Yale University

Cleanroom Core User Handbook

Version 4.0

May 2025

Past Revisions of the Yale Cleanroom Handbook

The handbook is a living document and has undergone several revisions over time, reflecting updates in policies, safety procedures, and facility improvements:

Version History

- **Rev. 1.1** – *Issued August 2007*
- **Rev. 2.1** – *Issued June 2008*
- **Rev. 2.1.2** – *Issued January 2009*
- **Rev. 2.1.3** – *Issued October 2009*
- **Rev. 2.1.4** – *Issued February 2014*
    - Amended user qualification and external customer requirements.
    - Updated policies on user fees, hours, and after-hours access.
    - Clarified cleanroom committee roles and toxic gas monitoring system response.
- **Rev. 2.1.5** – *Issued May 2017*
    - Replaced Coral with **FOM** (Facilities Online Management) for management software.
    - Revised application instructions.
- **Rev. 3.1** – *Issued October 2022*
    - Improved formatting, grammar, and clarity.
    - Updated entry/exit protocols and cleanroom training.
    - Modified toxic gas response and equipment list.
- **Rev. 3.1.2** – *Issued August 2023*
    - **Added Section 4.7**: Cleanroom Safety and Facility Update Meeting.
- **Rev. 4.0 – *Issued May 2025***
    - **Reformatted and rewrote sections for clarity**
    - **Integrated the West Campus Cleanroom handbook**

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1.0 Introduction to the Yale Cleanroom Core

The Yale Cleanroom is a core science facility administered by the Department of Applied Physics. It is a particle-free environment for the design, fabrication, and testing of micro- and nanofabricated devices.

Yale University's Cleanroom is a pivotal facility for advanced research, equipped with more than 30 specialized tools. These tools are supported by a knowledgeable staff who ensure their maintenance and provide comprehensive training. The facility is designed to support a wide range of research fields including nano-fabrication, materials science, biomedical engineering, quantum computing, chemical and environmental engineering, and applied physics, making it an essential environment for cutting-edge investigations.

The cleanroom's equipment and processes are organized into seven main categories: sputtering and evaporation, chemical vapor deposition, etching, lithography, metrology, back-end processing, and wet benches, along with a teaching cleanroom specifically for instructional purposes. This structured approach ensures that researchers have access to the necessary tools and support to advance their work.

1.1 Brief History of the Becton Cleanroom

Original Facility (1988)

- **Construction Cost**: $1.2 million
- **Size**: 2,600 sq. ft.
- **Cleanroom Classification**:
  - One bay: Class 100
  - Remainder: Class 1,000
- **Environmental Conditions**:
  - Temperature: 68 ± 4°F
  - Humidity: 40 ± 5%
- **Staffing**: 1 technician/manager
- **Funding**:
  - Entire budget covered by user fees
  - Building maintenance handled by Yale Physical Plant
- **Founding Faculty**: Dick Barker, T.P. Ma, Dan Prober, Bob Wheeler

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Facility Growth and Usage

- Expanded from supporting **5–6 faculty (3 departments)** to over **30 faculty (8 departments)**
- Over **130 active cleanroom users**
- Estimated research funding reliant on cleanroom usage (2004/05):
  - **Total**: $3–4 million/year
  - **Quantum computing**: ~$2 million/year (100% cleanroom-dependent)

2005 Assessment and Challenges

In early 2005, **Dean Fleury** established an **Executive Committee**:

- **Members**: Profs. T.P. Ma, J. Han, R. Schoelkopf
- **Findings (June 2005 Report)**:

1. Environmental System Failures

- Aging air handler accumulating water
- Cleanroom no longer meeting environmental specs
- Dehumidifier (DX coil) removed in 2003
- Antiquated pneumatic controls with no data logging

2. Safety Concerns

- Toxic and flammable gas storage not up to code
- Electrical code violations
- Inadequate ventilation at wet benches; too few benches; flammable materials risk

3. Obsolete Tool Set

- Lack of essential tools (e.g., plasma etching, mask making)
- Ongoing maintenance difficulties

4. Staffing Deficiency

- Understaffed
- No direct university support

University Response

1. **Authorized Staffing**:
    - Two new cleanroom staff positions funded by the Provost's Office
2. **Equipment Investment**:
    - ~$1.7 million for new tools authorized and funded by the Provost
3. **Facility Redesign**:
    - Comprehensive redesign initiated in 2005
    - **Midwest Cleanroom Associates (MCA)** hired as consultants and commissioning agents
4. **Major Renovation**:
    - Began: March 2007
    - Completed: September 2007
5. **Certification & Commissioning**:
    - Completed by October 2007

1.2 Brief History of the West Campus Cleanroom

The Yale West Campus Cleanroom was established in **2017** and officially opened to users on **February 1, 2018**. It is located in **Building 750 (Shipping & Receiving Center)**, with dedicated access along the southern exterior of the building.

Original Facilities (2018)

- **Total Area**: 1,200 sq. ft. of Class 1000-rated wet and dry cleanroom laboratories.
- **Wet Bay**:
    - Three process hoods for acid, base, and resist applications.
    - Equipped with integrated spin-coaters, hotplates, sonicators, and standard cleanroom utilities.
- **Dry Bay**:
    - Hosts advanced analysis and photolithography tools, including:
        - High-resolution **SUSS UV mask aligner**
        - **Zygo optical profiler** (non-contact)
        - **Stylus profiler**
- **Gowning Area**:
    - Includes storage space allocated for individual research groups.

Cleanroom Expansion (2020)

- **Added Space**: Additional 1,200 sq. ft. of wet and dry laboratory space.
- **New Equipment**:
    - **Ultra-High Vacuum Electron Beam Evaporator**
    - **Inductively Coupled Plasma Reactive Ion Etcher (ICP-RIE)**
- These tools significantly expanded the cleanroom's **nanofabrication capabilities**.

Research & Collaboration

The facility supports researchers from across Yale, including:

- **Energy Sciences Institute**
- **Systems Biology Institute**
- **Nanobiology Institute**
- Departments such as **Applied Physics**, **Electrical Engineering**, and **Materials Science**

1.3 Becton Cleanroom Specifications

Yale FOE Cleanroom 2.0 Design Specifications (2007)

Source: *Basis of Design, Midwest Cleanroom Associates, April 13, 2006*

Environmental Conditions

- **Temperature**: 68 ± 2°F
  - Monitored at 10 points with remote telemetry and logging
- **Relative Humidity**: 45 ± 5%
  - Monitored at 10 points with remote telemetry and logging

Air Handling

- **Total Make-Up Air Flow**: 17,600 SCFM
- **Total Exhaust Flow**: 16,000 SCFM
- **Cleanroom Classifications**:
  - ISO 5 (Class 100): < 100 particles/ft^3
  - ISO 6 (Class 1000): < 1,000 particles/ft^3
- **Particle Monitoring**:
  - 2 fixed particle counters
  - Remote telemetry and trending enabled

Deionized (DI) Water System

- **Reverse Osmosis (RO) Water Quality**:
  - Dissolved solids reduction: > 96%
  - Bacteria reduction: > 99%
  - Particulate removal: ≥ 5 µm
- **RO Capacity**: > 4,400 gallons/day
- **RO Storage Capacity**: 500 gallons
- **DI Resistivity**: 18×10^6 Ω·cm
  - With remote telemetry and logging
- **DI Loop Flow Rate**: 25 GPM
  - Duplex alternating distribution pumps
- **DI Delivery Pressure**: 90 PSI (at pump discharge)

- **Final Filter**: 0.2 µm, stainless steel housing
- **Resistivity Monitors**: Supply and return; temperature-compensated
- **DI Piping Material**: PVDF

Process Chilled Water

- **Maximum Flow**: 60 (units assumed GPM)
- **Maximum Heat Load**: 180,000 BTU/h
- **Supply Temperature**:
  - < 60°F (or just above dew point)
  - Adjustable, telemetered, and trended
- **Δ Pressure**: Adjustable, minimum 10 PSI

Utility Gases

- **Compressed Dry Air**:
  - 80–100 PSIG
  - Supplied from building system, dual lead-lag configuration
- **House Nitrogen**:
  - Approx. 60 PSIG
  - Supplied from liquid boil-off
- **House Vacuum**:
  - Minimum 21" Hg
  - Dual lead-lag pump system

1.4 West Campus Cleanroom Specifications

Environmental Conditions

- **Temperature**: 68 ± 2°F
- **Relative Humidity**: 45 ± 5%

Air Handling

- **Cleanroom Classifications**:
  - ISO 6 (Class 1000): < 1,000 particles/ft^3

Deionized (DI) Water System

- **Reverse Osmosis (RO) Water Quality**:
  - Dissolved solids reduction: > 96%
  - Bacteria reduction: > 99%
  - Particulate removal: ≥ 5 µm
- **DI Resistivity**: 18×10^6 Ω·cm
  - With remote telemetry and logging
- **DI Loop Flow Rate**: 25 GPM
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Utility Gases

- **Compressed Dry Air**:
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- **House Nitrogen**:
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  - Supplied from liquid boil-off
- **House Vacuum**:
  - Minimum 21" Hg
  - Dual lead-lag pump system

1.5 Modern Cleanroom Core Growth

Staffing (2023)

- One new Cleanroom Staff position funded by the Provost's Office.

Cleanroom Core Integration

- At the **end of 2024** the staffing needs at the West Campus Cleanroom facilitated the integration of the West Campus and Becton Cleanroom's **into one Cleanroom Core Facility.**
- **Training, Staff Expertise,** and **Tool Management** are all coordinated and facilitated by one cohesive Cleanroom team.
- **Financial** models between the West Campus and Becton Cleanroom's remain separated.

Becton Cleanroom Expansion (2025)

- **Added Space**: Additional 1,200 sq. ft. of ISO 7 (Class 10,000) dry laboratory space.
- **New Equipment**:
    - **Two Angstrom Engineering Sputtering Systems**
    - **Angstrom Engineering JJ Evaporator**
    - **Plassys Quantum JJ Evaporator**
- These tools are supported by the creation of **Yale's Quantum Foundry**.

2.0 Cleanroom Access Requirements

Cleanroom training for new users is offered on a monthly basis and consists of a safety presentation, walkthrough, and take-home exam. Information and links to the training calendar can be found at our website: research.yale.edu/cores/cleanroom#overview

New Users (Students, Researchers, Faculty)

1. Obtain PI Approval

- Get approval from a faculty member who agrees to be financially responsible for your cleanroom use.

2. Register in FOM

- Visit: http://fom.yale.edu/fom/welcome
- Steps:
    - Register with FOM
    - **Prox Card Tips**:
        - Find the number on the back of your Yale ID (lower-left corner, yellow)
        - **Do not** enter letters (e.g., "C-2175" → enter as "2175")
        - **Do not** include leading zeros (e.g., "C-00190" → enter as "190")
    - Enter a valid COA account
    - If your supervisor is missing, notify staff and complete registration anyway
    - Log into FOM:
        - Go to *Yale SEAS Cleanroom → Resources in this facility → Becton Cleanroom*
        - A user agreement pop-up will appear:
            - Click **Facility Agreement** to open the Cleanroom Handbook
            - Return to FOM, agree to the policy
            - Fill out and submit the **New User Application Form**

3. Complete Online Safety Training

- Complete the **Hazardous Waste Program** and the **Laboratory Safety Program** provided through the Yale Workday Training Portal.
- Upload the training certificates to your FOM account.

4. Attend Cleanroom Safety Training (In-Person)

Sign up for the in-person new user training on the website. Email the staff if you have a schedule conflict. There are two parts to the new user training.

- Safety Presentation
    - Cleanroom entry/exit, gowning, card access
    - Cleanroom classifications, pressure, particles
    - Layout, bay identification, protocol review

- Safety Presentation
    - PPE requirements
    - Emergency response and safety protocols
    - Chemical handling
    - Proper use of benches and hotplates

5. Written Exam

- Pass with **minimum 70%**
- Covers materials from step 4
- Those who fail may retake after further review

6. Tool Training, West Campus Cleanroom, and Student Cleanroom Access

- One-on-one training is required for tool and system usage
- The West Campus Cleanroom and Student Cleanroom are accessible by a walkthrough with the Staff
- Schedule on the website or with a staff member

7. Reactivation Requirement

- Users who do not use the Cleanroom for 365 days will have their access automatically suspended. Access can be reissued by requesting:
    - Approval from the cleanroom manager
    - Review of procedures with a staff member

Undergraduate Students Additional Requirements

1. **Supervision Required**:
    1. Must be accompanied by an **experienced grad student/postdoc/researcher or Staff member.**
    2. Faculty are ultimately responsible and encouraged to monitor
2. **Access Hours**:
    - **Weekdays only**, Monday–Friday, **8 AM to 5 PM**

External Customers & Affiliated Researchers

- Must **contact the Cleanroom Director**
- Access determined by appropriateness of affiliation with Yale
- Use of facilities is at the discretion of the Director

3.0 Cleanroom Training

3.1 Introduction to Cleanrooms

The following is an excerpt from 'A Basic Introduction to Cleanrooms' by Roger McFadden, Technical Director, Coastwide Laboratories:

A cleanroom is a controlled environment where products are manufactured. It is a room in which the concentration of airborne particles is controlled to specified limits. Eliminating sub-micron airborne contamination is really a process of control. These contaminants are generated by people, process, facilities and equipment. They must be continually removed from the air. The level to which these particles need to be removed depends upon the standards required. The most frequently used standard is the Federal Standard 209E. The 209E is a document that establishes standard classes of air cleanliness for airborne particulate levels in cleanrooms and clean zones. Strict rules and procedures are followed to prevent contamination of the product.

The only way to control contamination is to control the total environment. Air flow rates and direction, pressurization, temperature, humidity, and specialized filtration all need to be tightly controlled. And the sources of these particles need to be controlled or eliminated whenever possible. There is more to a clean room than air filters. Cleanrooms are planned and manufactured using strict protocol and methods. They are frequently found in electronics, pharmaceutical, biopharmaceutical, medical device industries and other critical manufacturing environments.

It only takes a quick monitor of the air in a cleanroom compared to a typical office building to see the difference. Typical office building air contains from 500,000 to 1,000,000 particles (0.5 microns or larger) per cubic foot of air. A Class 100 cleanroom is designed to never allow more than 100 particles (0.5 microns or larger) per cubic foot of air. Class 1000 and Class 10,000 cleanrooms are designed to limit particles to 1000 and 10,000 respectively.

A human hair is about 75-100 microns in diameter. A particle 200 times smaller (0.5 micron) than the human hair can cause major disaster in a cleanroom. Contamination can lead to expensive downtime and increased production costs. In fact, the billion-dollar NASA Hubble Space Telescope was damaged and did not perform as designed because of a particle smaller than 0.5 microns.

Once a cleanroom is built it must be maintained and cleaned to the same high standards. This handbook has been prepared to give professional cleaning staff information about how to clean the cleanroom.

What is Contamination?

Contamination is a process or act that causes materials or surfaces to be soiled with contaminating substances. There are two broad categories of surface contaminants: film type and particulates. These contaminants can produce a “killer defect” in a miniature circuit. Film contaminants of only 10 nm (nanometers) can drastically reduce coating adhesion on a wafer or chip. It is widely accepted that particles of 0.5 microns or larger are the target. However, some industries are now targeting smaller particles.

A partial list of contaminants is found below. Any of these can be the source for killing a circuit. Preventing these contaminants from entering the cleanroom environment is the objective. It requires a commitment by everyone entering the cleanroom to make it happen. Professional cleaning personnel need to be aware of the importance of controlling contaminants. Strict procedures should be followed whenever entering or cleaning a cleanroom. Compromise is not acceptable when cleaning in a cleanroom.

Sources of Contamination

This is a partial list of some of the commonly known contaminants that can cause problems in some cleanroom environments. It has been found that many of these contaminants are generated from five basic sources. The facilities, people, tools, fluids, and the product being manufactured can all contribute to contamination. Review this list to gain a better understanding of where contamination originates.

1. Facilities

- Walls, floors, and ceilings
- Paint and coatings
- Construction material (sheet rock, saw dust etc.)
- Air conditioning debris
- Room air and vapors
- Spills and leaks

2. People

- Skin flakes and oil
- Cosmetics and perfume
- Spittle
- Clothing debris (lint, fibers etc.)
- Hair

3. Tool Generated

- Friction and wear particles
- Lubricants and emissions
- Vibrations
- Brooms, mops, and dusters

4. Fluids

- Particulates floating in air
- Bacteria, organics, and moisture
- Floor finishes or coatings
- Cleaning chemicals
- Plasticizers (outgasses)
- Deionized water

5. Product generated

- Silicon chips
- Quartz flakes
- Cleanroom debris
- Aluminum particles

Key Elements of Contamination Control

We will look at several areas of concern to get a better idea of the overall picture of contamination control. These are the things that need to be considered when providing an effective contamination control program.

1. **HEPA (High Efficiency Particulate Air Filter)** - These filters are extremely important for maintaining contamination control. They filter particles as small as 0.3 microns with a 99.97% minimum particle collective efficiency.
2. **CLEANROOM ARCHITECTURE** - Cleanrooms are designed to achieve and maintain an airflow in which essentially the entire body of air within a confined area moves with uniform velocity along parallel flow lines. This air flow is called laminar flow. The more restriction of air flow the more turbulence. Turbulence can cause particle movement.
3. **FILTRATION** - In addition to the HEPA filters commonly used in cleanrooms, there are several other filtration mechanisms used to remove particles from gases and liquids. These filters are essential for providing effective contamination control.
4. **CLEANING** - Cleaning is an essential element of contamination control. Decisions need to be made about the details of cleanroom maintenance and cleaning. Applications and procedures need to be written and agreed upon by cleanroom management and contractors (if used). There are many problems associated with cleaning. Managers

need to answer the following questions before proceeding with any cleanroom cleaning program:

- What is clean?
- How is clean measured?
- What cleaning materials can be used in the cleanroom?
- When can the cleanroom be cleaned?
- How frequent does it need to be cleaned?

5. **CLEANROOM GARMENTS** - The requirements for cleanroom garments will vary from location to location. It is important to know the local garment requirements of the cleanroom management. Gloves, face masks and head covers are standard in nearly every cleanroom environment. Smocks are being used more and more. Jump suits are required in very clean environments.
6. **HUMANS IN CLEANROOMS** - There are both physical and psychological concerns when humans are present in cleanrooms. Physical behavior like fast motion and horseplay can increase contamination. Psychological concerns like room temperature, humidity, claustrophobia, odors, and workplace attitude are important. Below are several ways people produce contamination:
    - **Body Regenerative Processes**-- Skin flakes, oils, perspiration, and hair.
    - **Behavior**-- Rate of movement, sneezing and coughing.
    - **Attitude**-- Work habits and communication between workers.

    People are a major source of contamination in the cleanroom. Look at the people activities listed below. Notice the number of particles produced per minute during these activities.

PEOPLE ACTIVITY	**PARTICLES/MINUTE (0.3 microns and larger)**
Motionless (Standing or Seated)	100,000
Walking about 2 mph	5,000,000
Walking about 3.5 mph	7,000,000
Walking about 5 mph	10,000,000
Horseplay	100,000,000

7. **COMMODITIES** - Care is taken when selecting and using commodity items in cleanrooms. Wipers, cleanroom paper and pens and other supplies that service the cleanroom should be carefully screened and selected. Review of the local cleanroom

requirements for approving and taking these items into the cleanroom are essential. In fact, many cleanroom managers will have approval lists of these types of items.

8. **COSMETICS** - Many cosmetics contain sodium, magnesium, silicon, calcium, potassium, or iron. These chemicals can create damaging particles. Cleanroom managers may ban or restrict cosmetics in the cleanroom. This is usually dependent upon the threat to the product being made in the cleanroom. A recent mirror on a space telescope was fogged up from the cologne that was present in the cleanroom.
9. **MEASUREMENT AND INSTRUMENTATION** - Some important measurements related to contamination control are particle count, air flow & velocity, humidity, temperature, and surface cleanliness. Cleanroom managers usually have specific standards and/or instruments to measure these factors.
10. **ELECTROSTATIC DISCHARGE (ESD)** - When two surfaces rub together an electrical charge can be created. Moving air creates a charge. People touching surfaces or walking across the floor can create a triboelectric charge. Special care is taken to use ESD protective materials to prevent damage from ESD. Cleaning managers should work with their personnel to understand where these conditions may be present and how to prevent them.

General Cleanroom Regulations

Below is a list of general regulations recommended as a minimum for the successful operation of a cleanroom. All professional cleaning personnel should be aware and follow these regulations at all times.

1. All personal items such as coats, backpacks and purses should be stored under the bench or on the hangers in the Cleanroom entryway.
2. Valuable personal Items such as wallets may be permitted in the cleanroom provided they are NEVER removed from beneath the cleanroom garments.
3. NO eating or gum chewing allowed inside the cleanroom.
4. Only garments approved for the cleanroom should be worn when entering.
    a. Long Pants
    b. Close toed shoes, no heels
    c. Short or long sleeved shirts
5. NO cosmetics shall be worn in the cleanrooms. This includes rouge, lipstick, eye shadow, eyebrow pencil, mascara, eye liner, false eye lashes, hair spray, mousse, or the heavy use of aerosols, after shaves and perfumes.
6. Only approved cleanroom paper shall be allowed in the cleanroom.
7. Approved ball point pens shall be the only writing tool used.

8. Use of paper or fabric towels is prohibited. Only the use of the special cleanroom wipes are permitted.
9. Gloves or finger cots should not be allowed to touch any item or surface that has not been thoroughly cleaned.
10. Only approved gloves, finger cots (powder-free), pliers, tweezers should be used to handle product. Fingerprints can be a major source of contamination on some products.
11. Solvent contact with the bare skin should be avoided. They can remove skin oils and increase skin flaking.
12. Approved skin lotions or lanolin-based soaps are sometimes allowed. These can reduce skin flaking.
13. All tools, containers and fixtures used in the cleaning process should be cleaned to the same degree as the cleanroom surfaces. All these items are a source of contamination.
14. NO tool should be allowed to rest on the surface of a bench or table. It should be place on a cleanroom wiper.
15. ALL equipment, materials and containers introduced into a sterile facility must be subjected to stringent sterilization prior to entrance.
16. NO ONE who is physically ill, especially with respiratory or stomach disorders, may enter a sterile room.

Personal Actions Prohibited in Cleanrooms

1. Fast motions such as running, walking fast or horseplay.
2. Sitting or leaning on equipment or work surfaces.
3. Writing on equipment or garments.
4. Removal of items from beneath the cleanroom garments.
5. Wearing the cleanroom garment outside the cleanroom.
6. Wearing torn or soiled garments.

3.2 Cleanroom Gowning Protocol

1. Entry Procedures:

- Swipe your card to open the door into the Cleanroom entryway.
- Walk over a tacky mat to remove debris from shoes.
- Clean any items being brought into the cleanroom using lab wipes and IPA.
- If necessary, place personal items like cell phones in the passthrough before gowning.

2. Initial Gowning Steps:

- Put on blue shoe covers over regular shoes.
- Wear nitrile gloves to prevent contamination.
- Don a bouffant hair cover, ensuring all hair is tucked inside.
- If applicable, wear a beard cover.

3. Gowning Room Procedures:

- Step into the gowning room and onto another tacky mat.
- Select an appropriately sized hood and coverall.
- Wear the hood first, fastening the closure and adjusting the snaps.
- Put on the coverall while preventing it from touching the floor.
- Zip up the coverall, ensuring the hood is tucked inside the neck.

4. Boot and Final Accessory Wear:

- Choose cleanroom boots, securing them over shoe covers.
- Adjust and fasten straps and snaps to ensure a tight fit.
- Tuck the coverall into the boots properly.
- Put on safety glasses.
- Verify that gloves are suitable for the task.

5. Final Inspection and Entry:

- Check the gowning in a full-length mirror.
- If anything is incorrect, fix it before proceeding.
- Step onto the final tacky mat before entering the cleanroom.

6. Degowning Procedures:

- Remove garments in the reverse order (boots, coverall, hood) while still wearing gloves, blue booties, and hairnet.
- Store reusable items in the locker.
- Step into the entryway.

- Retrieve belongings from the passthrough.
- Dispose of used shoe covers, gloves, and hair/beard covers appropriately.
- Exit using the ID prox card, which logs the user out of the cleanroom

3.3 Chemical Safety and Handling Procedures

The following section provides detailed instructions for every phase of chemical handling in the Yale Cleanroom from storage through disposal. These procedures are designed to ensure the safety of everyone who uses the facility as well as to comply with federal and state regulations. Everyone who is admitted to the facility should be familiar with these procedures. Reading and knowing these procedures in no way qualifies you to enter or do any work in the cleanroom, although it is a pre-requisite. Further, some equipment discussed in this document, namely the *CMOS hood,* has additional procedural requirements that should not supersede these procedures but must be followed in addition.

Fresh Chemicals Storage and Transporting

Bottles of fresh chemicals are to be stored in one of the two chemical pass-through cabinets or in the small cabinets under the proper benches. The chemical bottles should be wiped down prior to being placed in the pass-through from the outside hallway to minimize particulates. **All chemicals must enter the Cleanroom through the passthrough cabinet**. If a user has a new bottle to bring into the Cleanroom, please ask the staff to access the cabinet from the hallway. Bottles of fresh acid or bases other than developer should be transported from the cabinet to the hoods using a rubber bucket and one heavy nitrile glove. This allows the user to have one free hand to open the door and one protected hand to carry the bucket. Bottles should be returned to the proper storage location immediately after use. Rubber buckets should be left near the pass-through cabinets.

1. **Acids**

   Fresh acids should be stored in the trays on the 1st and 2nd shelves of the corrosives pass-through. There is also room for ~ 8 bottles of acid under the *Acid Hood*. Only 1 bottle of each type of acid may be stored under the *Acid Hood* at any time. Also see item 6, CMOS Bench.

2. **Bases/Caustics**

   Fresh bases and caustic-based chemicals should be stored in the trays on the bottom shelf of the flammables pass-through. This includes developers as well as strong bases. There is room for ~8 bottles of caustics under the *Base/ Caustics Hood*. Develops will be stored on the left side and strong bases will be stored under the right side. As with the acids, only 1 bottle of each type of base may be stored under the *Base Hood* at any time. Also see item 6, CMOS Bench.

3. Hydrogen Peroxide

Hydrogen peroxide should be stored with the bases in the flammables pass-through. It may also be stored in the right-hand cabinet of the *Base Hood.*

4. Solvents

Fresh solvents should be stored on the top shelf of the flammable's cabinet. They will also be stored in the left-hand cabinet of *Spinner Hood #1* and the left side of the *Solvent Hood*. Some SU-8 related solvents such as SU-8 developer and EBR PG will be stored under the left side of the *MEMS Hood*.

5. Photoresists, E-beam resists, Primers

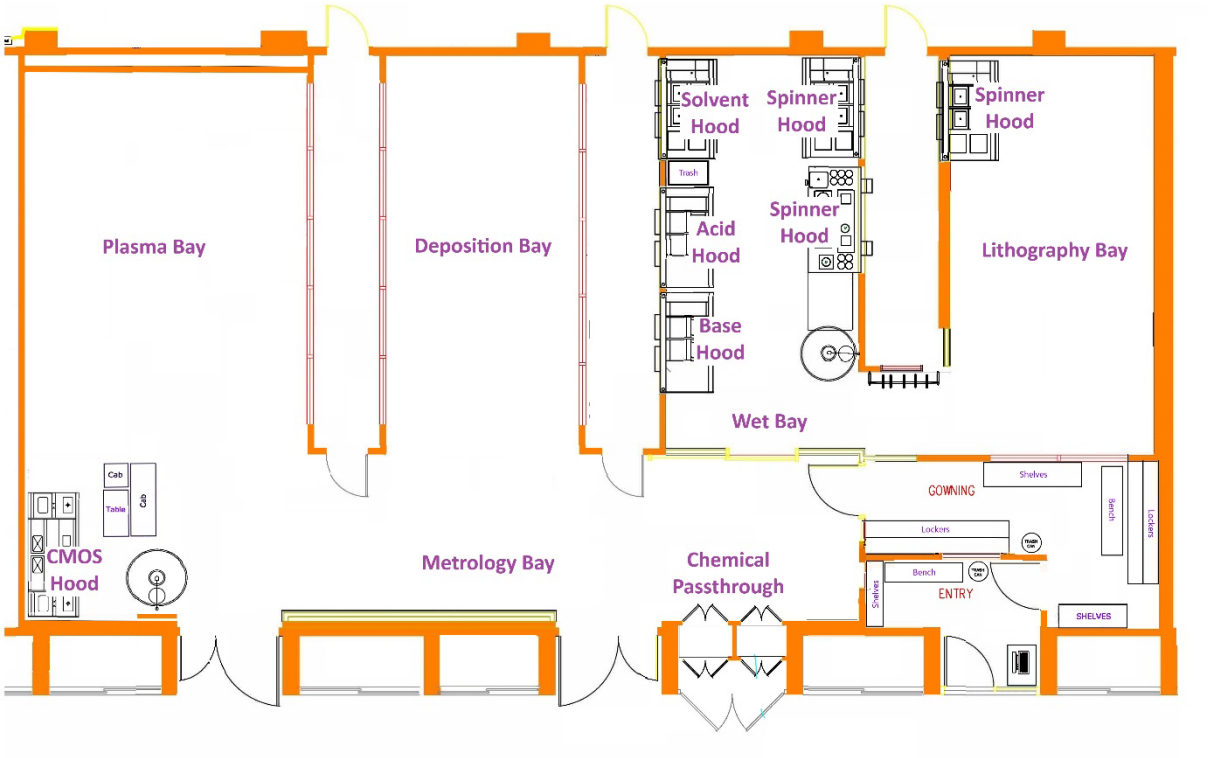
Fresh bottles of photoresist can be found along the side of the 2nd shelf of the flammables cabinet. In use bottles can be found inside the bench of *Spinner Hood #2*. Individual user bottles can be stored in the explosion-proof refrigerator in the lithography bay to preserve their lifetime. Small bottles in-use may be stored on the bench top of *Spinner Hood #1* and *Spinner Hood #2*. E-beam resists should be stored on the second shelf of the flammables passthrough. Photoresist primer should be stored on the first shelf of the flammables -pass through. Epoxy based resists such as SU-8 as well as fresh bottles of lift-off resists should be stored under the right side of the *MEMS Hood*.

6. CMOS bench

This bench is listed separately because it is the only place where acids, bases, and solvents are to be used in the same hood. There is room for a few commonly used chemicals in the cabinets under the hood. Fresh and waste acids will go in the left-hand cabinet. Fresh and waste bases will go in the right-hand cabinet.

7. West Campus

There is a corrosives and flammables cabinet at the end of the first dry bay to be used for chemical storage. Acids are found on the first shelf of the corrosives cabinet. Bases are found on the second shelf of the corrosives cabinet. Solvents are found in the flammables cabinet. Photoresists are found in the temperature controlled cabinet or the explosion proof refrigerator located at the end of the wet bay. Additional chemicals are located in the passthrough cabinets. Please ask the Staff before accessing the passthrough cabinet.



Location of the various wet hoods in the Becton Cleanroom

Personal Protective Equipment

Various tasks in the cleanroom carry various requirements for using personal protective equipment. The purpose of these rules is not to hinder your work but to keep you and those around you safe. Proper PPE will greatly reduce the risk of an injury should you or someone around you cause a chemical accident. Each chemical bench has specific PPE requirements for anyone working there. These requirements also apply to someone observing work at that bench.

1. **General Cleanroom areas**

   Users are required to wear safety glasses at all times when they are in the cleanroom. Nitrile gloves are also mandatory.

2. **Transporting Chemicals**

   For solvents and developer, the bottles may be carried wearing the basic required cleanroom PPE, namely the nitrile gloves and safety glasses. These may be safely transported without the rubber buckets.

Acids and bases require slightly more caution. Users should get a single green nitrile glove and a rubber bucket. Wearing the green glove, place the chemical into the bucket and carry it using the gloved hand. The ungloved hand should be used for opening the door to avoid contaminating the button. This procedure should be repeated when returning chemicals to the cabinet. This method should also be used when transporting chemicals to the CMOS hood. It will minimize the likelihood of dropping a bottle between the cabinet and the hood.

3. **Acid, Base and CMOS Hoods**

All users working or observing at these chemical hoods are required to wear safety glasses, a face shield, a chemical apron, and the heavy green nitrile gloves. Even if you are using what you believe are “less - dangerous” chemicals you must still use the full PPE because of the possibility that someone else has left “more dangerous” chemicals in the hood and the likelihood that the surfaces of the bench are contaminated with these chemicals.

The apron should be put on first with the opening on your backside, followed by the face shield, and finally the green gloves to avoid touching the apron and face shield with contaminated gloves. Green gloves should be removed before removing shield or apron. Rinse and dry any contaminated gloves before removing them.

4. **Solvent and Spinner Hoods**

Users at the spinner benches must wear at least safety glasses and regular nitrile gloves. Heavy nitrile gloves and face shield are strongly recommended when using heated solvents.

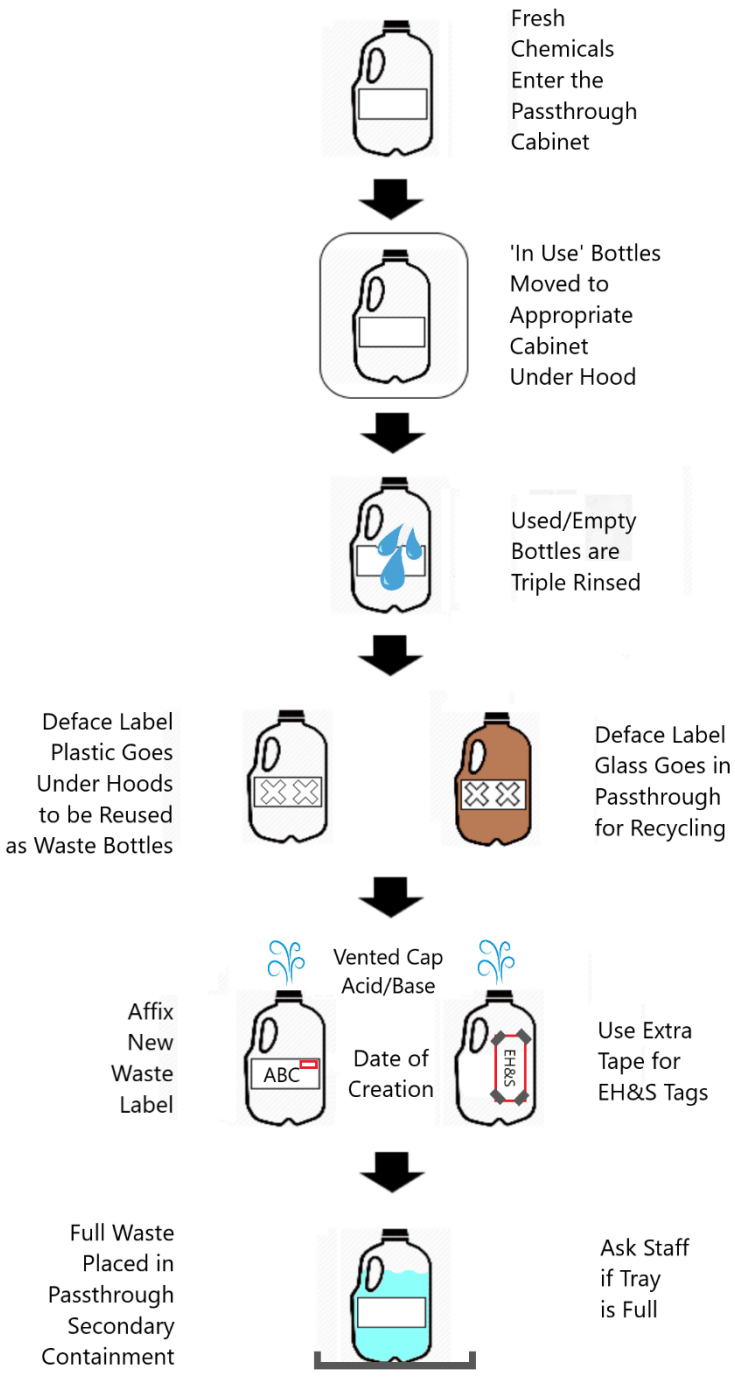
Chemical Pouring and Use Procedures

1. **Chemicals In-Use**
    - All chemicals must be properly labeled at all times with your name, date, time, and chemical names. Preprinted labels are provided on the fronts of the hoods
    - All chemicals are to be covered whenever you are not actively using them
    - Ensure there is a proper waste bottle before your pour your chemicals
2. **Process Tanks**
    - Tank heater and ultrasonic generator are disabled until/unless the fluid level is high enough to raise the twin floats at the back of the tank
    - The tank is filled manually and is drained into a built-in waste tank
    - Cover when not in use
3. **Empty Bottles**
    - It is the users responsibility to properly rinse and store bottles that have been used up

- Triple rinse with water, then take a marker to deface the label and write ‘3X Rinsed’
- Empty glass bottles are to be put along side the secondary containment tray in the passthrough to go out for recycling
- Empty plastic bottles are to be put under one of the chemical hoods to be reused for waste bottles

4. **Starting a New Waste Bottle**
    - Do not create more than one waste bottle of each type at each bench
    - For standard waste, get a preprinted label from the folder at the front of the bench. Note the date of creation on this label with a sharpie
    - For non-standard waste, fill out a red EHS tag. Attach to the bottle with additional tape
    - All acid and base mixtures require a vented cap
    - Never leave a waste bottle unlabeled
    - Never write directly on the bottle
5. **Pouring Out Waste**
    - Confirm that your reaction is cool before disposing
    - Place the waste bottle in the since and use a funnel to pour the waste
    - Do not overfill the bottle
    - Rinse the funnel and any drips on the side of the waste bottle
    - Rinse and dry glassware
    - If a waste container is full, transport it using the rubber bucket and gloves

Chemical Bottle Life Cycle



6. **Hot Plate Usage**
    - **Solvent and Spinner Hoods**
        - ***This hood is equipped with one explosion-proof hot plate, and one explosion-proof stirring hot plate.***
        - "Explosion-proof" simply means the hot plate does not contain any ignition sources, like thermostat contacts. It does **not** mean that the fluid you are heating will not catch fire! Do not heat any fluid above its flash point temperature with these hot plates (or any other hot plates, for that matter). See the MSDS to verify flash points.
        - These hot plates do not have temperature readouts. Use an immersion thermometer to monitor the temperature of the fluid you are heating. **Do not** "walk away" from a beaker of fluid being heated on a hot plate in this hood!
    - **Acid, Base, and CMOS Hoods**
        - These hoods are equipped with one ceramic-top stirring hot plate. These hotplates are intended for heating beakers, not for baking wafers. **These are not explosion proof, do not heat flammable solvents.**
        - The Acid and CMOS hood hot plates are equipped with temperature monitoring probes. After use, please wipe these down and return to their box outside the hood.
8. **Acid/Base Bench Protocol**

Preparation:

- Check the list of approved chemicals posted on the hood
- Find the appropriate glassware with lids
- Label the glassware with name, date, time, and chemical names
- Locate the appropriate waste bottle

Chemical Handling:

- Locate chemicals in designated storage areas
- Transporting acids: Use a rubber bucket and wear one heavy nitrile glove to carry the chemical safely while using the other hand for opening doors
- Always cover all chemicals when not in use

Working at the Bench:

- Don the PPE in the correct order: Apron, Face shield, Green Gloves
- Do not touch the green gloves anywhere but the work surface

- Ensure proper airflow in the fume hood before beginning work
- If using a heated process tank, ensure the fluid level is at least 60% full before enabling the heater
- Do not use HF-containing mixtures in the heated process tank

Waste Disposal:

- Confirm that your reaction is cool before disposing
- If you have removed your PPE, don the PPE in the correct order
- Place the waste bottle in the since and use a funnel to pour the waste
- Do not overfill the bottle
- Rinse the funnel and any drips on the side of the waste bottle
- Rinse and dry glassware

Post-Use Cleanup:

- Rinse the green gloves thoroughly before removing them
- Remove face shield and apron in reverse order
- If a waste container is full, transport it using the rubber bucket and gloves
- Dispose of used chemicals and waste according to cleanroom regulations

By strictly following these protocols, users can safely work with acids while minimizing contamination and potential hazards

9. Resist Dispense Protocol

- Resist / LOR will be dispensed using a disposable plastic pipette.
- The pipette will be used to draw a quantity of resist from a room-temperature “aliquot” bottle of resist, NOT from the quart or gallon “mother” bottle!
- Pipettes will not be reused – once the dispense and spin are completed, the pipette will be disposed of in the designated container on the benchtop.
- The “aliquot” bottle will be refilled from the “mother” bottle ONLY after the mother bottle is allowed to come to room temperature, thus avoiding the introduction of water vapor from the room air. After being used to refill the aliquot, the mother bottle can be tightly recapped and returned to the refrigerator.

10. Spinner Cleaning Protocol

- For AZ-type resists, the cleaning solvent of choice is Microchem EBR, **DO NOT SQUIRT ACETONE INTO THE LAUREL SPINNERS**, internal components are not compatible with acetone and will damage the spinner. For LOR resist, NMP seems to do a better job.
- Place a 3” dummy silicon wafer, properly centered, on the spinner chuck. Switch on the vacuum and close the lid. Program the spinner to use a speed of 1000 rpm

for two minutes (120 seconds). Start the spinner. While the wafer is spinning, use the squirt bottle to spray the solvent of choice onto the center of the wafer, through the hole in the lid of the spinner. Do this for about 15 seconds, then pause, then again for about 15 seconds. If the appearance of the spinner bowl suggests that more cleaning is required, continue to spray for another 15 to 30 seconds. Now stop the spinner, open the lid, take out the dummy wafer, and use a lab wiper to wipe off all the interior surfaces of the spinner. Dispose of the wipers in the cleanroom trash.

- Leave the spinner cleaner than you found it!

4.0 Cleanroom Safety and Emergency

All the Cleanroom policies and procedures are intended to create a safe working environment for all Users and Staff. Users are encouraged to speak with Staff when a policy or procedure is not clear.

4.1 Safety Data Sheets (SDS)

Binder's containing SDS's for all hazardous materials in the cleanroom will be kept in the gowning room. They are filed alphabetically with A-L in one binder and M-Z in the other.

The binders will be maintained by the cleanroom staff, with sections added when new chemicals or gases are approved and introduced into the cleanroom. Should you not find a datasheet that you think should be in the binders, please contact a staff member.

A copy of all the SDS sheets are stored virtually on the gowning room computer.

4.2 Toxic Gas Monitoring System

Status Panel

There are three status panels for the toxic gas monitoring system. One is in the cleanroom entryway, another is in the back of room 529, and the third is on the first floor of the Becton Center, near the Prospect St. entrance. The status panel normally displays the current detected quantity for 16 detection points in the cleanroom, and in the gas cabinets in room 528. If an alarm is raised, these panels can quickly provide information relating to the source of the alarm signal.

The cleanroom is equipped with two emergency gas cabinet shutoff buttons. Activation of these buttons will cause all gas flows from the gas cabinets in 528 to shut off. This includes all of the toxic gases, flammable/pyrophoric gases, and oxidizing gases. As an aside, the gas cabinets will also shut off their output flow if the building fire alarm is activated. The gas cabinets will require a manual reset in order to reestablish the gas flow.

Indicator lights and horns

There are several sets of indicator lights for the toxic gas monitoring system. Each set is composed of three lights arranged horizontally: one white, one yellow/orange, and one red. The white light indicates a "low-level" alarm. The yellow/orange light indicates a "mid-level" alarm. The red light indicates a "high-level" alarm. When activated, the lights will "strobe" at a rate of about twice per second.

Actions to take in response to an alarm condition

Low-level "white light" alarm

- Place experiments in standby, exit through the gowning area and degown, contact Staff, gather in the hallway until the alarm is off and cleared by staff.
- **If after hours, leave the cleanroom normally**, notify staff or safety, do not re-enter until alarm is cleared.

Mid-level "yellow/orange light" alarm

- Place experiments in standby, exit the cleanroom through the nearest exit, **do not degown**, assemble outside in hall, contact Cleanroom Staff as well as Yale ER Team (YPD, YFM, OEHS)
- Do not re-enter cleanroom until alarms clear and staff members indicate it is safe to re-enter

High-level "red light" alarm

LEAVE IMMEDIATELY

- Building fire alarm will sound.
- **Leave the cleanroom through the nearest door, DO Not stop to degown, leave the building**
- Assemble outdoors on Prospect Street
- **Do not leave the area until you inform the Cleanroom Staff to confirm you exited safety**
- Do not re-enter building until alarms clear and fire department indicates it is safe to re-enter building
- Do not re-enter cleanroom until staff members indicate it is safe to re-enter

4.3 Chemical Spills

Chemical Spills – No Exposure

All qualified cleanroom users have been trained in chemical spill response as part of the required on-line chemical safety training. Refer to Section 2.5 of the Yale University Chemical Hygiene Plan for spill cleanup information.

For all spills, alert people in immediate area and restrict access to spill location.

Identify the materials involved, quantity, and specific location of the spill. Evaluate hazard(s) and address personal contamination/injury. Summon any additional emergency services needed.

Only attempt to clean up a chemical spill if you are comfortable and confident that it can be done safely – if in doubt, use one of the ringdown phones to call for help. If the spill has caused the evolution of noxious vapors, leave the area immediately and call for help (785-3555 – OEHS emergency phone number). If possible, cover with absorbent material to reduce vapors before leaving the area.

Wear basic protective equipment appropriate to hazard to clean small spills – if respiratory protection is needed, the incident is NOT minor and OEHS should be contacted immediately.

To clean minor spills, spill kits and neutralizer for acids, bases, and HF are kept in the wet process bay. Use appropriate material to absorb or neutralize spilled material. Work from perimeter inwards. Collect residue, place in heavy plastic bag or other receptacle, affix waste label describing contents, and contact Environmental Services for waste pick-up.

Clean spill area with soap and water.

Chemical exposure

Personal exposure to wet chemicals, particularly caustics, requires immediate action. Eyewashes and safety showers are located in the wet chemistry areas, as well as in the hallway outside the cleanroom. The victim should use the shower or the eyewash for at least 15 minutes to mitigate and dilute the chemical. Those assisting the victim should use the ringdown phone to call for emergency assistance (use the red button, no dialing required).

First Aid

The first aid kit is kept in the gowning room, along with the gowning supplies.

Minor cuts, scrapes, burns can be treated using the supplies in the first aid kit. Move the victim to the gowning room for treatment if possible and appropriate.

If there is ANY possibility that the injury is anything beyond minor, or if the victim exhibits ANY symptoms of shock, use the ringdown phone (red button, no dialing required) to call for medical assistance

ALL cleanroom injuries, no matter how minor, must be reported to a lab staff member for documentation and, if appropriate, remediation of the hazard that caused the injury.

HF (Hydrofluoric Acid) Exposure Protocol

Hydrofluoric acid (HF) is **extremely hazardous**, capable of causing severe injuries or death if not handled properly. Immediate action is required in case of exposure.

Emergency Response for HF Exposure

1. **Remove Contaminated PPE and Clothing Immediately**
    - Do not waste time. Quickly remove gloves, lab coat, and any clothing contaminated with HF.
2. **Rinse the Affected Area for 5 Minutes**
    - **Use an emergency shower or eyewash station** if necessary.
    - Rinse with copious amounts of water for at least **5 minutes** to remove the acid.
3. **Apply Calcium Gluconate Gel**
    - Gently massage **2.5% calcium gluconate ointment** onto the exposed area.
    - Continue application **until medical responders arrive**.
    - If the ointment is unavailable, continue rinsing for a **minimum of 15 minutes**.
4. **Seek Immediate Medical Attention**
    - **Call 911** or instruct someone nearby to do so.
    - Inform emergency responders that the injury involves **HF exposure**, as **special medical treatment is required**.
    - The affected individual must be transported to a medical facility **even if no immediate pain is felt**, as HF can penetrate the skin and cause delayed but severe tissue damage.
5. **Report the Incident**
    - Once the immediate emergency is addressed, report the exposure to the **Cleanroom Director** and appropriate safety personnel.
    - Document the incident for safety review and future prevention.

Key Safety Measures

- Always have **calcium gluconate gel** available when working with HF.
- Ensure that all users handling HF are **properly trained**.
- Wear **full PPE**, including:
    - **Face shield**
    - **Safety glasses**
    - **Chemical apron**
    - **Heavy nitrile gloves**
- Never work alone with HF—use the **buddy system**.
- Follow strict **chemical waste disposal protocols** to prevent accidental exposure.

HF is **one of the most dangerous chemicals in the cleanroom**, and proper handling, along with swift emergency action, is critical to preventing severe injury or fatalities.

4.4 Fire

The two double doors from the cleanroom to the hallway are the emergency exits. A fire alarm pull box is located adjacent to each door. An alarm will sound when the door is opened from the inside, so don't be surprised. ***Do not worry about your cleanroom garment when exiting the cleanroom under an emergency condition – you can remove it after you are in a place of safety***.

Should it be needed, a fire blanket is located in a vertical cabinet next to chase 2. It can be used to help douse the flames on a person who has caught fire. To use, pull the blanket out of the cabinet, then roll the person up in the blanket to smother the flames.

There are two fire extinguishers next to the emergency exits (double doors that go into the hallway). All cleanroom users are required to take the on-line Yale Fire Marshal's Fire Extinguisher Training. Fire extinguishers are located at several places in the cleanroom. They are of the "CO_2" type. Before employing an extinguisher, pull a fire alarm box to summon assistance.

Operation of the extinguisher requires four steps:

1. **Pull the pin.**
2. **Aim at base of flames**
3. **Squeeze the trigger to release the CO_2 vapor**
4. **Sweep the nozzle horizontally back and forth to smother the flames**.

The memory key is “P A S S”: **P**ull, **A**im, **S**queeze, **S**weep.

Only attempt to put out a fire if you have a clear escape path behind you, and you feel comfortable operating the extinguisher.

In the event that the building fire alarm sounds, leave the cleanroom immediately (but in an orderly fashion: Don’t Panic) using the emergency exits to the hallway. Do not linger to shut down tools/processes. Do not worry about removing your cleanroom gown until you are in a place of safety. Do not reenter the building until the alarm has been turned off, and the Fire Department has indicated it is safe to reenter.

4.5 Ringdown Phones

The Becton cleanroom is equipped with three “ringdown boxes”: one in the wet process bay, adjacent to the sliding door; one adjacent to the CMOS process bench at the end of the metrology bay; and one at the end of the thermal bay. These boxes function similarly to the blue security boxes we see sprinkled around campus. Depending on how you actuate them, they can serve as a normal campus telephone, or to summon immediate emergency assistance from campus security and/or Yale Police.

To operate as a telephone,

Press the black button. you will hear a dial tone.

Now dial the phone number on the touchtone pad. The ringdown box now functions like a speakerphone for the remainder of your conversation.

To end the call, press the black button again.

In case of emergency, press the red button. No touch tone pad dialing is required. Yale Security (911) will answer the call, and the box will again function like a speakerphone.

Be advised that Yale Security will know your location when they answer the call (they see “Becton Center, 5th floor, cleanroom”). Please be clear when stating your emergency to the dispatcher, who will then be able to summon the appropriate emergency responder. If Security does not get a response, a Yale Security Officer will be immediately dispatched to this location.

4.6 Emergency Contact

At the end of each Bay in both the Becton and West Campus Cleanrooms is a list of the current staff and their cell phone numbers. After hours, please try calling twice, leave a voicemail, and follow up with a text message. When in doubt call 911.

Group or Agency	**Individual**	**Business Hours**	**Off-Hours/Cell Phone**
Facilities Operations Control Center	Dispatcher	203-432-6888	203-432-6888
Yale Environmental Health & Safety Office	Emergency Line	203-785-3555	203-785-3555
West Campus Security		203-737-3111	203-737-3111
Yale Police Department		911 (Yale phone) 203-432-4400	911 (Yale phone) 203-432-4400
Medical Emergencies		911	911

5.0 Cleanroom Management

The following procedures and polices have been developed with the consideration and the cooperation of the Dean of School of Engineering and Applied Science, SEAS clean room staff, SEAS clean room faculty advisory committee, the Office of Environmental Health and Safety and the Provost's Office. Every effort has been made to accommodate the needs of the research community while ensuring for prudent and necessary budget controls, as well as the maintenance of a strong culture of safety.

The SEAS clean room management is fully empowered to implement and enforce policy including disciplinary protocol.

As with the Cleanroom Handbook, this is a living document and will evolve over time with our experiences. Questions or comments regarding the content of this document should be submitted through the cleanroom staff at regularly scheduled user meetings. Changes to this document will be posted on the cleanroom web site and distributed to the user community.

5.1 User Fees

Every effort has been made to develop a chargeback policy that is fair and consistent and adheres to all generally accepted accounting principals.

User fees will be reviewed by the Yale Provost's Office and cleanroom Director once per fiscal year or more frequently as warranted. Recommended fee adjustments are initiated by the Provost's Office and forwarded to the cleanroom Director for review and approval.

Up to date user fees are listed on the Cleanroom website.

5.2 Time Keeping and FOM

All cleanroom users are required to swipe their proximity card at the main entrance reader upon entering and upon exiting the facility. This applies regardless of if the door is previously open for someone else.

Random review of surveillance date will be conducted to validate compliance. **Failure to comply with this protocol will result in discipline outlined by the below policies.**

The Facility Online Manager (FOM) is the interface used to manage user scheduling, time accounting, qualifying permissions for equipment access and communication with users and equipment managers.

All tools that require training to use are interlocked in FOM (everything except the Zeta-20 microscope and the wet benches). Users are required to log into a tool via FOM to enable it before use. If a user wishes to use a tool, they may make a reservation. Or if a tool is not currently reserved by any other user, it may be logged on in real time until the start of the next users reservation. Some of the heavy use tools have reservation limits in place.

5.3 Visitors and Guests

A visitor or guest is defined as anyone who is not a qualified cleanroom user and has permission to enter the cleanroom with a host for the purposes of observation.

A host is defined as a qualified cleanroom user. Anyone wishing to bring a guest into the cleanroom should first notify the cleanroom manager for permission.

The host is responsible for the conduct and safety of their visitor/guest while in the cleanroom.

A visitor/guest may not perform any operations or operate any equipment in the cleanroom.

5.4 External Customers

External customers are non-Yale researchers who have been approved by the FoE business office, to have met and acknowledged the requirements and agreed to the nonacademic rate structure of the clean room.

5.5 Precious Metals

Precious metals are defined as gold, palladium and platinum. This may also include evaporation materials that are priced more than $5/gram. Check with the Staff for a list of currently provided materials.

The cleanroom inventory does not include precious metals, purchase, and storage of precious metals for deposition, or other process requirements, will be the responsibility of each research group.

5.6 After-Hours Policy

Hours of Operation

Business hours are considered as the standard hours for Yale staff offices, which are generally 8:00 am to 5:00 pm Monday through Friday. During this time all operations are unrestricted.

After Hours

After hours are defined as the hours outside of standard working hours. This includes posted Yale holidays. All other closures will be posted. Anyone who needs to work in the cleanroom after hours is required to adhere to the after-hours policies. **Failure to comply with these protocols will result in discipline outlined by the policies below.**

After-Hours Policies

A cleanroom user who has accumulated 30 hours or more in both the Becton and West Campus facilities without safety violation may request after-hours access from the Staff. This means, a users badge will only work during normal business hours until this requirement is met and approved by the staff.

An approved after-hours user may use allowed after-hour operations under the condition that they are accompanied by a safety buddy. A safety buddy is defined as another trained cleanroom user with after-hours access. The safety buddy must be present on campus, in communication with the after-hours user, and aware of their activities in the Cleanroom should they need to call for help.

After-hours users must fill out the log on the entry way computer each day they access Cleanroom after-hours or if their safety buddy changes.

Random audits of the after-hours logs and surveillance cameras will be conducted to validate safety compliance. **Failure to comply with these protocols will result in discipline outlined by the policies below.**

Allowed Operations

The following tools and processes have been approved for unrestricted after-hours use, in conjunction with the above protocols:

1. Lithography tools, including vacuum bake, vapor prime, resist spin and bake, exposure, development, microscope inspection
2. Physical vapor deposition systems
3. Metrology tools
4. Fluorine RIE/ICP etching

5. Thin-film plasma bay tools (furnaces, ALD, PECVD, RTA, plasma asher)
6. Wet benches for any processes not restricted as listed below

Restricted Operations

Due to extended EHS and emergency support services response times after-hours, the following operations are banned outside of business hours.

1. HF Vapor etcher
2. Chlorine RIE/ICP etching
3. The following wet bench processes: HF, BOE, Sulfuric Acid, Aqua Regia mixture, and use of hydrogen peroxide >30%

5.7 Annual User Meeting

Users are required to attend the yearly Cleanroom Safety and Facility Update meeting, held every summer. This meeting is intended to review safety guidelines and the common safety mistakes/violations, as well as give an update to available Cleanroom tools and technology. Users who do not attend the meeting or make alternative arrangements with the Staff will lose their Cleanroom access.

5.8 Discipline

The clean room has enjoyed an excellent record of safety, a tribute to the level of professionalism we have at Yale. On the rare occasions we must take disciplinary action, it is imperative we follow a procedure that ensures fairness and a quick resolution.

Every CR user is responsible for ensuring that laboratory safety procedures and protocols are followed. All users and staff members have the authority and responsibility to take immediate action to mitigate a safety or policy violation and to report it to the manager in charge.

The Record of Discussion report will contain a brief description of the violation, the actual or potential outcome due to the violation, an account of any interviews, likely reasons for violation, corrective actions, signatures of involved parties. Multiple RoD's will result in stiffer penalties for subsequent offenses.

A Safety Review Board is made up of the following people: Cleanroom Director, Faculty Advisor, Cleanroom Staff, and EHS Officer. This review board has the responsibility to review Level 1 and 2 violations that result in injury. The board will generate an incident report along with any notices or policy changes needed to prevent future accidents. Incident reports are intended as educational tools; thus, names will be omitted prior to filing for public display.

A Non-Safety Review Board is made up of the following people: Cleanroom Director, Faculty Advisor, and Cleanroom Staff. This review board has the responsibility to review Level 1 and 2 violations that do not result in injury. The board will generate an incident report of the incident and decide on any cost liability and responsibility. Incident reports are filed privately in the Cleanroom drive.

Safety and Chemical Handling Violations

Level	**Description**	**Staff Action**
Level 1	Knowingly disregards safety procedures, resulting in **injury to self or another**	**Immediate and indefinite revocation of cleanroom access**. A **Record of Discussion** is generated within 10 days. A **Safety Review Board** is convened to investigate the incident.
Level 2	Unknowingly disregards safety procedures, resulting in **injury to self or another**	**Immediate 3-month suspension of cleanroom privileges**. A **Record of Discussion** is generated within 10 days. A **Safety Review Board** is convened to investigate the incident.
Level 3	Knowingly disregards safety procedures, but no injury occurs	**Minimum 2-week suspension**. A **Record of Discussion** is generated within 10 days, and corrective actions are required.
Level 4	Unknowingly disregards safety procedures, but no injury occurs	**Minimum 2-week suspension**. A **Record of Discussion** is generated within 10 days, and corrective actions are required.

Protocol and Equipment Operation Violations

Level	Description	Staff Action
Level 1	Knowingly disregards training, causing **policy violations, damage, or contamination**	**Immediate and indefinite disqualification** from the cleanroom. A **Record of Discussion** is generated within 10 days. A **Non-Safety Review Board** assesses damages.
Level 2	Unknowingly disregards training, causing **policy violations, damage, or contamination**	**Minimum 2-week suspension from affected equipment**. A **Record of Discussion** is generated within 10 days, and future use is limited and monitored. A **Non-Safety Review Board** assesses damages.
Level 3	Knowingly disregards procedures, but no damage occurs	**Minimum 2-week suspension from affected equipment**. A **Record of Discussion** is generated within 10 days, and corrective actions are required.
Level 4	Unknowingly disregards procedures, but no damage occurs	**Minimum 2-week suspension from affected equipment**. A **Record of Discussion** is generated within 10 days, and corrective actions are required.

5.9 Policy Changes

There will be times that warrant either a change or addition of policies wich govern the cleanroom. To maintain fairness and careful consideration to safety and protocols:

1. The proposal will be reviewed and may be discussed with EHS and the Cleanroom Committee.
2. Any changes or differences will be discussed and/or edited.
3. The final version goes to the Cleanroom Director for approval.

5.10 Cleanroom Committee

This committee is a faculty review committee administered by the Provost Office. It also includes the deputy provost, FoE business manager, director of YINQE, and the Cleanroom director. Its primary responsibility is to review cleanroom capabilities, discuss additions in capitol equipment, and review and discuss costs and charges.