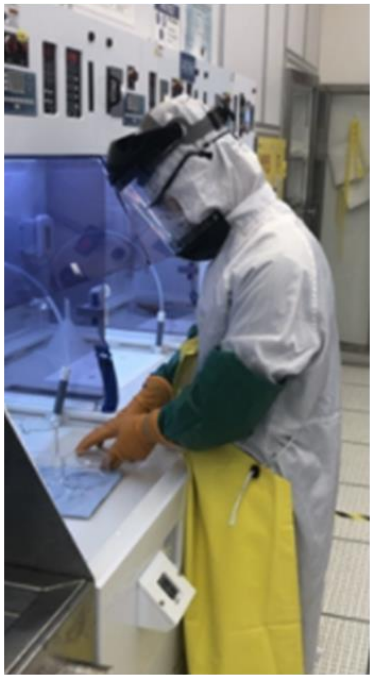
The CNST NanoFab Safety Manual



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

CNST NanoFab Manager, nfmanage@nist.gov

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1 Overview

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 online safety training and in-person orientation walk through. The online safety training is required annually to maintain access.

Detailed guidance on working safely in the NanoFab can be found in the CNST NanoFab Safety Manual. The CNST NanoFab Safety Manual can be found on the safety page of our website at https://www.nist.gov/cnst/safety. 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.

For additional information about the NanoFab including operating hours, location, rates, and more, please visit our website at https://www.nist.gov/cnst.

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 online safety training and in-person orientation walk through, 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 F and G corridors 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.

The CNST NanoFab laboratories include

Class 100 cleanroom, building 215 room D101

Post processing lab, building 215 room C02-2

G corridor labs, building 216 G corridor

F corridor labs, building 216, F102, F108, and F110

SubFab, building 215 room A001

Bead blast, building 215 room D08

2 General Lab Procedures

2.1 Access

The experience of potential users will be determined prior to granting access to the required CNST NanoFab safety training. Potential users will be required to fill out a form outlining their processing and safety experience. Users with limited experience may need additional guidance before being permitted to work in the NanoFab.

Access to the NanoFab is only granted to certified users who have completed the required online safety training and in-person orientation walk through. The online safety training includes testing of the safety training material and is required annually. The user will be granted 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 Access for NIST internal users

Prior to starting the CNST NanoFab specific training the group leader is responsible for assigning the following courses and verifying the completion for their staff.

NIST S 7101.21: Personal Protective Equipment Program Training

NIST S 7101.59: Chemical Hazard Communication Program Training

NIST S 7101.60: Chemical Management Program Training

NIST S 7101.60: Hydrofluoric Acid Safety for NIST Staff

2.3 New User Orientation and Safety Training

The online safety training and NanoFab orientation walk through is required to gain access to any NanoFab laboratory. The in-person orientation walk through is available every week on Monday morning and takes about 2 hours to complete; if NIST is closed on a Monday, then orientation will be offered on Tuesday. Please contact the NanoFab User Office to schedule your online and in-person training. The training is done in two parts:

Online course assessment covers chemical handling, general laboratory safety, best practices and course assessment at https://cnst-training.nist.gov.

The online safety training includes 40 knowledge check questions. A score of 90 % or higher is required to complete the course.

*** (NOTE–Internal NIST users must first be assigned this training by their supervisor/group leader through the SET website.) ***

NanoFab Orientation is a staff-guided walking tour through the NanoFab pointing out need to know locations, safety devices, and specific NanoFab working procedures.

2.4 Cleanroom

The NanoFab cleanroom is a class 100 cleanroom defined as having less than 100 particles 1 micrometer in size in one cubic foot of air. There is a specific gowning protocol that all personnel who enter must adhere to. Many normal laboratory activities are restricted.

2.4.1 Main Cleanroom Entrance (Building 215/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 into the cleanroom without permission.***

2.4.2 Locker Rooms

The lockers and hangers are for all users of the cleanroom. Non-frequent users 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, notebooks, etc. Locks are not to be kept on overnight. ***Do not store chemicals in lockers or locker room***.

2.4.3 Gowning

This area is a controlled environment and should only be accessed by certified users. Do not bring dirty or questionable items into this area. Regular paper or cardboard is not allowed. ***Do not bring process chemicals through the gowning area, including fresh chemicals, chemical waste, or other hazardous materials***.

Pre-gowning: Prior to entering the gowning area, users must pre-gown in the locker room. Pre-gowning is required to access the class 1000 areas and service chases however is not sufficient to access the class 100 lab space. Pre-gowning consists of:

Safety glasses

Shoe covers

Hair net

Face mask

Gloves

NOTE: pre-gowning items are not removed until exiting the lab. Do not remove pre-gowning items in the gowning room.

Final gowning: Prior to entering the class 100 areas all personnel must don final gowning that can be found on the shelves just outside of the locker rooms. Final gowning must be performed from top down and consists of:

Class 100 hood

Class 100 coveralls

Class 100 boots

NOTES:

do not allow any part of the class 100 gown to drag on the floor.

De-gowning is performed in reverse order from the bottom up, be sure to keep your pre-gowning items on.

Only take one gown per week. If returning, place your gown into a labeled cubby.

Notify staff if your gown was damaged.

2.4.4 Cleanroom

The Cleanroom areas can be accessed by a certified user, NanoFab staff member, Environmental Services and authorized Plant Personnel. 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 NanoFab staff members. The chemicals for the Cleanroom are retrieved from the chemical storage areas and properly transferred (see section 5.1 Chemical Handling) to the service chases adjacent to the Cleanroom bays and placed into the appropriate chemical pass-throughs, fume hood cabinets or bay storage cabinets.

2.4.5 Class 1000 areas

The outside hall located on each side of the cleanroom is the class 1000 area. The class 1000 areas contain safety showers, eyewash stations, fire extinguishers, and automatic external defibrillator (AED) stations.

2.4.6 Service areas (NanoFab Staff Only)

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 building 215 can be accessed by NanoFab staff members, vendor delivery personnel, and plant personal only.

2.4.7 Cleanroom logout

The logout tablet will indicate any issues on logout.

A green screen indicates the user is logged out of the cleanroom and all tools.

An orange screen indicates the user is logged out of the cleanroom but still logged into at least one tool.

A red screen indicates a problem, and the user must contact the user office.

2.5 Non-Cleanroom Laboratories

2.5.1 Building 216/F corridor

This area houses the soft-lithography lab, the TEM sample preparation laboratory, sample characterization equipment, and posting processing including wire bond and die bond.

2.5.2 Building 216/G corridor

This area houses the advanced imaging equipment, e-beam lithography, and XRD metrology.

2.5.3 Building 215/C02

This area houses the post processing equipment such as dicing and CMP.

2.6 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.

2.7 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 3.6). Authorized users utilizing the Cleanroom outside of these operating hours must have authorization and comply with any and all responsibilities defined by the NanoFab management.

2.8 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.

2.9 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.

2.10 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.

2.11 NEMO

The CNST NanoFab utilizes a web application named NanoFab Equipment Management Operation (NEMO) to manage the laboratory. It is available to qualified users at https://nemo.nist.gov. NEMO performs many functions including allowing users to reserve and enable tools and alert staff when users encounter problems with the tools. The tools are interlocked and will not function unless enabled by a qualified user in NEMO. NEMO can also be used to alert staff of safety problems. A NEMO tutorial can also be found on the CNST NanoFab website at https://www.nist.gov/cnst.

2.12 Picture and Video Policy

Recording video is not allowed in any CNST NanoFab laboratory. This includes recording with cell phones or any other type of video recording device. Pictures may be taken with permission from the CNST NanoFab management. Equipment alarm or error log screens may be photographed for the purpose of sharing with the NanoFab staff.

2.13 NanoFab closure

Weather related and other closures of the NanoFab labs will be announced through email and NEMO. If the NIST campus is closed, the NanoFab will also be closed. The NIST campus status can be checked on the NIST website at nist.gov.

2.14 Emergencies

There are many dangers in the NanoFab labs. The proper course of action for most emergency situations is to use a laboratory phone to dial extension 2222 to reach NIST emergency services and follow their instructions. In the event a laboratory phone cannot be used, call 911 from a mobile phone. Clearly identify the type of emergency and your location as NIST.

Response to chemical spill emergencies is detailed in section 4, Chemical Safety.

2.15 Etiquette

2.15.1 Chemical Safety Questions

If you are unsure about something, ASK

Staff members wear blue hoods so they are easily identifiable

Not sure how to dispose of a chemical, ASK

Unsure of how to mix something, ASK

Not sure what PPE to use, ASK

Not sure what labware to use, ASK

2.15.2 General user etiquette

Clean up after yourself

Answer the phone

Consult with a staff member when questions or problems arise

Follow safety guidelines

Report any safety violations to staff

Do not take other users tools

Bring your own tweezers

Do not use Teflon process boats to store substrates

2.15.3 Prohibited items

Pencils are not allowed in the cleanroom, always use pens

Regular paper and cardboard are not allowed in the cleanroom

Cleanroom paper and cleanroom notebooks are available from the CNST NanoFab, see a staff member

2.15.4 Supplies and substrates

Supplies such as silicon wafers, tweezers, and cleanroom notebooks are available from the CNST NanoFab for purchase if needed

Supplies are stocked and sold in limited quantities and should not be considered a primary means of procurement

Users are allowed to bring in solid substrates such as silicon, gallium arsenide, quartz, alumina or other pre-approved substrates

Substrates cannot be immersed in liquid when entering or leaving the NanoFab labs

2.15.5 Storage bins

Keep storage bins neat

Do not keep chemicals in storage bins

Users are allowed only one storage bin, excess items should not be stored in the cleanroom

Contact the NanoFab user office for more information about storage bins

2.15.6 Fume hood etiquette

Label all beakers and chemicals while in use including name, contact information, and date.

Label chemicals and beakers left unattended including name, contact information, date, and when you plan to return.

Cover all chemical dishes

Hotplates may not be used overnight

Dispose of waste appropriately

Do not leave dirty dishes

Put rinsed dirty glassware on the cart

Remove any photoresist residue

Cleanup inside hoods and benches

2.16 Equipment Use

2.16.1 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. Requests for tool training can be made directly to the staff member assigned to the tool. Tool staff owners can be found on the CNST NanoFab website tool listings or in NEMO.

2.16.2 Equipment Login/Logout

Equipment must be activated in NEMO prior to use. Be sure to log out of all tools you are no longer using prior to leaving the lab. Adjustments to usage time will only be considered for tool problems. A usage adjustment for failing to logout of a tool will not be considered. When exiting the cleanroom, there is a tablet near the gowning room that lists all tools that users are currently logged into.

2.16.3 Equipment Operations

Standard operating procedures (SOP) are shown to the user during equipment training. Users must follow the instructions of the SOP while operating the equipment. An SOP is available at each tool for reference.

2.16.4 Equipment Problems

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

3 Laboratory Practices

3.1 Qualified Users

Only qualified CNST NanoFab users are allowed access to the CNST NanoFab cleanroom and external laboratories.

Qualified users are defined as NanoFab users who went through the NanoFab safety orientation training, have an active project and an active NIST badge.

3.2 Visitors

Visitors and observers are not allowed in the CNST NanoFab cleanroom and the external laboratories.

CNST NanoFab staff can provide a short window tour that generally lasts 30 minutes by request to nfmanage@nist.gov

Video tours are available on the CNST NanoFab website at https://www.nist.gov/cnst.

3.3 Badge Access

Each user must badge into the cleanroom or external lab. Do not follow someone else into the cleanroom or lab without badging in. If your ID does not unlock the door, see the user office. When exiting the cleanroom, be sure to badge out.

3.4 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 4.3.3).

3.5 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 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.

3.6 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 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.

3.6.1 Authorization

Users must receive prior authorization EACH time off hours lab access is needed. Authorization is approved by the CNST NanoFab management only. Send a request to nfmange@nist.gov including details of what off hour access is requested and who their buddy will be. Also, be sure to CC your buddy.

3.6.2 Buddy system

Any user wishing to access the Cleanroom off hours must be accompanied by another qualified NanoFab user. Both users must be signed in.

3.7 NanoFab Shutdown

NanoFab shutdowns are regularly scheduled events and may also occur in the event of a storm, building faults, emergency, etc. NanoFab staff members are 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. Updates can be found on the NEMO homepage.

3.8 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. All safety glasses must meet ANSI Z87.1 standards and have side shields. Safety Glasses are required at all times when working in the Cleanroom 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.

3.9 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.

3.9.1 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, the shelter-in-place is in the men's or women's locker room. In the building 216 laboratories, the shelter-in-place is located in the center hallway of the building (E-corridor).

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 gowning 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 an 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 verbal instructions to evacuate the building. Toxic gas detector alarms are only in building 215. Please evacuate the lab immediately — ***do not stop to remove gowning 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 an EMS responder or NanoFab Staff member).

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.

3.9.2 Emergency Evacuation Procedure

Activate the nearest fire pull box or call extension 2222 if a fire occurs.

Do not stop to remove your gown if you are in the Cleanroom.

Contain any hazardous work in progress if possible.

Leave the lab through the nearest exit.

Avoid heading towards the Oxidation/Diffusion Furnace room (B106). This area has many of the hazardous gases being used.

Proceed to the evacuation area

> Cleanroom and building 215 laboratories evacuation meeting area is across the street.
>
> Building 216 laboratories evacuation meeting area is in the building 216 parking lot near the solar panels.

3.10 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.

4 Chemical Safety

4.1 Chemical usage

4.1.1 Fume Hoods and wet benches

Chemicals may only be used inside a fume hood or wet bench. Stainless steel hoods are for solvents. Poly (plastic) hoods and wet benches are for acids, bases, and developers. Fume hoods and wet benches are exhausted so chemical fumes are removed from the cleanroom. The PPE required is posted at each fume hood. When multiple users are working at a wet bench or fume hood, be aware of the chemicals in use and be respectful of others space.

Fume hoods with adjustable sashes must be set to the proper level to protect the users face as well as to ensure adequate exhaust.

To ensure fume hood safety users:

- Must immediately report odors or problems to the NanoFab staff
- Must never put your head inside of the hood
- Must never block the exhaust returns
- Must never work outside or at the extreme edge of the exhausted area
- Must rinse and dry hood surface completely when finished
- Must not leave any dirty dishes or wipes behind

When working at wet decks users:

- May aspirate and drain RCA SC1 and SC2
- May aspirate and drain baths at any temperature
- Must rinse and dry decks completely when finished
- Must replace all covers when finished
- Must not leave any dirty dishes or wipes behind

Fume hood and wet bench etiquette

- Label all beakers and chemicals while in use including name, contact information, and date.
- Label chemicals and beakers left unattended including name, contact information, date, and when you plan to return.
- Cover all chemical dishes
- Hotplates may not be used overnight
- Dispose of waste appropriately
- Do not leave dirty dishes
- Put rinsed dirty labware on the cart
- Remove any photoresist residue
- Cleanup inside hoods and benches

4.1.2 Chemical containers

The CNST NanoFab provides a variety of containers for wet chemistry applications. The labware used should be chemically compatible and large enough to easily work with samples.

NOTE:

- Piranha solutions should always be prepared in a pyrex or glass container
- Hydrofluoric (HF) acid should only be prepared in a Teflon or plastic container
- A watch-glass cannot be used as a chemical container. A watch-glass is used to cover labware with chemicals

All labware containing chemicals must be covered

4.1.3 Pouring chemicals

When pouring chemicals always:

Wear appropriate PPE

Hold the bottle you are pouring from with two hands

Hold one hand firmly around the neck and the other supporting the bottom

Pour only what is needed for the process. Fill level should be slightly above substrate surface

Minimize waste

Label the container even if it contains water

Cover the container

When pouring chemicals never:

Pour with one hand

Pour too fast

Allow the chemical to splash

Overfill a container. Overfilled containers are a spill hazard

Full chemical bottles can be difficult to pour especially into a shallow dish. When pouring from a full bottle, first pour into a tall form factor beaker then pour from the beaker into a shallow dish. Dispose of any extra chemical. Never pour chemicals back into the bottle.

4.1.4 Diluting chemicals

When diluting a chemical with water, mix by adding the chemical to the water. Never add water to chemicals. To mix:

Measure the desired amount of water into a beaker

Measure the desired amount of chemical into a separate beaker

Pour water into the container first

Then, add the measured chemical to the container with the water **(Always add chemical to water)**

Cover the diluted chemical with a watch-glass

4.1.5 Chemical exposure

In case of accidental chemical exposure:

Do not stop to contain the spill

Remove contaminated clothing

Rinse with copious amounts of water at a sink, eyewash station, or safety shower

Seek assistance by calling extension 2222

HF exposure requires special procedures outlined in section 4.9 HF Safety.

4.2 Chemical compatibility

4.2.1 Acids and solvents

Acids and organic solvents:

Should never come in contact with each other

React chemically to produce violent reactions

Produce gases and large amounts of heat when mixed

4.2.2 Heating solvents

For safety reasons, the CNST NanoFab only allows heating of resist removers 1165 and Remover PG. The maximum **hotplate** temperature allowed is 80 °C. No other solvents may be heated.

4.2.3 Oxidizers

Oxidizers should never come in contact with:

Organic acids

Organic solvents

Reactions produce gases and large amounts of head when mixed.

4.3 Receive, Transport, Storage, Label and Record Keeping

Handling chemicals in the NanoFab laboratories is a common practice. Chemicals are stored in chemical cabinets, passthroughs and chemical storage bins under acid and solvents hoods throughout the cleanroom.

4.3.1 Chemical Deliveries/Receiving

Chemicals are delivered to building 215, room D108.

NanoFab staff members will retrieve the chemicals and enter them into the Chemical Inventory Management System (CIMS).

NanoFab contractor will print out the CIMS label, place a barcode sticker on the container, wipe them down, and place them into the appropriate chemical storage locations.

All chemicals must be handled with chemical resistant gloves and eye protection.

4.3.2 Transport

Do not carry chemicals by hand

Use bottle carriers when transporting bottles. Use the chemical cart if transporting multiple bottles

Do not transport chemicals that are in compatible

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

4.3.3 Chemical Storage

Chemicals are to be stored in the properly designated areas

Signs are posted next to the chemical storage

In-use chemical storage is located underneath the fume hoods

Small volumes of solvents are kept in plastic bottles on the counter or underneath fume hoods.

Never store a solvent next to an acid

Never store a base next to an acid

Ammonium hydroxide is stored with oxidizers

4.3.4 Labeling

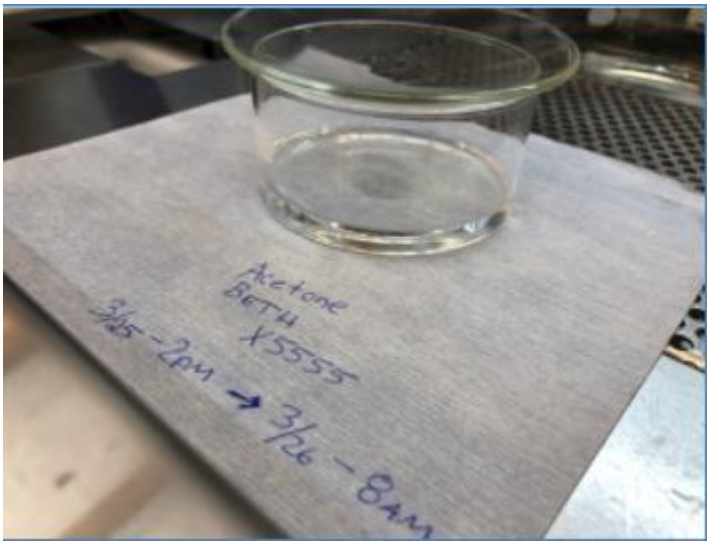
Federal regulations require all hazardous chemical containers to be properly labeled according to OHSA 1910.1200 Hazard Communication. This regulation states that the chemical hazard information for all materials must be transmitted to the end user and anyone who may be in contact with the material at any time.

Labels used in NanoFab

CIMS labels are used on original manufacture bottles. An example of the label is shown in picture below:

Orange labels are used on small bottles – decanted from the large ones. An example of the orange label is shown in picture below:

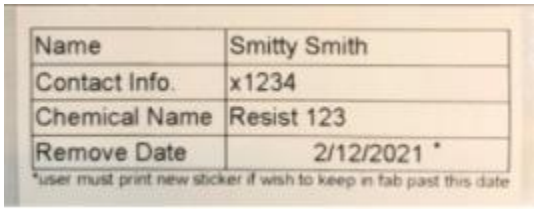
Temporary labels are used when users are working at a bench. The temporary labels must include chemical name, the owner's name, the owner's contact information and date, and return date and time if owner will be used for subsequent days. Unlabeled containers will be tested using a liquid identification kit to determine proper disposal and your project will be charged for the kit. An example of the temporary label is shown below:



Labeling User Owned Chemicals

User owned chemicals must add a sticker put on the bottle in addition to CIMS label. This allows NanoFab staff to distinguish user owned chemicals from general NanoFab owned chemicals.

The sticker must include chemical name, owner's name, owner's contact information and removal date. The removal date will be one year from the date the label was created. The removal date is used so the NanoFab staff can periodically remove chemicals that are no longer utilized. Users must obtain a new sticker before the date is reached if user wishes to continue using the chemical. Chemicals with labels past the removal date will be disposed without any notification. If a user wants to keep a chemical past the expiration, they are responsible for printing a new sticker using the label printer found in cleanroom bay B101. An example of the sticker is shown below:



Name	Smitty Smith
Contact Info.	x1234
Chemical Name	Resist 123
Remove Date	2/12/2021 *

*user must print new sticker if wish to keep in fab past this date

NO CHEMICALS INCLUDING WATER SHALL BE USED IN THE NANOFAB WITHOUT PROPER LABELING.

Record Keeping

All hazardous materials used or stored in the NanoFab are entered into a CIMS, a NIST-wide chemical inventory database. This system is accessible on NIST internal website: https://nistsafety.nist.gov/CIMS/Product.

4.4 Personal Protective Equipment

Proper Personal Protective Equipment (PPE) is mandatory when using chemicals. In addition, special protective equipment and PPE trainings are required for NanoFab staff members when performing toxic gas bottle changes (ex. SCBA, respirators).

4.4.1 PPE Requirements when using chemicals

There are several types of fume hoods and wet decks that are used in the NanoFab labs. A sign with all required PPE is posted at each. PPE should only be worn while in use at a hood or bench. Do not use other equipment or computers while wearing PPE. Prior to donning PPE, inspect each piece of PPE. Discard the piece of PPE if any damage is found.

Solvents

Solvent PPE required is listed below and should be put on in the following order:

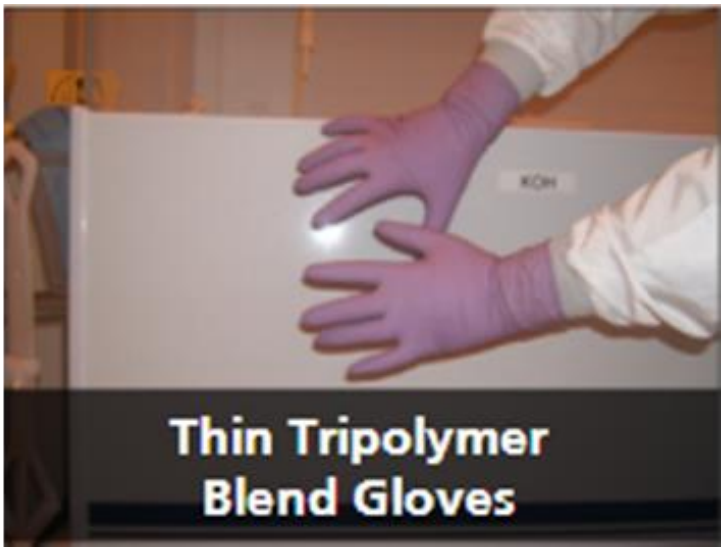
Face shield

Thin Tripolymer-Blend Gloves over Cleanroom gloves

NOTE:

Do not touch face shield with solvent gloves

Remove in reverse order, dispose solvent gloves in solid solvent waste container



Acids, Bases, developer and TMAH

The PPE required for acid, base, developer, and TMAH is listed below and should be put on in the following order:

Chemical apron

Face shield

Thick Tripolymer-Blend Gloves over Cleanroom gloves

Protective Arm Sleeves

NOTE:

Do not touch face shield with gloves

Remove in reverse order

4.4.2 PPE Training, certificate and testing (NanoFab Staff Only)

SCBA equipment and training for toxic gas bottles:

This training can only be provided to NanoFab staff who have completed the required medical exam and have passed fit testing

The medical exam will be done at NIST Health Unit and is arranged by the staff member

The fitting test is conducted on the NIST Gaithersburg Campus. Contact OSHE at x5375, option 3 to schedule

Annual training on Compressed Gas Safety (NIST S 7101.61) is required

Bottle change-outs training from a certified outfit (NFPA 318) is required

The certification for SCBA equipment is good for one or two years depending on the medical evaluation

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

The supervisor will keep a record of a staff member's SCBA certificates and required trainings.

The supervisor will assign repeat trainings before the certificate expires

The supervisor will maintain a list of technicians performing this duty

4.5 Chemical Spills

A chemical spill is an unintentional release of a product in an area that was not intended to contain the material.

In the event of a chemical spill:

Know what to do

Act swiftly

Immediate judgements must be made regard the degree of potential risk to personnel and the environment.

When a spill occurs, determine the severity by asking:

What was spilled?

How much was spilled?

Where was the material spilled?

4.5.1 Emergency chemical spills

Emergency chemical spills present an immediate danger to life and health. All unknown chemical spills are to be considered emergencies.

In the event of an emergency chemical spill:

Evacuate all personnel through an exit away from the spill

Assure the no one enters the area

Contact the NIST Fire Protection Group at x2222 or by pulling a fire pull box

Proceed to the evacuation area as described in section 3.9 NanoFab Alarms/ Evacuation

4.5.2 Non-Emergency chemical spills

Non-emergency chemical spills present absolutely no harm to personnel or the environment. Examples include spills of water, pump oils, and commercial cleaners.

In the event of a non-emergency chemical spill:

Contact the NanoFab staff using a phone away from the spill

Initiate cleanup procedures if applicable

4.5.3 Spill response procedures

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.

4.6 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 station use

activate the eyewash

using the thumb and fingers, hold open the eyes, and rinse for several minutes

call NIST Emergency Services at x2222

Eyewash station locations

At the ends of the chemical wet benches (B101, B102)

In the class 1000 corridors immediately outside the Cleanroom proper.

Safety Showers

In the class 1000 corridors immediately outside the Cleanroom proper. If you are exposed to a spilled material, remove contaminated clothing and activate the shower by pulling down the handle.

4.7 Safety Data Sheets (SDS)

SDS provides information about a 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 SDS information when purchasing chemicals. The safety data sheet should be read and understood prior to working with an unfamiliar chemical. Safety Data Sheets are available on NIST CIMS (https://nistsafety.nist.gov/CIMS/Product).

In addition, users can review safety data sheets by following the SDS Directory link on the NEMO landing page at https://nemo.nist.gov/. This feature requires the use of Internet Explorer.

4.8 User Chemical Approval

CNST NanoFab users must obtain approval from the NanoFab Manager prior to ordering chemicals. This includes chemicals that may have been approved in the past or are currently being used. Approvals are not guaranteed. Requests maybe turned down if the chemical is too hazardous or incompatible with other NanoFab laboratory processes, or user chemical storage space reaches limitation.

Users should email a request to the NanoFab manager (nogchemistry@nist.gov) including SDS of the chemical, detailed write-up of the processes that highlight how the chemical will be used in the CNST NanoFab, chemical volume and how long the chemical will be used in NanoFab.

Users shall wait for approval with instruction. Users shall never order or ship chemicals prior to receiving approval.

Users are not allowed to carry chemicals onto NIST campus – this is in violation of Department of Transportation (DOT) laws. All chemicals must be shipped to NIST following all DOT laws for hazardous shipments.

Once the chemical arrives NanoFab, staff will enter the necessary information into CIMS and place appropriate labels.

For external NanoFab users, chemicals are not allowed to leave the NanoFab facility after they are approved and shipped. NanoFab will dispose the chemicals after they are no longer needed in the NanoFab. Unapproved shipped chemicals will be disposed.

4.9 HF Solutions

Hydrofluoric acid (HF) is very dangerous chemical. Buffered Oxide Etch (BOE) contains HF. Because HF and BOE are 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.

High concentration burns from HF (above 12.5 % concentration) will produce immediate symptoms. Low concentration burns may be initially painless.

HF etches glass. Do not use glass dishes for HF. Use Teflon or plastic dishes when working with HF.

How to use HF or BOE

4.9.1 Exposure Controls

All work All work involving HF or BOE solutions must be done inside an acid fume hood to prevent inhalation exposures. Wear proper laboratory attire (pants and closed-toe shoes required under Cleanroom gown), and acid PPE.

4.9.2 Safe Handling

Always use Teflon or plastic dishes to prepare HF or BOE solutions. HF and BOE etch glass and must never be prepared in a Pyrex or glass containers.

Use small quantities to reduce spill hazards and minimize waste. The amount should be slightly above the surface of the substrate.

The container should always be covered and labeled properly.

4.9.3 Pouring Procedure

Always use Teflon or plastic dishes

Carefully pour and measure the solution into a plastic or Teflon beaker.

The amount poured should be slightly above the surface of the substrate.

Cover with a Teflon watch-glass and label the container.

4.9.4 Waste Storage and Disposal

After use, dispose the solution to the NanoFab waste neutralization system.

Do not store waste HF or BOE solutions.

Thoroughly rinse all chemical containers with water and place on the dirty dish cart.

4.9.5 Emergency Procedures

Eye/ Skin Contact:

When exposed to HF or BOE:

Remove all contaminated clothing.

Rinse with copious amounts of water for minimum 15 minutes.

Apply 2.5 % Calcium Gluconate (Calgonate) topical gel, and massage into the affected area. Calcium Gluconate can be found at each HF processing bench.

Immediately have someone Call extension 2222 to report the incident.

Visit local hospital.

Spills:

Notify personnel in the area and call x2222. Restrict access.

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 An HF solution spill that is health threatening, or is greater than 30 ml.

4.10 Chemical Storage

Chemicals are to be stored in the properly designated areas in the NanoFab cleanroom. Make sure to read all the signs in the cleanroom. In-use chemical storage is located underneath the fume hoods. Small volumes of solvents are kept in plastic bottles on the counter or underneath fume hoods.

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 a base next to an acid. They can react violently causing the substance to splash onto the user. Ammonium hydroxide is stored with oxidizers and not with other solvents.

Never store chemicals in storage bin. 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 requirement 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).

4.11 Pregnancy

Users who are pregnant are permitted to use the NanoFab but may want to discuss the situation with the NanoFab manager, their personal physician, or with the NIST Health Unit Physician.

4.12 Chemical Waste Disposal

4.12.1 Non-Chlorinated Solvent Disposal

Non-Chlorinated solvents (acetone, isopropanol, 1165) can be disposed in the general solvent waste containers

Each solvent fume hood has a funnel or opening in the deck where general solvent waste can be disposed

The labware container shall be then rinsed with water, and the water rinse waste can be disposed down the sink drain

Place rinsed dirty labware container on the dirty dish cart

Empty solvent bottles should be capped and placed on the bottom shelf of the dirty dish cart

4.12.2 Chlorinated Solvent Disposal

Chlorinated solvents (methylene chloride used for PMMA liftoff) cannot be disposed in the general solvent waste containers.

Specially labeled “Chlorinated Solvent Waste” bottles are used for disposal of chlorinated solvents.

Special process:

Pour chlorinated solvent from labware container into the chlorinated solvent waste bottle

Rinse with isopropanol with rinse waste going into the chlorinated solvent waste bottle (NOTE: this step is necessary because chlorinated solvents do not rinse well from labware containers)

The labware container shall be then rinsed with water, and the water rinse waster can be disposed down the sink drain

Place rinsed dirty labware container on the dirty dish cart

Empty bottles should be capped and placed on the bottom shelf of the dirty dish cart

4.12.3 Acid and Base Disposal

Signs are posted above the sinks where acids and caustics may be dumped. Most acid and base solutions should be drained in the acid deck. There are many acids and caustics that can be poured directly down the drain. However, this is not the case for all of them. If you are unsure of a certain chemical, be safe and ask the NanoFab staff.

Most acid, corrosive and etchant can be poured down the drain in quantities less than 750 milliliters. However, there are exceptions. The acids and caustics that must be collected are posted at the acid hoods and include Titanium Etch, Nickel Etch, Gold Etch, Silver Etch, Chrome Etch, EKC 265 and organic acids such as Acetic Acid, SECCO Etch, Succinic Acid and Chromium etchant. Acid, corrosive and etchant waste not approved for disposal down the drain should be collected in a rinsed waster container and properly labeled. If you are not sure, ask the NanoFab staff.

Users may aspirate acid baths as needed.

After disposing of your chemical waste, rinse out your dishes in the lab sink and place them on the top shelf of the dirty dish cart.

Empty bottles should be capped and placed on the bottom shelf of the dirty dish cart.

4.12.4 TMAH Disposal

TMAH based developer waster is collected in containers located on the developer benchtop.

After disposing of your chemical waste, rinse out your dishes in the lab sink and place them on the top shelf of the dirty dish cart.

Empty bottles should be capped and placed on the bottom shelf of the dirty dish cart.

4.12.5 Liquid Waste Disposal Summary

A detailed list of chemicals and how they should be disposed of is listed in table below.

Chemical Waste Disposal Information Chart			
Chemicals	**Contents**	**Category**	**Disposal**
Acetic acid solutions	C2H4O2	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	***Collect***
Silver etchant type TFS	Iodine Complex, Potassium Iodide	Potassium Iodide Solutions	***Collect***
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	H2O2	Hydrogen peroxide Solutions	Neutralizer Drain
Nitric acid solutions	HNO3	Nitric acid Solutions	Neutralizer Drain
Ammonium fluoride	NH4F	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	C6H8O7	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	SiOx(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	H3PO4	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	***Collect***
Sulfuric acid solutions	H2SO4	Sulfuric acid Solutions	Neutralizer Drain
Non-Chlorinated Solvents	All	Non-Chlorinated Solvents	**Solvent Waste Funnel**
Chlorinated Solvents	All	Chlorinated Solvents	***Collect***

4.12.6 Solid Waste Disposal

Solid solvent waste – solid waste contaminated with solvents must be thrown away in the red waste cans.

Solid acid/base waste – solid waste contaminated with acids or bases must be thoroughly rinsed with DI water, wrung out, and thrown away in the regular trash receptacles.

Sharps waste such as broken glass or broken silicon wafers must be thrown away in a red sharps container.

Empty chemical bottles – cap empty chemical bottle and place on the bottom shelf of the dirty dish cart for disposal by the NanoFab staff.

If you are unsure, ask a staff member.

4.12.7 Chemical waste storage bottles

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 online Waste Pickup Request Form at https://nistsafety.nist.gov/CWP/PickupRequest/ to have the waste chemicals retrieved for disposal.

4.12.8 Accidental mixing of incompatible chemicals

If two chemicals that shouldn't be mixed are accidentally mixed:

If chlorinated and non-chlorinated solvents are mixed, notify NanoFab staff. There is no compatibility issue but the entire container must be disposed as chlorinated solvent.

If acids and solvents are mixed

Leave the cap off the bottle if it's been capped for less than one minute. Otherwise, leave the cap on.

Close the sash on the hood and evacuate the bay

Immediately notify the NanoFab staff

If NanoFab staff is not available, call extension 2222.

4.13 Pyrophoric Liquid and Organometallic Safety (Staff only)

The atomic layer deposition system uses organometallic precursors that are pyrophoric liquids. 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 liquid pyrophoric and organometallic materials currently in use in the NanoFab include Trimethylaluminum, (Trimethyl) Methylcyclopentadienyl platinum(IV), Bis(tert-Butylamino) silane, and Tetrakis (ethylmethylamino) hafnium.

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!

4.13.1 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.

4.13.2 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.***

4.13.3 Atomic Layer Deposition Precursor Chemical Hazard Summary Table

ALD Precursor Safety Information Spreadsheet				
Chemical Name	*Trimethylaluminum*	*(Trimethyl) Methylcyclopentadienyl platinum(IV)*	*Bis(tert-Butylamino) silane*	*Tetrakis (ethylmethylamino) hafnium*
MSDS Name	TMA	MeCpPtMe3	BTBAS	TEMAH
NFPA Hazard Ratings	**H=3, F=4, R=3** Special=~~W~~	**H=4, F=2, R=0** Special=~~W~~	**H=3, F=3, R=2** Special=~~W~~	**H=3, F=2, R=2** Special=~~W~~
Chemical Family	Aluminum alkyls	Metal Organic	Organosilane	Metal amide complex
Pyrophoric	yes	no	no	no
Water Reactive	yes, violently	yes	yes, violently	yes
Flammable	yes, extremely	no	yes, highly	yes
Extinguishing Media	Dry powder, vermiculite, soda ash, dry sand, or lime.	Water spray, alcohol-resistant foam, dry chemical or carbon dioxide	CO_2, dry chemical or foam	Dry chemical powder
Corrosive	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.	Avoid contact with skin and eyes. Avoid formation of dust and aerosols. Provide appropriate exhaust ventilation at places where dust is formed. Keep container tightly closed in a dry and well-ventilated place. Air sensitive. Handle and store under inert gas.	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.	Use a full-face supplied air respirator. Handle with gloves. Face shield and safety glasses. Complete suit protecting against chemicals,	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.	Air, water and moisture	Water, alcohols, acids, halogens or strong oxidizers.	Water, air, alcohol, acids, strong bases

4.14 Piranha Solution

Piranha solutions are a mixture of sulfuric acid with hydrogen peroxide in a ratio of 3:1 (H_2SO_4:H_2O_2). Piranha solutions are used to remove trace amounts of organic residue from the substrate's surface. When mixed,

the exothermic reaction produces heat in excess of 100 °C. Nano-Strip is a safer alternative to Piranha solution and should be used if possible.

4.14.1 Exposure Controls

All work All work involving piranha solution must be done inside an acid fume hood to prevent inhalation exposures. Wear proper laboratory attire (pants and closed-toe shoes required under Cleanroom gown), and acid PPE.

4.14.2 Safe Handling

Piranha solutions should always be prepared in a Pyrex or glass container.

Use a ratio of 3:1 sulfuric acid (H_2SO_4) to hydrogen peroxide (H_2O_2). Higher concentrations of hydrogen peroxide are not allowed.

Mixing order is critical. Always add the hydrogen peroxide to the sulfuric acid.

Use small quantities to reduce spill hazards and minimize waster. The amount should be slightly above the surface of the substrate.

The piranha container should always be covered and labeled properly.

4.14.3 Mixing Procedure

Carefully pour and measure the sulfuric acid into a beaker.

Carefully pour and measure the hydrogen peroxide into a separate beaker.

First, add the sulfuric acid to an empty glass container.

Then, slowly pour the hydrogen peroxide to the same container.

Cover and label the container.

4.14.4 Waste Storage and Disposal

After use, allow the solution to cool for 10 minutes before disposing the solution to the NanoFab waste neutralization system.

Do not store waste piranha solution.

Thoroughly rinse all chemical containers with water and place on the dirty dish cart.

4.14.5 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.

4.15 Chemicals and Gases Used at the NIST CNST Cleanroom

The chemical Inventory is listed in **CIMS** (available from inside NIST only). The dangers of each chemical are summarized in the CIMS system.

In addition, users can review safety data sheets by following the SDS Directory link on the NEMO landing page at https://nemo.nist.gov/. This feature requires the use of Internet Explorer.

5 Gas Safety (NanoFab staff only)

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.

5.1 Compressed Gas Delivery Emergency Response Program

This program is in place in case of a catastrophic release of any Hazardous Process Materials (HPM) 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.

5.2 Compressed Gas Safety Data Sheets

The compressed gas inventory is listed in **CIMS** (available from inside NIST only). The dangers of each gas are summarized in the CIMS system.

In addition, users can review safety data sheets by following the SDS Directory link on the NEMO landing page at https://nemo.nist.gov/. This feature requires the use of Internet Explorer.

5.3 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.	LHL Tube 4 LTO RHL Tube 4 Poly, PECVD	B106	HPM Bunker E05-2
Dichlorosilane	$SiCl_2H_2$	Corrosive, Toxic	LHL Tube 3 Nitride RHL Tube 3 Nitride	B106	HPM Bunker E05-2
Phosphine	PH_3	Unpredictable, burns in moist air. Poison	RHL Tube 4 Poly	B106	LPCVD Gas Box, B106
Ammonia	NH_3	Corrosive, Toxic	LHL Tube 3 Nitride, RHL Tube 3 Nitride	B106	Subfab A08
Hydrogen	H_2	Flammable	Atomic Layer Depositon, Oxford III-V Etcher, Oxford Metal Etcher, Oxford Silicon Etcher, LHL Tube 1 Oxide	B106, A106	Subfab A08, HPM Bunker E05-2
Oxygen	O_2	Supports combustion	4Wave Cluster Sputter; 790 RIE Middle; 790 RIE Nitride Left 790 RIE Right; Atomic Layer Deposition; Downstream Asher LHL Tube 1 Oxide; LHL Tube 2 Anneal; LHL Tube 4 LTO Microwave Asher; Oxford Metal Etcher ; Oxford Silicon Etcher RHL Tube 1 Oxide; RHL Tube 2 Anneal; SPTS Deep Si Etch; Unaxis Deep Si Etcher Unaxis ICP Etcher; AnnealSys RTA; E-Beam Evaporator; Ion Mill Oxford III-V Etcher; Sputter B104 Left; Sputter B104 Right	A104, A106, B106, B105, B104	Subfab A08
Sulfur Hexafluoride	SF_6	Low toxicity level	PECVD ; SPTS Deep Si Etch; Unaxis Deep Si Etcher; Unaxis ICP Etcher 790 RIE Middle; 790 RIE Nitride Left; 790 RIE Right Atomic Layer Deposition Oxford Metal Etcher Oxford Silicon Etcher	A106, B105, B106	Subfab A08
Trifluoromethane	CHF_3	Non-toxic. Asphyxiation.	790 RIE Middle; 790 RIE Nitride Left 790 RIE Right; Oxford Silicon Etcher	B105,m A106	Subfab A08
Nitrous Oxide	N_2O	Asphyxiation	PECVD	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	AnnealSys RTA	B106	Subfab A08
Octafluorocyclobutane	C_4F_8	Asphyxiation	SPTS Deep Si Etch; Unaxis Deep Si Etcher Oxford Silicon Etcher; Unaxis Deep Si Etcher	B105, A106	Subfab A08
Boron Trichloride	BCl_3	Highly Toxic	Oxford III-V Etcher, Oxford Metal Etcher, Unaxis ICP Etcher	B105, A106	Subfab A08
Chlorine	Cl_2	Corrosive, Highly Toxic	Oxford Metal Etcher , Unaxis ICP Etcher, Oxford III-V Etcher	B105, A106	Subfab A08
Carbon Tetrafluoride	CF_4	Asphyxiation	790 RIE Middle; 790 RIE Nitride Left; 790 RIE Right Microwave Asher; Oxford Metal Etcher ; Oxford Silicon Etcher	B105, A106	Subfab A08
Argon	Ar	Asphyxiation	4Wave Cluster Sputter; Ion Mill; LHL Tube 2 Anneal Sputter B104 Left; Sputter B104 Right 790 RIE Middle; 790 RIE Nitride Left; 790 RIE Right AnnealSys RTA; Atomic Layer Deposition Downstream Asher; Ion Mill Oxford Metal Etcher; Oxford Silicon Etcher PECVD ; SPTS Deep Si Etch Unaxis Deep Si Etcher; Unaxis ICP Etcher; Wafer Bonder	B103, B104, B105, B106, A106	Subfab A08
Silicon Tetrachloride	$SiCl_4$	Corrosive, Highly Toxic	Oxford III-V Etcher Oxford Metal Etcher	A106	Subfab A08
Methane	CH_4	Asphyxiation, Extremely Flammable	Oxford III-V Etcher Oxford Metal Etcher	A106	Subfab A08
Hydrogen Bromide	HBr	Toxic, Corrosive	Oxford III-V Etcher Oxford Metal Etcher	A106	Subfab A08
Hexafluorane	C_2F_6	Non-toxic. Asphyxiation.	Oxford Silicon Etcher	A106	Subfab A08

5.4 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.

5.5 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 4.4.2) 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.

5.6 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.

5.7 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!

5.8 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.

6 Nanoparticle Material Safety

6.1 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.

6.1.1 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.

6.1.2 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

6.1.3 Nanoparticle Confinement

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

Nanoparticle users must clean the nano-enclosure 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.

6.1.4 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 nano-enclosure requires training, including review of the NanoFab Nanoparticle Handling Policy. The nano-enclosure must be reserved through NEMO. Nanoparticles on the preapproved list are allowed in the nano-enclosure; those not on the preapproved nanoparticle list must be approved by the NanoFab Manager. Nano-enclosure use will be tracked by a log sheet adjacent to the hood.

Preapproved List of Nanoparticles	
Nanoparticle	**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

6.2 Nanoparticle Safety Committee

The details of the Nanoparticle Safety Committee and the Nanotechnology Safety Policy are available through the Dispersible Engineered Nanomaterials (DEMS) program available from inside NIST only at https://nistsafety.nist.gov/Programs/Programs/ViewRequirements/11/157

7 Emergency Services

7.1 Fire Response

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

7.2 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.

7.3 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.

8 Contacts

8.1 Staff Directory

A listing of all NanoFab staff can be found on the CNST NanoFab website at:

https://www.nist.gov/cnst/staff-directory

In addition, a staff directory is available on NEMO by following the Contact the NanoFab staff link on the NEMO landing page.

9 NIST Policy on Chemical Container Labeling (NanoFab Staff Only)

9.1 Introduction

Chemical labeling is a major part of the NIST Hazard Communication (HazCom) Program (NIST S7101.59). 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.

9.2 NFPA 704 Warning Ratings

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

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:

Process vessels and reactors that have readily accessible alternate written documentation.

Working solutions prepared in a laboratory that are under control of the researcher and are used and disposed of in one working day.

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.

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.

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

Table 1, National Fire Protection Association Hazard Identification System

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.

9.3 Obtaining NFPA Hazard Ratings

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

On most Material Safety Data Sheets (MSDSs), or

At ChemWatch - http://nist.chemwatch.us/ - type in the chemical name.

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.

9.4 Procedures

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

9.5 Specific Chemical Labeling Instructions

9.5.1 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.

9.5.2 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.

9.5.3 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.

9.5.4 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.

9.5.5 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:

The term "Peroxide Forming Compound."

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.

9.5.6 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.

9.5.7 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.

9.6 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. CIMS), that include equivalent information, are acceptable.

9.7 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.

9.8 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.

LC50 - 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.

LD50 - 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.

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).

9.9 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.

9.9.1 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 37.8 °C (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.

9.9.2 Source

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

10 Compressed Gas Cylinders (NanoFab Staff Only)

10.1 Introduction

The compressed gas cylinder safety policy and procedures adheres to the guidelines provided by NIST S7101.61 Compressed Gas Cylinder Safety Policy and Procedures.

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.

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.

10.2 Lecture bottles

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.

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.

10.3 General Rules

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' Safety Data Sheet (SDS) should be available for review by the researchers and emergency services personnel.

Labeling Cylinders/ Cylinders with Unknown Contents: All compressed gases cylinders and liquefied gas containers are to be appropriately labeled and recorded in CIMS. 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.

10.4 Toxic Gases

What are Toxic Gases? Toxic gases are those with an NFPA 7041[1] Health Hazard Rating 3 or 4 or having a Health Hazard Rating of 2 with no physiological warning properties.

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.

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.

10.5 Cylinder Storage and Use

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.

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.

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.

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

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.

	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

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

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.

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.

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.

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.

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.

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.

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.

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.

10.6 Transporting and Handling Gas Cylinders

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.

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.

10.7 NFPA Health Hazard Ratings*

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.**

10.8 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
Ammonia[1]	15 - 28	MGD	Hydrogen Chloride	(a)	
Boron Trichloride	(a)	MGD	Hydrogen Fluoride	(a)	
Carbon Tetrafluoride	(a)		Methane	5 - 15	325M, 627
Chlorine	(a)		Oxygen	(a)	
Ethane	3.0 - 12.5	325M, 627	Phosphine	(c)	
Fluorine	(a)		Silane	(c)	
Hydrogen	4 - 75	325M, 627	Silicon Tetrafluoride	(a)	
Hydrogen Bromide	(a)		Sulfur Hexafluoride	(a)	

[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

11 Chemical Waste Satellite Accumulation (NanoFab Staff Only)

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).

Typical Satellite Accumulation Area at NIST

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.

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 pickup request can be submitted at:

https://nistsafety.nist.gov/CWP/PickupRequest/

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).

12 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.
11/23/2020	3.0	NOG	Rewrite to streamline and align with online training.