drain
Hydrogen peroxide	H_2O_2	Hydrogen peroxide Solutions	Neutralizer Drain
Nitric acid solutions	HNO_3	Nitric acid Solutions	Neutralizer Drain
Ammonium fluoride	NH_4F	Other Chemical Solutions	Neutralizer Drain
APS copper etchant 100	Ammonium Persulfate	Other Chemical Solutions	Neutralizer Drain
Ammonium Hydroxide solutions	NH4OH	Ammonium Hydroxide Solutions	Neutralizer Drain
Citric acid solutions	$C_6H_8O_7$	Other Chemical Solutions	Neutralizer Drain
Copper etchant type CE100	Ferric Chloride, Hydrogen Chloride	Other Chemical Solutions	Neutralizer Drain
Hydrobromic acid	HBr	Other Chemical Solutions	Neutralizer Drain
Silicic acid solutions	$SiO_x(OH)_{4-2x}$	Other Chemical Solutions	Neutralizer Drain
Tin etchant TE-100	Ferric Chloride, Hydrogen Chloride	Other Chemical Solutions	Neutralizer Drain
Aluminum etch 16-1-1-2	80% PHOSPHORIC ACID, Nitric, Acetic	Phosphoric acid Solutions	Neutralizer Drain
Aluminum etchant type A	80% PHOSPHORIC ACID, Nitric, Acetic	Phosphoric acid Solutions	Neutralizer Drain
Aluminum etchant type D	Phosphoric Acid, Sodium-M-Nitrobenzene Sulfonate, acetic	Phosphoric acid Solutions	Neutralizer Drain
PAE Etchant (Phosphoric Acid Etch)	PHOSPHORIC ACID	Phosphoric acid Solutions	Neutralizer Drain
Phosphoric acid	H_3PO_4	Phosphoric acid Solutions	Neutralizer Drain
Potassium Hydroxide solutions etch	KOH	Potassium Hydroxide Solutions	Neutralizer Drain
GE8148- gold etchant	Iodine Complex, Potassium Iodide, Ammonium Phosphate Dibasic	Potassium Iodide Solutions	Neutralizer Drain
Sulfuric acid solutions	H_2SO_4	Sulfuric acid Solutions	Neutralizer Drain
Non-Chlorinated Solvents	All	Non-Chlorinated Solvents	Solvent Waste Funnel
Chlorinated Solvents	All	Chlorinated Solvents	Collect

5.11 Pyrophoric Liquid and Organometallic Safety

A **Pyrophoric** material can spontaneously ignite in air. Many pyrophoric materials are also water reactive, reacting vigorously with water or high humidity, often igniting upon contact. The utmost care must be given to these products during receiving, storing, and use. This chapter highlights the safety issues related to the use of pyrophoric materials.

Examples of pyrophoric materials include organometallic reagents such as alkyllithiums, alkylzincs, alkylmagnesiums (Grignards), and some finely divided metal powders. Specific examples include diborane (B_2H_6), diethylzinc ($Zn(CH_2CH_3)_2$), *tert*-butyl lithium ($LiC(CH_3)_3$), and diphosphine (P_2H_4). (See attached Hazard Summary Table on page 17).

These highly reactive substances are quite useful in the synthesis of organic chemicals, but special training is required to store and handle these materials safely. Most typically, pyrophoric materials are manipulated in an inert (nonreactive) atmosphere of nitrogen or argon using specialized glassware.

Fires involving pyrophoric materials generally require a Class D fire extinguisher. CNST is equipped with sodium chloride powder extinguishers. Be absolutely sure the proper extinguisher is available before attempting to handle any pyrophoric material. For example, using a carbon dioxide extinguisher on an alkylmagnesium fire would actually cause the fire to burn **more** intensely!

Hazard Risk Assessment for Pyrophoric and Organometallic Materials:

- Major hazard of using pyrophoric and organometallic materials is fire or explosion; which can be spontaneous.
- The materials are typically toxic, with an NFPA 704 health rating of 3.
- Most of organometallic materials are corrosive and extremely water reactive.

General Handling Procedures for Pyrophoric and Organometallic Materials: Pyrophoric materials should only be used or handled by those with explicit training in their hazards, properties and use.

- Before working with pyrophoric materials, be sure to remove all unused equipment and flammable materials from the area (including waste containers, solvent squirt bottles, etc.)
- Ensure that a Class D extinguisher is immediately available. These are located in the class 1000 hallway surrounding the Cleanroom bays and in the service chase next to bay A106.
- Never work alone with pyrophoric materials.
- Always use proper personal protective equipment (PPE), including safety goggles, face shields, inert glove box, aluminized lab coats, and aprons. The use of Nomex® pilot's gloves is recommended for the handling of pyrophoric materials; these are manufactured by Sperian (Bacou Dalloz) and are sold commercially through several vendors. These are not fireproof, but are a good compromise between dexterity and (limited) flame resistance.

- In addition, when using pyrophoric materials, know the location of the nearest safety shower(s) and emergency telephone.
- Such operations should be carried out in an inert atmosphere glove box or fume hood.
- Again, ***never work with pyrophoric materials alone***.

Additional Information

- http://tis.eh.doe.gov/techstds/standard/hdbk1081/hbk1081.html at the U.S. Department of Energy (DOE). Lots of info on individual flammable and pyrophoric metals.

Aldrich Chemical offers some technical data sheets which are useful for those working with pyrophoric materials. The following are in PDF format:

- Aldrich Technical Bulletin AL-134, Handling Air-Sensitive Reagents
- Aldrich Technical Bulletin AL-164, Handling Pyrophoric Reagents

In addition, the American Chemical Society's, Division of Chemical Health and Safety (DCHAS) has made available a very useful paper, *Safe Handling of Organolithium Compounds in The Laboratory*. This article discusses proper techniques as well as recent non-pyrophoric alternatives to traditional reagents such as *n*-butyllithium.

Atomic Layer Deposition Precursor Chemical Hazard Summary Table

ALD Precursor Safety Information Spreadsheet							
Chemical Name	*Trimethylaluminum*	*Titanium Isoproproxide*	*Titanium Tetrachloride*	*tert-Butylimino-tris(diethylamino) tantalum*	*Pentakis (dimethylamino) tantalum*	*Bis(tert-Butylamino) silane*	*Tetrakis (ethylmethylamino) hafnium*
MSDS Name	TMA	TIPO	TiCl4	TBTDET	PDMAT	BTBAS	TEMAH
NFPA Hazard Ratings	**H=3, F=4, R=3** Special=~~W~~	**H=2, F=3, R=0**	**H=3, F=0, R=2** Special=4 (PPE) extreme corrosive	**H=3, F=3, R=2** Special=~~W~~	**H=3, F=1, R=1** Special=~~W~~	**H=3, F=3, R=2** Special=~~W~~	**H=3, F=2, R=2** Special=~~W~~
Chemical Family	Aluminum alkyls			Metal amide complex	Metal amide complex	Organosilane	Metal amide complex
Pyrophoric	yes	no	no	no	no	no	no
Water Reactive	yes, violently	yes, slightly	yes	yes	yes	yes, violently	yes
Flammable	yes, extremely	yes	no	yes	low	yes, highly	yes
Extinguishing Media	Dry powder, vermiculite, soda ash, dry sand, or lime.	Dry chemical, CO_2, water spray, or alcohol resistant foam	Non-flammable	CO_2, dry chemical or foam	CO_2, dry chemical, or foam	CO_2, dry chemical or foam	Dry chemical powder
Corrosive	yes	no	yes	yes	yes	yes	yes
Handling/Storage	Under inert atmosphere in N_2 or Ar containing less than 10 ppm O_2, within a glove box. Avoid static discharge. During sampling, disconnecting lines or opening connections, an aluminized suit should be worn.	Keep away from heat, sparks, and flame. Store in flammables cabinet.	Store in a corrosive safety cabinet away from alkalis, metals and moisture.	Under inert atmosphere in N_2 or Ar. Store and use in a closed system or glove box.	Under inert atmosphere in N_2 or Ar. Store and use in a closed system or glove box.	Under inert atmosphere in N_2 or Ar. Store and use in a closed system or glove box.	Keep away from acids, alcohol, oxidizing agents, flammables, and strong bases. Store in dry area under inert atmosphere and away from direct sunlight.
Personal Protective Equipment (PPE)	Use in dry glove box, suitable gloves, safety glasses, aluminized suit, ventilation and/or respirator.	Safety glasses, protective gloves, good ventilation or respirator.	Gloves, Face Shield, good ventilation or respirator.	Use in glove box, rubber gloves, safety glasses.	Use in glove box, rubber gloves, safety glasses.	Use in glove box, rubber gloves, safety glasses.	Use in glove box, rubber gloves, safety glasses.
Incompatible Materials (materials to avoid)	Air, water, moisture and oxidizers.	Oxidizing agents, anhydrous hydrazine, moisture.	Alkalis, moisture and highly reactive with metals.	Water, moisture, air and oxidizers, acids, alcohol and other solvents, strong bases.	Water, alcohols, acids, halogens or strong oxidizers.	Water, alcohols, acids, halogens or strong oxidizers.	Water, air, alcohol, acids, strong bases

5.12 Piranha Solution

Piranha solutions are strong oxidizers used to remove organic residues from substrates. As such, piranha solutions are extremely corrosive, reactive, and potentially explosive. Most commonly used is the acid piranha, typically a 3:1 mixture of sulfuric acid (H_2SO_4) and hydrogen peroxide (H_2O_2).

Exposure Controls: All work involving piranha solution must be done inside a chemical fume hood to prevent inhalation exposures. Use signage in the fume hoods such as *"Caution, Piranha solution in fume hood, highly energetic and corrosive"*, to warn users of this hazard. Wear proper laboratory attire (pants and closed-toe shoes required under Cleanroom gown), neoprene or rubber gloves, neoprene apron, safety goggles, and a face shield.

Safe Handling:

- Consult with the NanoFab Manager prior to initial use of piranha solutions. Consultation should include discussion regarding special hazards and required safety precautions.
- Only use glass or Pyrex or poly-lined (recommended) containers; Because of the high temperature exothermic reaction, piranha solutions are not compatible with most plastics.
- **Piranha solution is very energetic and reactive:**
  - When preparing acid piranha solution the peroxide concentration must be kept below 50 %, ***so the peroxide should always be added slowly to the acid***.
  - Mix/ prepare small batches (a few millimeters to less than 750 milliliters) of fresh solutions for each application. Do not store solution for reuse.
  - Handle with care — the solution may reach up to 100 C.
- **To prevent potential explosion:**
  - ***Ensure the H_2O_2 concentration remains below 50 %.*** Concentrations greater than 50 % are potentially explosive.
  - Avoid mixing with incompatible materials such as acids, bases, or organic solvents (acetone, isopropyl alcohol, etc.)
  - Ensure all substrates are rinsed and dried before placing them in a piranha solution.
  - Avoid using airtight containers.

Waste Storage and Disposal:

- After use, cool down the solution in an open container inside a labeled fume hood. The solution should be cooled down to room temperature prior to waste neutralization.
- Do not store waste piranha solution in airtight containers; over-pressurization (explosion) can occur.

- After the solution has cooled to room temperature it can be carefully poured down the sink drain in the fume hood to be neutralized and treated. See section 5.10 in this manual for the proper procedure for disposing of waste Piranha solutions.

Emergency Procedures:

- **Eye/ Skin Contact:** Flush contamination from eyes/skin using the nearest emergency eyewash or safety/shower for a minimum of 15 min. If one eye is affected, be careful not to flush contaminated water into the other eye.
- Remove any contaminated clothing.
- If medical attention is required, immediately call x2222 from any NIST phone.
- Notify the exposed person's supervisor or NIST host as soon as possible.
- **Spills:** Notify personnel in the area and call x2222. Restrict access and eliminate all sources of ignition.
- ***Small spills*** (<30 ml) may be absorbed with wet paper towels. Keep towels wet and collect for disposal. Contact a NanoFab staff member for assistance.
- ***Large spills:*** Immediately call x2222 to report a piranha solution spill that is health threatening, or is greater than 30 ml.

5.13 Chemicals and Gases Used at the NIST CNST Cleanroom

The chemical Inventory is listed in **NanoFab_Cleanroom_Chemical_Inventory** file (available from inside NIST only). The dangers of each chemical are summarized in the file, and can be found in the MSDS books located in the main entrance of the Cleanroom.

6. Gas Safety (See section 11 for NIST Compressed Gas Safety Information)

This section contains information on safety of gasses used in the NanoFab; however note that gas cylinder operations are to be performed exclusively by NanoFab staff members.

6.1 Compressed Gas Delivery Emergency Response Program

This program is in place in case of a catastrophic release of any HPM (Hazardous Process Materials) upon delivery. This program is the responsibility of the NIST Fire Protection Group. If there is a compressed gas delivery accidental gas release, leave the local area and contact **x2222** (HAZMAT) to report the incident and location.

6.2 Hazardous and Non-Hazardous Gases Used

The following compressed gases are used in the Cleanroom:

Gas	Assay	Hazard	Usage point	Location	Gas Source Location
100% Silane	SiH_4	Unpredictable, burns in moist air. Toxic.	LPCVD, PECVD	B106	HPM Bunker E05-2
Dichlorosilane	$SiCl_2H_2$	Corrosive, Toxic	LPCVD	B106	HPM Bunker E05-2
Phosphine	PH_3	Unpredictable, burns in moist air. Poison	LPCVD	B106	LPCVD Gas Box, B106
Ammonia	NH_3	Corrosive, Toxic	LPCVD,YES Oven	B106	Subfab A08
Hydrogen	H_2	Flammable	ATM Furnaces	B106	Subfab A08
Oxygen	O_2	Supports combustion	ATM Furnaces, RIE, PECVD, LPCVD	B106, B105	Subfab A08
Sulfur Hexafluoride	SF_6	Low toxicity level	RIE, PECVD, DRIE	B105, B106	Subfab A08
Trifluoromethane	CHF_3	Non-toxic. Asphyxiation.	RIE	B105	Subfab A08
Nitrous Oxide	N_2O	Asphyxiation	RIE, PECVD, DRIE	B105, B106	Subfab A08
Nitrogen	N_2	Asphyxiation	Facility Wide	Facility Wide	Subfab A08. Outside Tanks near bldg 215 loading dock
Forming Gas	N_2/H_2	Flammable	ATM Furnaces, RTP	B106,	Subfab A08
Octafluorocyclobutane	C_4F_8	Asphyxiation	Deep Silicon Etcher	B105	Subfab A08
Boron Trichloride	BCl_3	Highly Toxic	Metal RIE	B105	Subfab A08
Chlorine	Cl_2	Corrosive, Highly Toxic	Metal RIE, Metal ICP	B105	Subfab A08
Carbon Tetrafluoride	CF_4	Asphyxiation	RIE	B105	Subfab A08
Argon	Ar	Asphyxiation	Sputter, ATM Furnaces, RTP	B104, B105, B106	Subfab A08
Silicon Tetrachloride	$SiCl_4$	Corrosive, Highly Toxic	Oxford Etcher	A106	Subfab A08
Methane	CH_4	Asphyxiation, Extremely Flammable	Oxford Etcher	A106	Subfab A08
Hydrogen Bromide	HBr	Toxic, Corrosive	Oxford Etcher	A106	Subfab A08
Hexafluorane	C_2F_6	Non-toxic. Asphyxiation.	Oxford Etcher	A106	Subfab A08

6.3 Cylinder Leak Check

Process gas cylinders should be checked for leaks before receiving delivery. This check is typically done by the delivery company before loading the truck and again on-site before making the gas delivery.

6.4 Toxic Gas Cylinder Change-out

Toxic (and pyrophoric) gas cylinder change-out is a two-person operation. Both individuals are required to be properly trained (see section 5.2) and must wear SCBA equipment during the change-out. The hallways leading to the sub-fab area must be barricaded until the cylinder is installed. A call to the NIST Fire Protection Group must be placed, providing the information that a toxic gas cylinder change-out is in progress. A return call must be placed after the installation is completed.

6.5 SCBA Program

The requirements for using a Self Contained Breathing Apparatus (SCBA) at NIST are a medical exam, fit test, and usage training. This is coordinated by the NanoFab Safety Officer in conjunction with the NIST Medical Unit, NIST Fire Protection Group and with the NIST Safety Office. The certification is good for two years.

6.6 Highly Toxic Gases Used

The Cleanroom has gases that are considered highly toxic; examples of toxic gases are boron trichloride (BCl_3) and chlorine (Cl_2). These gases are used in the metal etching systems in room 215/B105. If chlorine odors are detected, evacuate the Cleanroom and contact a NanoFab staff member. If a staff member is not immediately available, call the HAZMAT Team at **x2222**, and report the odor.

Remember, when in doubt, GET OUT!

6.7 Toxic Gas Handling and Usage

Proper handling and training are required when using toxic gases. **All** gas cylinders are to be transported using an approved cylinder truck with attachable chain. Gas bottle hook-up must be done with two people and a Scott Pack SCBA if toxic gases are used. *All gases are to be handled by trained and certified Cleanroom staff members only*. Users are not authorized to access the gas cabinets located in the sub-fab.

When opening a cylinder of process gas, just open the valve enough to get the gas pressure up, but **do not crank the valve all the way open**. When the valve is cranked wide open, it can be mistaken for a closed valve. Place appropriate signs for charged process gas lines inside the cabinets so that it is visible from the closed door position.

7. Nanoparticle Material Safety

7.1 Overview

Nanoparticles are defined as materials that have diameters on the order of 100 nm or less. Special handling of nanoparticles is required in the NanoFab as described below.

Current Status of Nanoparticle Safety: Potential health risks associated with exposure to nanoparticles are not well known, with considerable research ongoing. Because many health and safety issues involving nanoparticles are not yet fully understood, the NanoFab handles such materials carefully. Three routes of entry into the body—inhalation, ingestion, and dermal penetration—are likely to be of primary significance and should be kept in mind.

Proper Personal Protective Equipment (PPE)

- Lab coats (elastic at wrists)
- Gloves (longer ones to cover the wrists)
- Breathing masks/respirators (suggested N95)
- Glasses/goggles
- Proper use of hoods

Nanoparticle Confinement: All nanoparticle handling and reactions will be confined in order to minimize possible "contamination" in the designated nanoenclosure in 216/G101. All nanoparticles in the powder state must be handled in this nanoenclosure. A closed container must be used when transporting loose nanoparticles or nanoparticles in a solvent from room to room.

Nanoparticle users must clean the nanoenclosure after completing their work as other researchers will be sharing many spaces within NanoFab laboratories. In addition, nanoparticle users must inform other researchers working in the laboratory of their nanoparticle handling to reduce potential exposure.

Proper personal protective equipment (PPE). Depending on the nanoparticle type and the quantity used, proper gloves and lab coats should also be used (remove gloves and lab coats when leaving the lab).

All work done in G101 must be approved by the lab owner and/or the NanoFab Manager. Use of the nanoenclosure requires training, including review of the NanoFab Nanoparticle Handling Policy. The nanoenclosure must be reserved through NEMO. Nanoparticles on the preapproved list are allowed in the nanoenclosure; those not on the preapproved nanoparticle list must be approved by the NanoFab Manager. Nanoenclosure use will be tracked by a log sheet adjacent to the hood

Preapproved list of nanoparticles	HMIS rating
Carbon nanotubes	2 0 0
Au	0 0 0
Ag	0 0 1
Al	1 0 0

Fe	1 2 2
CdSe	2 3 0
Latex	0 0 0

7.2 Nanoparticle Safety Committee:

Click to link to committee member list (available from inside NIST only)

7.3 Nanoparticle Safety Policy

Nanotechnology Safety at NIST (available from inside NIST only)

8. Emergency Services

8.1 Fire Response

At NIST the emergency phone number for a fire in the lab or building is x2222.

8.2 Chemical Spills

Chemical spills at NIST can be reported to the Fire department at x2222. Be prepared to provide all pertinent information to the Fire Department such as **what**, **where,** and **how much** was spilled.

8.3 Medical Emergencies

Medical emergencies such as chemical burns, inhalation injuries, falls, heart attacks, etc. require one to contact the NIST Fire Protection Group at x2222.

9. Contacts

9.1 Staff Directory

Click this link for Staff Directory

Robert Celotta	CNST Director	301-975-8001
Lloyd J. Whitman	CNST Deputy Director	301-975-8001
Russ Hajdaj	CNST Safety Officer	301-975-2699
Vincent Luciani	NanoFab Manager	301-975-2886
Jessie Zhang	NanoFab Asst. Manager	301-975-4565
Jerry Bowser	Operations Team Leader	301-975-8187
Marc Cangemi	Process Engineer	301-975-5993
Lei Chen	Process Engineer	301-975-2908
Gerard Henein	Process Engineer	301-975-5645
Richard Kasica	Process Engineer	301-975-2693
Alline Myers	Process Engineer	301-975-3775
Robert Newby	Process Engineer	301-975-6070
Joshua Schumacher	Process Engineer	301-975-8065
Kerry Siebein	Process Engineer	301-975-8458
Liya Yu	Process Engineer	301-975-4590
Joe Di Pasquale	Engineering Technician	301-975-2242
Jim Bittner	Engineering Technician	301-975-3363
Elise Pilat	Engineering Technician	301-975-6014

10. NIST Policy on Chemical Container Labeling

INTRODUCTION

Chemical labeling is a major part of the NIST Hazard Communication (HazCom) Program. The HazCom program ensures that all NIST staff are aware of the chemical hazards that they may encounter in their work place. Proper labeling of chemicals provides immediate access to hazard information. NIST has adopted the National Fire Protection Association (NFPA) Hazard Identification System for labeling chemicals. The NFPA system is most easily recognized by its diamond shape. It is widely used both in industry and government for hazard communication. The NFPA Hazard Identification System is described in detail in Table 1.

NFPA 704 Warning Ratings

This includes chemicals used in laboratories, work areas, and storage areas. The following materials need to be labeled:

a. Chemicals in all forms (liquids, gases, and solids) and conditions (new, old, excess, diluted, used, mixtures, spent, waste, synthesized, samples, etc.).

The following items do not need to be labeled:

a. Process vessels and reactors that have readily accessible alternate written documentation.
b. Working solutions prepared in a laboratory that are under control of the researcher and are used and disposed of in one working day.
c. Small quantities (such as those found in ordinary households) of properly labeled consumer products such as paints, detergents, hand cleaning agents, bathroom cleaners, window cleaners video-monitor screen cleaners, plant fertilizers, insecticides, furniture polish, etc. The vendor's label is adequate.
d. Containers of chemicals (other than hazardous wastes) that have been prepared for shipment off NIST grounds. These containers must meet the labeling requirements of the transportation regulations and the carrier. Contact the NIST or NOAA Shipping and Receiving Office for assistance.

Table 1, National Fire Protection Association Hazard Identification System

NFPA SYMBOL	COLOR CODE
	**Blue indicates health hazard.**
	Red indicates flammability hazard
	Yellow indicates reactivity hazard
	White represents other hazards such as if a chemical reacts violently with water (W) or is an oxidizer (OXY).
	NUMERICAL RATING
	0 = no or minimal hazard
	1 = slight hazard
	2 = moderate hazard
	3 = serious hazard
	4 = extreme hazard

Blue/Health
4. Very short exposure could cause death or major residual injury.
3. Short exposure could cause serious temporary or residual injury
2. Intense or continued but not chronic exposure could cause temporary incapacitation or possible residual injury
1. Exposure would cause irritation but only minor residual injury.
0. Exposure under fire conditions would offer no hazard beyond that of ordinary combustible material.

Red/Flammability
4. Will rapidly or completely vaporize at normal atmospheric pressure and temperature, or that are readily dispersed in air and will burn readily.
3. Liquids and solids that can be ignited under almost all ambient temperature conditions.
2. Must be moderately heated or exposed to relatively high ambient temperature before ignition can occur.
1. Must be pre-heated before ignition can occur.
0. Will not burn.

Yellow/Reactivity
4. Readily capable of detonation or explosive decomposition at normal temperatures and pressures.
3. Capable of detonation or explosive decomposition but requires a strong initiating source, must be heated under confinement before initiation, or reacts explosively with water.
2. Undergoes violent chemical change at elevated temperatures and pressures, reacts violently with water, or may form explosive mixtures with water
1. Normally stable, but can become unstable at elevated temperatures and pressures.
0. Normally stable, even under fire exposure conditions, and is not reactive with water)

White/Special
The white "special notice" area can contain several symbols: '~~W~~' - reacts with water in an unusual or dangerous manner; 'OX' - oxidizer; "BIO' -

Biohazardous; The radioactive trefoil ( ) - is radioactive; 'COR' - corrosive; strong acid or base 'ACID' and 'ALK' to be more specific. *Note: Only '~~W~~' and 'OX' are officially part of the NFPA 704 standard, but other self-explanatory symbols are occasionally used in an unofficial manner.*

OBTAINING NFPA HAZARD RATINGS

The NFPA numerical hazard ratings for chemicals can be found at the following sources:

a. On most Material Safety Data Sheets (MSDSs), or
b. At ChemWatch - http://nist.chemwatch.us/ - type in the chemical name.
c. If you cannot find the numerical ratings for a chemical using one of the above methods, contact the Safety Office at x5818 in Gaithersburg or x7389 in Boulder.

If contradictions are found between two sources of hazard ratings, in general, the higher rating will be assumed to apply. Contact the Safety Office to resolve any significant discrepancies.

PROCEDURES

All chemicals that are used or stored at NIST must be labeled with a CISPRO label.

Specific Chemical Labeling Instructions

a. Newly Acquired Chemicals

- Chemicals labeled properly by the manufacture will require a CISPRO label.
- The manufacture's label should not be removed.
- Compressed gas cylinders should have a CISPRO label placed on each of them.

b. Chemicals Prepared in the Lab

- Chemicals synthesized, mixed, or transferred from one container to another in a NIST lab (working solutions) shall have a label containing the chemical name, date, owner name, supervisor name, and contact information.

e. Chemicals with Unknown Hazards

- If you have a chemical for which the hazards cannot be determined, call the Safety Office in Gaithersburg at x5818 or in Boulder at x7389 for assistance.

f. Biohazards and Radioactive Material

- Labeling and handling precautions for Radioactive Materials shall be coordinated with the NIST Health Physics Group, at x5800 in Gaithersburg or x7285 in Boulder. Labeling and handling of biohazards shall be coordinated with a NIST Industrial Hygienist at x5821 in Gaithersburg or x7389 in Boulder.

g. Chemicals Requiring Special Labeling

- Chemicals that are known or suspected carcinogen must be labeled to indicate the cancer hazard. The word "CARCINOGEN" should be written on the NIST Chemical Label or on a separate label with a white background. The carcinogen labels must not obscure any other label information.
- Peroxidizable compounds must be labeled and monitored for their safe. Lab workers and supervisors shall devise their own monitoring system (as needed) to comply with the special requirements of HSI 6.

Peroxidizable compounds shall have the following information included on the chemical label:

1. The term **"Peroxide Forming Compound."**

2. The date of acquisition, date when first opened, and the discard date which must be no later than 3 months after date when first opened.

h. Chemical Waste Labeling

Chemical waste containers shall be identified with a NIST Chemical Waste Label and be prepared for disposal using Hazardous Chemical Waste Disposal procedures. NIST Chemical Waste Labels are available in the NIST Storeroom or from the Safety Office at x5818 in Gaithersburg or x7389 in Boulder.

i. Other Hazard Rating Systems

There are a number of other systems that also use numerical hazard ratings. While the systems described below are not identical to the NFPA, for NIST's purposes, they can be used in the same way as the NFPA hazard ratings. If a manufacturer's labels its product using Baker/Mallinckrodt' Saf-T-Data System or the National Paint and Coating Association's Hazardous Material Identification System (HMIS), transferring the number from any of those systems to a NIST label is acceptable.

Acquiring Chemical Labels

Pre-printed (hardcopy) labels are available in the NIST Storeroom. These labels shall be filled in using a permanent pen or marker.

Electronic files for each type of chemical label are available on the NIST Internal Website at "Online Forms" (http://inet.nist.gov/forms/nist-forms.cfm). Information can be filled in to these labels prior to printing. The electronic files can be printed on blank commercial label material available in the NIST Storeroom. **LABELS MUST BE PRINTED ON A COLOR PRINTER, PREFERABLY A COLOR LASER PRINTER.** If there is a concern with running ink, you can place transparent tape over the label.

Labels produced by chemical inventory software (e.g. CISPro®), that include equivalent information, are acceptable.

References:

National Fire Protection Association, "NFPA 704, Standard System for the Identification of Hazardous Materials for Emergency Response," 2007 Edition.

Occupational Safety and Health Administration, 1910.1450, "Occupational exposure to hazardous chemicals in laboratories," 2009.

DEFINITIONS AND ACRONYMS

ACGIH - American Conference of Governmental Industrial Hygienists.

CERCLA - Comprehensive Environmental Response, Compensation, and Liability Act (Superfund): implemented by the U.S. Environmental Protection Agency (EPA).

CFR - U.S. Code of Federal Regulations.

EPA - U.S. Environmental Protection Agency.

HSI - Health and Safety Instruction, issued by the Occupational Health and Safety (OHS) Division of the NIST, U.S. Department of Commerce. Note: HSIs will be used to update and replace all SPGs (Safety Program Guides) previously issued by the NIST. "HSI" and "SPG" will be used interchangeably until all SPGs have been replaced.

LC_{50} - The Median Lethal Concentration of a substance, administered by continuous inhalation in a prescribed manner for a given period of time, that is most likely to kill 50% of a group of animals within a specified time under test conditions. Specific terms and values are given in table 5.

LD_{50} - The Median Lethal Dose of a substance, administered orally or by continuous contact in a prescribed manner for a given period of time, that is most likely to kill 50% of a group of animals within a specified time under test conditions. Specific terms and values are given in table 5.

MASC - Mountain Administrative Support Center, U.S. Department of Commerce.

MSDS - Material Safety Data Sheet.

NIST - National Institute of Standards and Technology, U.S. Department of Commerce.

NFPA - National Fire Protection Association.

OSHA - Occupational Safety and Health Administration, U.S. Department of Labor.

PEL - The Permissible Exposure Limits established by OSHA, specifying allowable concentrations of air contaminants in the work environment. PELs may be given as a person's average exposure--a Time Weighted Average (TWA)--to airborne contaminants in any 8-hour work shift of a 40-hour workweek, or as ceiling values that are not to be exceeded. PELs are expressed as ppm (by volume) of vapor or gas in air, or as mg of chemical substance per cubic meter of air. Standards are given in 29CFR1910.1000, Subpart Z.

PLNR - PRECAUTIONARY LABELING NOT REQUIRED: signal words on the green NIST label.

SCF - Standard Cubic Feet, the volume occupied by a gas at 1-atmosphere pressure and 21.1°C (70°F).

TLV - The Threshold Limit Values established by the ACGIH, recommending allowable concentrations of airborne contaminants for avoidance of adverse health effects. TLVs may be given as a Time Weighted Average (TWA) concentration for a normal 8-hour workday and a 40-hour workweek, as a Short Term Exposure Limit (STEL) which is the maximum 15-minute TWA concentration allowed, or as a ceiling concentration that should not be exceeded during a workshift. TLVs are expressed in the same units as PELs. TLVs are listed in the ACGIH booklet entitled "Threshold Limit Values and Biological Exposure Indices," Cincinnati, Ohio (updated annually).

Container Capacity Limitations* for Flammable and Combustible Liquids Stored in the Lab.

	CONTAINER MATERIAL		
	Glass or Approved Plastic	**Metal****	**Safety Cans**
Flammable Liquids			
Class IA	0.47l (1 pint)†	3.79l (1 gallon)	7.57l (2 gallons)
Class IB	0.95l (1 quart)†	18.93l (5 gallons)	18.93l (5 gallons)
Class IC	3.79l (1 gallon)	18.93l (5 gallons)	18.93l (5 gallons)
Combustible Liquids			
Class II	3.79l (1 gallon)	18.93l (5 gallons)	18.93l (5 gallons)
Class III	3.79l (1 gallon)	18.93l (5 gallons)	18.93l (5 gallons)

* Limitations apply to new, excess, used, or waste liquids.

** Excludes DoT metal drums.

† The use of larger glass or plastic containers requires an exemption from the NIST/MASC Safety Office and must meet OSHA 29CFR1910.106 requirements. If the use of larger glass containers [up to 3.79l (1 gallon)] is permitted, they must be stored in approved carriers or containers capable of holding the contents of the glass container.

Definitions

Flammable Liquid: A Class I liquid having a flash point below 37.8°C (100°F) and a vapor pressure not exceeding 276 kPa (40 psia) at 37.8°C (100°F).

Class 1A liquids have flash points below 22.8 °C (73 °F) and boiling points below 37.8C (100°F).
Class 1B liquids have flash points below 22.8°C (73 °F) and boiling points at or above 37.8°C (100°F).
Class 1C liquids have flash points at or above 22.8° C (73°F) and below 37.8°C (100°F).

Combustible Liquid: A liquid having a flash point at or above 37.8°C (100°F).

Class II liquids have flash points at or above 37.8°C (100°F) and below 60°C (140°F).
Class IIIA liquids have flash points at or above 60°C (140°F) and below 93.4°C (200°F).
Class IIIB liquids have flash points at or above 93.4°C (200°F).

Flash Point: The minimum temperature at which a liquid within a test vessel gives off vapor in sufficient concentration to form an ignitable mixture with air near the surface of the liquid, as determined by appropriate ASTM test procedures and apparatus.

Source: Adapted from NFPA Code 45 (August 1991) and OSHA 29CFR1910.106 (July 1991).

11. NIST/CNST Compressed Gas Cylinder Safety Policy and Procedures

COMPRESSED GAS CYLINDERS

INTRODUCTION

a) Using compressed gas cylinders in laboratories presents many problems not generally encountered in industrial use. These problems include the variety of flammable, toxic and radioactive materials and special mixtures with properties that are frequently unfamiliar to the researcher. The tendency of laboratory personnel is to modify, adapt, and repair cylinder valves and regulators themselves, rather than to leave such work to the supplier or specially trained personnel. Incorporating a cylinder into an experimental apparatus so that foreign materials can enter the cylinder or so that the cylinder or systems may be subjected to extreme pressures is an extremely hazardous practice that unfortunately has been fairly common in some research laboratories.

b) Compressed gas cylinders can be safely used in laboratories if the NFPA codes and following general rules (as published in the CRC Handbook of Laboratory Safety) are complied with completely during cylinder receiving operations, storage, transportation to the laboratory or other use point, usage and return of empty cylinders.

LECTURE BOTTLES

a) Using cylinders other than lecture bottles is encouraged. Many suppliers will no longer accept lecture bottles for return and NIST must pay a high cost to dispose of them.

b) If you must use a lecture bottle, check with the suppliers and use one who will allow you to return it. Even though the returnable lecture bottle may cost more, not having to pay the disposal cost will offset the high purchase cost.

GENERAL RULES

a) Know the Gas and its Properties: Researchers should know the properties and hazards of the gases they are going to use. Knowledge of the gases properties is essential to laboratory operations due to the unusual uses to which gases may be put, as well as the uncommon gases or special gas mixtures used. Not only should the flammability, corrosiveness or oxidation potential be known but also the physiological properties must be kept in mind--such as toxic, anesthetic, or irritating qualities. Two examples are carbon monoxide, which is both toxic and flammable, and hydrogen sulfide, which is toxic and has the ability to desensitize the sense of smell. A copy of the gases' Material Safety Data Sheet (MSDS) should be available for review by the researchers and emergency services personnel.

b) Labeling Cylinders/ Cylinders with Unknown Contents: All compressed gases cylinders and liquefied gas containers are to be appropriately labeled and recorded in CISPro. More specifically, compressed gas cylinders and liquefied gas containers **must** bear some legible marking, tag or label to clearly indicate their contents (e.g., hydrogen, fluorine, propane, etc.). Do not remove this identification marking from empty cylinders as this might present a hazard to the supplier. Also, do not rely on color codes for cylinder content identification as this varies from supplier to supplier, and many persons are color blind.

CYLINDERS CONTAINING TOXIC GAS

a) What are Toxic Gases? Toxic gases are those with an NFPA 704[1][1] Health Hazard Rating 3 or 4 or having a Health Hazard Rating of 2 with no physiological warning properties.

b) Storing Toxic Gases: When new storage areas are designed or existing ones are renovated, toxic gases must be stored in continuously mechanically ventilated gas cabinets. Toxic gases with a Health Hazard Rating of 4 will require a gas detection system.

[1][1]NFPA 704: Standard for the Identification of the Fire Hazards of Materials for Emergency Response, 1996 Edition

c) Using Toxic Gases: When renovating or making major modification to a lab that uses or will use a toxic gas, the cylinders must be stored in a continuously mechanically ventilated hood or gas cabinet. No more than three (3) of these cylinders may be stored in a hood or gas cabinet.

CYLINDER STORAGE AND USE

a) Store Cylinders Appropriately: Store and use cylinders in ventilated areas away from heat and ignition sources. Segregate flammable gases from other gases, particularly oxygen. Limit the quantity stored in one location. Cylinders containing gases under high pressure could very quickly render an area unsafe if the large volume of gas should be released. Most cylinders, except those in toxic gas service, are equipped with safety relief devices of the rupture disk or spring-loaded type. The rupture disc type pressure-relief devices may function prematurely if cylinders are heated to a temperature in excess of 52 C (125 F) and release the entire content of the cylinders. Also, cylinders containing low vapor pressure liquids could become liquid filled at elevated pressures and burst. If a cylinder must be heated, this should be done in a very well thermostated water bath heated to no more than 52 C (125 F). However, this is a hazardous procedure at best, and should be avoided, especially with full cylinders.

b) Securely Fasten Cylinders: Whether in use or being stored, all cylinders must be securely fastened. If a cylinder should fall or rolls off a bench, the regulator or valve might break off and release a large quantity of gas. This may cause the cylinder to pinwheel, which can injure employees or damage equipment. Another danger is that the valve could shear off and the cylinder might "rocket" like a projectile due to the sudden release of pressure. The storeroom stocks supports (clamps) available for securing cylinders to a bench, a wall, etc. Where cylinders must stand away from a wall or bench, cylinder stands for large (6" to 9 1/4"diameter cylinders), small (4" to 6" diameter cylinders) and lecture bottle (2" diameter) are commercially available. Although there are innumerable commercial holders, stands, etc., available for supporting cylinders, a length of chain, cable or rope can also be used to secure a cylinder to a work bench or other fixed object. The main consideration is that cylinders must be adequately secured.

c) Keep Caps on Cylinders Not in Use: Caps used for valve protection should be kept on the cylinder except when the cylinder is in use. Removing the cap when **not** using the cylinder, exposes the valve to being damaged and leaking.

d) Maximum Number of Cylinders in a Lab: The following table from NFPA 45 *Standard on Fire Protection for Laboratories Using Chemicals, 1996 Edition* gives the maximum number of compressed or liquefied gas cylinders that may be place in a laboratory work area.

Maximum Number of Compressed or Liquefied Gas Cylinders in a Laboratory Work Area

	Flammable or Oxidizing Gases		Liquefied Flammable Gases		Gases with Health Hazard Rating of 3 or 4
	Sprinklered Space	Nonsprinklered Space	Sprinklered Space	Nonsprinklered Space	Sprinklered or Nonsprinklered Space
Max. No. of cylinders per 46.5 m^2 (500 ft^2) or less	6	3	3	2	3

e) Do Not Tamper with Cylinders: Never tamper with cylinder valve, safety plugs or packing nuts. Tampering with these could create a leak and a potentially hazardous atmosphere. If a hazardous condition is created in the laboratory, exit the lab and call for emergency help. There have been fatalities in laboratories caused by unfamiliarity with valves. In one instance, the safety nut was confused with an outlet cap, which is frequently installed on the outlet, and the safety nut was completely removed. Note that the safety nut connects directly to the valve inlet (pressure side) and once removed, the flow of gas cannot be stopped.

f) Leaking Cylinders: Leaking cylinders should be marked as “leakers” and removed to an open area until picked up by the supplier. Do not put unmarked leaking cylinders among the empties. DOT transportation regulations forbid shipping leaking containers by common carrier. Note: Call X2222 for assistance with leaking cylinders.

g) Do Not Strike Arcs on Cylinders: Do not strike an electric arc on cylinders. This rule is directed primarily to industrial users, where inert gases are used for shielded arc welding. It is very tempting to test the arc on the large metal surface. Arc burns,

however, not only are stress raisers, but due to metallurgical changes, could cause the heat affected portion of the cylinder to become brittle.

h) Use Compressed Gases with Appropriate Equipment: Only use regulators that are suitable for the cylinder. Proper mating hardware should fit; do not force the connection. Do not use homemade adapters. The importance of this rule cannot be overemphasized. Accidents have occurred because of attaching flammable gas regulators to oxygen cylinders, improperly identifying the contents of a cylinder, and so forth. American National/Compressed Gas Association Standard for Compressed Gas Cylinder Valve Outlet and Inlet Connections lists the various standard connections for compressed gases. The connections listed are classified into four thread divisions. There are left and right-hand threads and internal and external threads, plus some pipe threads and yoke type connections. The various gases are assigned to connections so that hazardous interconnections cannot be made. Generally speaking, left-hand threads are reserved for flammable gases and right-hand threads for nonflammables. There are a few exceptions made necessary by previous practice. Almost always, hazardous connections cannot be made except by homemade adapters or by forcing the connection.

i) Use of Cylinder Regulators: Cylinders contain pressures greater than the pressures which most laboratory equipment can withstand, even steel or nonferrous tube. Always use a regulator with high-pressure cylinders (above 500 psi). The inadvertent closing of a vent valve or stopcock or the plugging of a line or mercury trap could cause a violent failure of the apparatus. There are fine needle valves available which can reduce the flow of gas from the high-pressure cylinder to a few bubbles a minute. Such valves are not regulators and the design of any equipment used with them must keep this fact in mind. Use needle valves only with low-pressure cylinders (below 500 psi). Valves are only flow regulators, not pressure regulators.

j) Close Cylinder Valves When Not in Use: Do not stop the gas flow from cylinders overnight by only backing off on the regulators. Even the best of regulators can develop seat leaks and allow excessive pressures to develop in using equipment. Closing the cylinder valve will eliminate this hazard. If this rule is followed meticulously, any question as to the position of a cylinder valve in an emergency is removed. Finally, no foreign materials can enter the cylinder if through leakage or other malfunction the cylinder pressure should become lower than the pressure in some other part of the apparatus.

k) Close Valves on Empty Cylinders and Mark the Cylinder Empty or "MT": If cylinders are returned to the supplier with the valve open, the interior will become contaminated with atmospheric air and moisture. Such cylinders cannot be used for high purity gases without extensive reconditioning. If the cylinder had contained such materials as anhydrous hydrogen chloride, or chlorine, this resultant humid atmosphere would corrode the cylinder very rapidly. Empty cylinders should be so marked "MT" and stored separately to avoid returning full cylinders to the supplier or sending empties to the laboratories or other use point.

l) Never Attempt to Refill a Cylinder: It is very tempting to refill your own small cylinders from large ones by interconnecting them with high pressure tubing. There are a number of reasons why this practice is hazardous. The cylinder being filled may have a lower working pressure than the large cylinder. Filling too rapidly can result in extremely high cylinder temperatures which could damage the valve. The cylinder being filled may contain a residue of a reactive material. It is extremely difficult to completely purge a cylinder. For cylinders containing liquids, DoT prescribes filling weights which allow for a vapor space at temperatures and pressures for which the safety device functions. If these weights are exceeded, the cylinders may become liquid-full at room temperatures and fail. Finally, at least one supplier of laboratory gases uses a very lightweight welded, thin-wall aluminum, or one-time use cylinder (i.e., DoT 39) which is classified as non-refillable by DoT. For safety reasons such a single-use cylinder must be discarded after use the same as the common aerosol spray cans.

TRANSPORTING AND HANDLING CYLINDERS

a) Handle Cylinders Carefully: Cylinders are primarily shipping containers and as such are constructed to be as light as possible consistent with safety, durability and pressurization requirements. Cylinders should be moved with great care, preferably strapped to a cart. As the valve assembly is the weakest part of the cylinder, avoid striking the valve against anything. Rough handling or abuse could seriously weaken the cylinder and render it unfit for further use.

b) Transport Cylinders Safely: Transport large cylinders only on a wheeled cart. Do not slide or roll them even one at a time, since it is easy to lose control of a cylinder while rolling or dragging no matter how much practice a person might have. If one falls, it could land on the foot. Additionally, avoid dragging cylinders as this procedure introduces other manual handling hazards. Mishandling of cylinders in transit is the cause of many pulled muscles, back injuries and foot injuries.

NFPA HEALTH HAZARD RATING SYSTEM*

A health hazard is any property of a material which, either directly or indirectly, can cause injury or incapacitation, either temporary or permanent, from exposure by contact, inhalation, or ingestion.

Rating	Description
4	Materials which on very short exposure could cause death or major residual injury even though prompt medical treatment is given, including those which are too dangerous to be approached without specialized protective equipment. This degree includes: materials which can penetrate ordinary rubber protective clothing; materials which under normal conditions or under fire conditions give off gases which are extremely hazardous (i.e., toxic or corrosive) through inhalation or contact with or absorption through the skin. Examples of compressed and/or liquefied gases of this degree include: Cyanogen, Fluorine, Hydrogen Cyanide and Hydrogen Fluoride.**
3	Materials which on short exposure could cause serious temporary or residual injury even though prompt medical treatment is given, including those requiring protection from all bodily contact. This degree includes: materials giving off highly toxic combustion products; materials corrosive to living tissue or toxic by skin absorption. Examples of compressed and/or liquefied gases of this degree include: Anhydrous Ammonia, Chlorine, Diborane, Ethylamine, Hydrogen Bromide, Hydrogen Chloride, Hydrogen Sulfide, Methylamine, Methyl Bromide and Phosphine.**
2	Materials which on intense or continued exposure could cause temporary incapacitation or possible residual injury unless prompt medical treatment is given, including those requiring use of respiratory protective equipment with independent air supply. This degree includes: materials giving off toxic combustion products; materials giving off highly irritating combustion products; materials which either under normal conditions or under fire conditions give off toxic vapors lacking warning properties. Examples of compressed and/or liquefied gases of this degree include: 1,3-Butadiene, Carbon Monoxide, Dimethyl Ether, Ethyl Chloride, Ethylene Oxide, Formaldehyde, Methyl Chloride, Methyl Mercaptan, Sulfur Dioxide, Tetrafluoroethylene, Trimethylamine, Vinyl Bromide and Vinyl Chloride.**
1	Materials which on exposure would cause irritation but only minor residual injury even if no treatment is given, including those which require use of an approved canister type gas mask. This degree includes: materials which under fire conditions would give off irritating combustion products; materials which on the skin could cause irritation without destruction of tissue. Examples of compressed and/or liquefied gases of this degree include: Acetylene, r.-Butane, iso-Butane, 1-Butene, 2-Butene,Cyclopropane, Ethane, Ethylene, Methane, Natural Gas, iso-Pentane, Propane, Propylene and Vinyl Fluoride.**

FLAMMABILITY CHARACTERISTICS OF COMMON COMPRESSED AND LIQUIFIED GASES

This list is not inclusive or exhaustive. Practically all compressed and liquefied gases present varying health hazards to personnel. Therefore, users are urged to seek additional information from reliable references to adequately assess the reactivity or toxicity of the material. Contact the Safety Office in Gaithersburg (X5375 option 3) for additional information, as needed.

GAS	FLAMMABLE RANGE (if Flammable, percent by vol.)	REFERENCE SOURCE	GAS	FLAMMABLE RANGE (if Flammable, percent by vol.)	REFERENCE SOURCE
Acetylene	2.5 - 82	MGD	Hydrogen Cyanide[1]	5.6 - 40	325M, 627
Allene[1]	1.5 - 11.5	MGD	Hydrogen Fluoride	(a)	
Ammonia[1]	15 - 28	MGD	Hydrogen Iodide	(a)	
Arsine[1]	(b)	MGD	Hydrogen Selenide[1]	(b)	
Boron Trichloride	(a)	MGD	Hydrogen Sulfide	4 - 44	325M, 627
Boron Trifluoride	(a)	MGD	Ketene	(b)	
1,3-Butediene[1]	2 - 12	627	Methane	5 - 15	325M, 627
n-Butane[1]	1.6 - 8.4	325M	Methylacetylene[1](Propyne)	2 - 11.1	325M
iso-Butane[1]	1.8 - 8.4	325M	Methylamine[1]	4.9 - 20.7	325M
I-Butene[1]	1.6 - 10	627, 325M	Methyl Bromide[1]	10 - 16	325M
2Butene	1.7 - 9.7	627	3 - Methyl-1-butene[1]	1.5 - 9.1	325M, 627
Carbon Monoxide	12.5 - 74	627	Methyl Chloride[1]	8.1 - 17.4	325M
Carbonyl Chloride (Phosgene)	(a)		Methyl Fluoride[1]	(b)	
Carbonyl Fluoride	(a)		Methyl Mercaptan[1]	3.9 - 21.8	325M
Carbonyl Sulfide[1]	12 - 29	325M	2-Methylpropene	1.8 - 9.6	325M, 627
Chlorine	(a)		Natural Gas	3.8/6.5 - 13/17	325M
Chlorine Dioxide	(a)		Nitric oxide	(a)	
Chlorine Trifluoride	(a)		Nitrogen Dioxide	(a)	
1-Chloro-l,l-Difluorethane[1]	9 - 14.8	MGD	Nitrogen Trioxide	(a)	
Chlorotrifluoroethylene[1]	8.4 - 38.7	MGD	Nitrogen Trifluoride	(a)	
Cyanogen[1]	6 - 32	MGD	Nitrosyl Chloride	(a)	
Cyanogen Chloride[1]	(a)		Oxygen	(a)	
Cyclopropane[1]	2.4 - 10.4	MGD, 627	Oxygen Difluoride	(a)	
Deuterium	5 - 75	325M	Ozone	(a)	
Diazomethane	(b)		iso-Pentane[1]	1.4 - 7.6	325M
Diborane	0.8 - 88	325M, 627	Perchloryl Fluoride	(a)	
1,1-Difluoroethane[1]	3.7 - 18	MGD	Phosphine	(c)	
1,1-Difluoroethylene[1]	5.5 - 21.3	MGD	Propane	2.1 - 9.5	325M, 627
Dimethyl Ether[1]	3.4 - 27	325M, 627	Propylene[1]	2.0 - 11.1	325M
2,2-Dimethytpropane[1]	1.4 - 7.5	325M, 627	Selenium Hexafluoride	(a)	
Ethane	3.0 - 12.5	325M, 627	Silane	(c)	
Ethytacetylene[1]	(b)		Silicon Tetrafluoride	(a)	
Ethylamine[1]	3.5 - 14	325H	Stibine	(b)	
Ethyl Chloride[1]	3.8 - 15.4	325M	Sulfur Dioxide	(a)	
Ethylene	2.7 - 36	325M, 627	Sulfur Tetrafluoride	(a)	
Ethylene Oxide[1]	3 - 100	MGD	Sulfuryl Fluoride	(a)	
Fluorine	(a)		Tetrafluoroethylene[1]	10/11 - 50/60	MGD, 325M
Formaldehyde	7 - 73	325M	Tetrafluorohydrazine[1]	(b)	
Germane	(b)		Trimethylamine[1]	2 - 11.6	MGD, 325M
Hexafluoroacetone	(a)		Vinyl Bromide[1]	9 - 15	325M
Hydrogen	4 - 75	325M, 627	Vinyl Chloride[1]	3.6 - 33	325M, 627
Hydrogen Bromide	(a)		Vinyl Fluoride[1]	2.6 - 21.7	MGD
Hydrogen Chloride	(a)		Vinyl Methyl Ether[1]	(b)	

[1]Liquefied Gases

Notes on Flammable Range: (a) - Not flammable,(b) - Flammable but range not reported, (c) - Spontaneously flammable

Reference source for flammable ranges:

- 325-NFPA 325 - *Guide to Fire Hazard Properties of Flammable liquids, Gases, and Volatile Solids*

- 627-U.S. Bureau of Mines Bulletin 627, *Flammability Characteristics of Combustible Gases and Vapors*
- MGD-*Matheson Gas Data Book*

12. Chemical Glove Resistance Guide

Chemical Name	NFPA Health Rating	Nitrile	Natural Rubber Latex	Recommended Alternate Material
ACETALDEHYDE	3	P	G	
ACETIC ACID (GLACIAL)	3	F	G	
ACETIC ANHYDRIDE	3	F	G	
ACETONE	1	F	G	
ACETONITRILE	2	F	F	Butyl (E)
ACRYLIC ACID	3	G	G	
AMMONIUM ACETATE		E	E	
AMMONIUM CARBONATE		E	E	
AMMONIUM FLUORIDE, 30-70%	3	E	E	
AMMONIUM HYDROXIDE,30-70%		E	E	
AMMONIUM HYDROXIDE, <30%		E	E	
AMYL ALCOHOL	1	E	G	
ANILINE	3	F	G	
AQUA REGIA		P	P	Neoprene (F)
AZT			G	
BENZALDEHYDE	2	P	F	Butyl (E)
BENZENE	2	F	P	Viton (G)
BORIC ACID		E	G	
BROMOPROPIONIC ACID		F	G	
BUTYL ACRYLATE	2	P	P	Teflon (G)
BUTYL CELLUSOLVE		G	G	
CALCIUM HYDROXIDE		E	E	
CARBON DISULFIDE	3	G	P	
CARBON TETRACHLORIDE	3	P	P	Viton (G)
CHLOROBENZENE	2	P	P	Viton (G)
CHLORODIBROMOMETHANE		P	P	Viton (G)
CHLOROFORM	2	P	P	Polyvinyl Alcohol (G)
CHLORONAPTHALENES	1	P	P	Viton (G)
CHROMIC ACID	3	F	P	(G)
CISPLATIN		G	G	
CITRIC ACID, 30-70%		E	E	
CYCLOHEXANE	1	E	P	
CYCLOHEXANOL	1	E	G	
CYCLOHEXANONE	1	P	P	Butyl (G)
CYCLOHEXYLAMINE	3	P	P	
DI-N-AMYLAMINE	3	E	P	
DI-N-BUTYLAMINE	3	E	P	
DI-N-BUTYLPHTHALATE	0	E	F	
DI-N-OCTYLPHTHALATE	0	E	F	
DIACETONE ALCOHOL	1	G	F	
DIALLYLAMINE		P	P	Viton (G)
DICHLOROACETYL CHLORIDE	3	P	P	Viton (G)
DIESEL FUEL	0	E	P	
DIETHANOLAMINE	1	E	E	
DIETHYLAMINE	3	G	F	
DIETHYLENE GLYCOL	1	E	E	
DIETHYLENETRIAMINE	3	P	P	Neoprene (G)
DIISOBUTYL KETONE	1	G	P	
DIISOBUTYLAMINE	3	E	P	
DIMETHYL ETHER		G	P	
DIMETHYL SULFOXIDE (DMSO)	1	G	E	
DIMETHYLACETAMIDE	2	F	G	
DIMETHYLFORMAMIDE (DMF)	1	P	P	Butyl (G)

1, 3-DIOXANE		P	F	Butyl (G)
1, 4-DIOXANE	2	P	P	Butyl (G)
EPICHLOROHYDRIN	3	P	F	Butyl (G)
ETHANOL	0	G	G	
ETHYL ACETATE	1	P	F	Butyl (G)
ETHYL ETHER	1	G	P	
ETHYLENE GLYCOL DIMETHYL ETHER	2	F	F	Butyl (G)
ETHYLENE DICHLORIDE	2	P	P	Polyvinyl Alcohol (E)
ETHYLENE GLYCOL	1	E	E	
FORMALDEHYDE, 30-70%	3	E	G	
FORMIC ACID	3	G	E	
FREON 113 OR TF		E	P	
FREON TMC		F	F	Polyvinyl Alcohol (E)
FURFURAL	3	P	P	Butyl (G)
GASOLINE, 40-50% AROMATICS	1	E	P	
GASOLINE, UNLEADED	1	G	P	
GLUTARALDEHYDE, <5%		G	G	
GLYCEROL		E	E	
HEPTANES	1	E	P	
HEXANE	1	E	P	
HYDRAZINE	3	E	F	
HYDROCHLORIC ACID, <30%	3	G	E	
HYDROCHLORIC ACID, 30-70%		G	G	
HYDROFLUORIC ACID,<10%	4	G	G	
ISOBUTYL ALCOHOL	1	E	P	
ISOOCTANE	0	E	P	
ISOPROPYL ALCOHOL	1	E	E	
ISOPROPYLAMINE	3	P	P	Teflon (G)
JET FUEL <30% AROMATICS 73-248C	1	G	P	
KEROSENE		E	P	
LACTIC ACID		E	E	
LAURIC ACID		E	E	
MALATHION,30-70%		G		
MALEIC ACID		G	G	
METHANOL	1	F	F	Neoprene (G)
METHYL ACETATE	1	P	P	Butyl (G)
METHYL ETHYL KETONE	1	P	P	Butyl (E)
METHYL ISOBUTYL KETONE	2	P	P	Butyl (G)
METHYL METHACRYLATE	2	P	P	Polyvinyl Alcohol (E)
METHYLENE CHLORIDE	2	P	P	Polyvinyl Alcohol (G)
AMYL ACETATE	1	F	P	Butyl (G)
BUTYL ACETATE	1	F	P	Butyl (G)
BUTYL ALCOHOL	1	E	E	
N-METHYL-2-PYRROLIDONE	2	P	E	
N-NITROSODIETHYLAMINE		P		Butyl (G)
PROPYL ALCOHOL		E	E	
NAPHTHA, 15-20% AROMATICS		E	P	
NAPHTHA , <3% AROMATICS	1	E	P	
NITRIC ACID, <30%	3	G	G	
NITRIC ACID, 30-70%	3	P	P	Neoprene (G)
NITROBENZENE	3	F	F	Butyl (G)
NITROETHANE	1	P	G	
1-NITROPROPANE	1	P	F	Butyl (G)
2-NITROPROPANE	1	P	P	Butyl (G)
OCTANE	0	G	P	
OCTYL ALCOHOL	1	E	E	
OLEIC ACID	0	E	G	
OXALIC ACID	3	E	E	
PALMITIC ACID		G	F	
PCB (POLYCHLORINATED BIPHENYLS)	2	G	P	

PENTACHLOROPHENOL	3	G	P	
PENTANE	1	E	P	
PERCHLORIC ACID, 30-70%	3	F	F	Neoprene (F)
PERCHLOROETHYLENE	2	G	P	
PEROXYACETIC ACID		P	P	Butyl (G)
PETROLEUM ETHERS, 80-110C	1	G	P	
PHENOL	4	F	F	(F)
PHOSPHORIC ACID	3	G	F	
PICRIC ACID	3	E	G	
POTASSIUM HYDROXIDE	3	E	G	
POTASSIUM IODIDE		G	G	
PROPYL ACETATE	1	F	P	Butyl (F)
PYRIDINE	3	P	P	Butyl (G)
SODIUM CARBONATE		E	E	
SODIUM CHLORIDE		E	E	
SODIUM FLUORIDE	3	G	G	
SODIUM HYDROXIDE,30-70%	3	G	E	
SODIUM HYPOCHLORITE		E	E	
SODIUM THIOSULFATE		G	G	
STYRENE	2	P	P	Polyvinyl Alcohol (G)
SULFURIC ACID, <70%	3	F	G	
SULFURIC ACID, >70%	3	P	P	Butyl (G)
TANNIC ACID	0	G	G	
1,1,1,2-TETRACHLOROETHANE		F	P	Viton (G)
TETRAHYDROFURAN	2	F	P	Teflon (G)
TOLUENE	2	F	P	Viton (G)
TOLUENE-2,4-DIISOCYANATE (TDI)	3	P	P	Butyl (G)
1,2,4-TRICHLOROBENZENE	2	F	P	Teflon (G)
1,1,1-TRICHLOROETHANE	2	P	P	Viton (G)
1,1,2-TRICHLOROETHANE	2	P	P	Viton (G)
TRICHLOROETHYLENE	2	P	P	Viton (G)
TRICRESYL PHOSPHATE	2	G	G	
TRIETHANOLAMINE	2	E	E	
TURPENTINE	1	E	P	
XYLENES	2	F	P	Viton (G)

The National Fire Protection Association (NFPA) has developed a system for indicating the health hazards of chemicals:

4	**Danger, may be fatal on short exposure. Specialized protective equipment required.**
3	**Warning, corrosive or toxic.**
2	**Warning, may be harmful if inhaled or absorbed.**
1	**Caution, may be irritating.**
0	**No unusual hazard.**
	No information available. Avoid skin contact or inhalation..

The compatibility of the glove films with each chemical is color coded as follows:

P	**POOR chemical resistance**
F	**FAIR chemical resistance**
G - E	**GOOD to EXCELLENT chemical resistance**

13. Chemical Waste Satellite Accumulation

As required by the U.S. Environmental Protection Agency and the Maryland Department of the Environment, each laboratory at NIST that generates chemical waste must have a designated Satellite Accumulation Area (SAA) (see example below). Each Division at NIST must assemble a list of SAAs and submit this list to the NIST Safety, Health, and Environment Division (x5822). Each SAA must meet the following requirements:

- Chemical waste must be stored in containers* that are in good condition and compatible with the chemical constituents.
- Chemical waste containers must be labeled** with a list of the constituents, an estimate of the percent volume of each constituent, the hazards associated with the waste, and contact information for the individual generating the waste (see NIST Chemical Waste Label below).
- Chemical waste containers must be sealed with a screw on lid. If the waste is undergoing an active chemical reaction that will generate a gas and build up pressure in a sealed container, do not seal the container until you are certain that the reaction is complete. Alternatively, containers can be purchased that have pressure relief valves.

Typical Satellite Accumulation Area at NIST

- Allowing chemical waste to evaporate as a means of disposal is not acceptable.
- Chemical waste containers must be kept closed (funnels removed) when they are not being filled.
- Chemical waste containers must be stored within spill containment bins.
- Incompatible chemical wastes must be segregated into separate bins.

Chemical waste pick up requests can be submitted at:

https://safetyp.nist.gov/apps/waste/SitePages/default.aspx

Up to 55 gallons of hazardous waste and 1 quart of acutely hazardous waste*** can be stored at a SAA. If either of these maximum quantities is reached at an SAA, the waste must be removed immediately. Notify the NIST Safety, Health, and Environment Division (x5822) at least two weeks prior to reaching the maximum quantities.

Chemical waste containers are available, free of charge, from the NIST Safety, Health, and Environment Division.

***Chemical Waste Labels are available, free of charge, from the NIST Storeroom and from the NIST Safety, Health, and Environment Division.*

NIST	CHEMICAL WASTE				
Chemical Name:					
Hazard (NFPA 704)	Circle One (4 being the highest hazard)				
Health:	4	3	2	1	0
Flammability:	4	3	2	1	0
Reactivity:	4	3	2	1	0
Special Hazards:					
Contact Name:					
Div./Bldg./Rm:					
Extension:					
Constituents % Volume	Name of Each Constituent (no acronyms or trade names)				

NIST Environmental Compliance Group: 301-975-5822/5130
Pick Ups: http://www-i.nist.gov/admin/ohsd/chemwast.htm

****Acutely hazardous wastes are defined in the Code of Maryland Regulations 26.13.02.19 and the Code of Federal Regulations 40 CFR 261, Subpart C. A current listing of acutely hazardous wastes can be obtained from the Safety Health and Environment Division (x5822).*

14. Change Log

Date	Version	Initials	Changes
7/01/09	1.0	REH	Added Change log. Removed old labeling instructions from appendix, section 12. Added updated labeling instructions HSI #15-May 2009. Updated Chemical Storage, Section 5.8, defining the chemical shelf heights for user and bulk storage areas. Added neutralization instructions for disposing of acids and bases, section 5.10. Added new process gases, hazards, and locations to the compressed gas table (HBr, SiCl4, CH4, C2F6), Section 6.2. Added hyperlinks to nanoparticle safety section 7.2 and 7.3 Added a section on pyrophorics and organometallics, section 5.11
12/14/10	1.1	REH	Modified section 2.2 to reflect new orientation procedure Modified section 2.5 to reflect new hours of operation
1/4/11	1.2	REH	Updated Section 4.4, After-hours usage policy
1/6/11	1.3	REH	Updated introduction. Added chemical record keeping information to section 5.1 Updated chemical deliveries section 5.1 Updated chemical labeling section 5.1 Updated section 5.2 PPE (SCBA training updated)
1/7/11	1.4	REH	Changed section 5.5 title MSDS to Material Safety Data Sheets (MSDS) Updated Section 5.5 Material Safety Data Sheets
2/24/11	1.5		Updated Section 5.1
2/25/11	1.6	REH	Updated section 5.7, 5.8
2/28/11	1.7	REH	Rewrote section 5.10 to include waste neutralization instructions
3/02/11	1.8	REH	Added chemical waste disposal information charts to section 5.10 Updated section 5.11, Pyrophoric liquid and Organometallics Added section for Piranha Solutions
3/03/11	1.9	REH	Removed section 2.9, NanoFab Safety Committee as per Vince's request Updated contacts in section 9.1
4/12/11	1.10	REH	Revised section 5.10 • Added scope • Deleted chemical categories chart • Modified disposal chart-collect Chrome etch • Modified instructions • Added labeling is present at all neutralizer drains and sinks

			• Added “Never pour toxic organics to drain” • Added safe pH range for dumping 7 to 9 pH.
4/14/11	1.11	REH	Updated section 2.3; removed restriction on cleaners entering into locker rooms Finalized section 5.10, Waste Neutralization
5/12/11	1.12	REH	Restricted Iodide etchants from neutralization on table, page 14
6/10/13	1.13	JLB	Updated section 9 and 10
8/21/13	1.14	REH/JLB	Updated to include all NanoFab laboratories
9/4/13	2.0	LJW	Some content editing for clarity; remove some redundant appendices; complete reformatting.