



Cleanroom Design and Operations

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USPAS Course:

SRF Technology: Cleanroom Design and Operations

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Topics

- **Introduction**
- **Contamination**
- **Design**
- **Operation**
 - Monitoring
 - Protocols, Materials, Processes
 - Equipment
- **Resources**

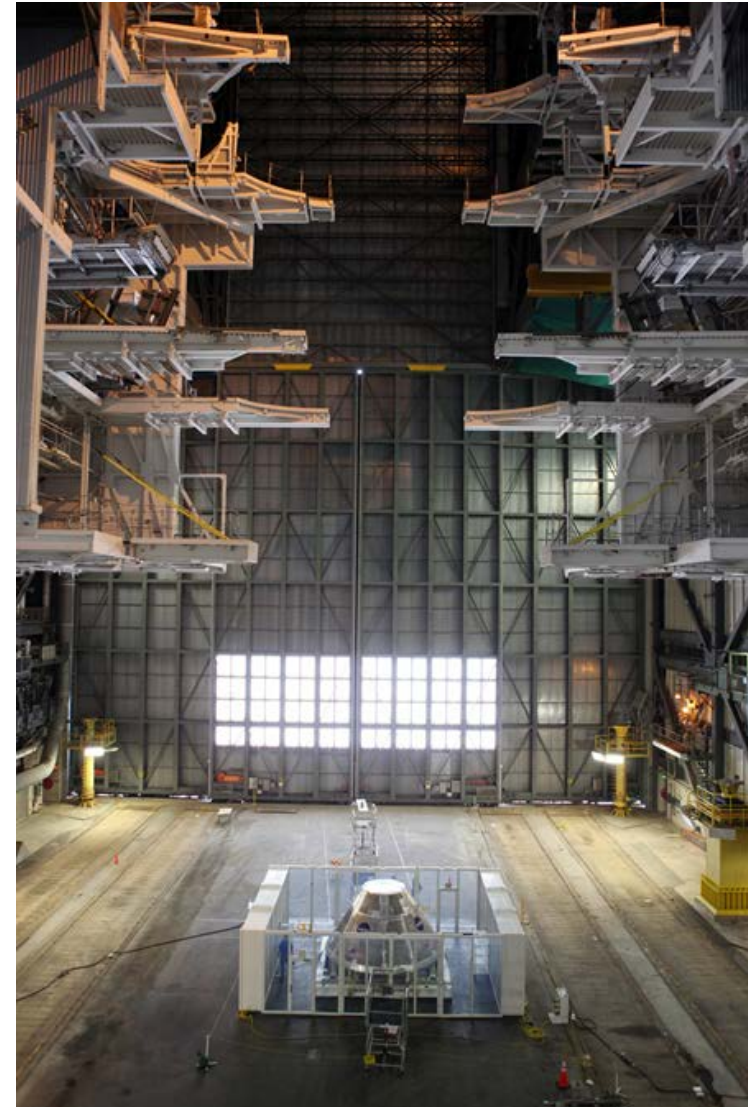
Introduction

- **What is a cleanroom:** ISO14644-1 “A room in which the concentration of airborne particles is controlled, and which is constructed and used in a manner to minimize the introduction, generation, and retention of particles inside the room and in which other relevant parameters inside the room and in which other relevant parameters, e.g. temperature, humidity and pressure, are controlled as necessary.”
- **Airborne Particles**
 - Particles (dust)
 - Airborne microbes (viruses)
 - Aerosol and Chemical vapors (solvents)
 - Airborne Molecular Contamination (AMC)
- **Other Relevant Parameters**
 - Temperature , Humidity, Pressure
 - Vibration-Noise
 - Lighting
 - Magnetic-Electromagnetic Flux
 - Electro Static Discharge



Introduction

- **Who uses cleanrooms?**
 - Aerospace / Defense
 - Semiconductor / Microelectronics
 - Pharmaceuticals / Medical Device
 - Healthcare / Hospitals
 - Food
 - Industrial (Auto, Solar, Optics, etc...)
 - Research / University



Introduction

- **How do we get clean air and protect the room?**

- Dilution

- With no air ventilation in a cleanroom, particles build up quickly. Ventilation expels contaminated air to the outside or recirculates through the filter system. Thus new make-up air dilutes existing air in the cleanroom.
 - Air Changes

- Filtering

- Pre-Filters (Similar to house hold air filter) – used for gross filtering outside air.
 - Secondary Filters (MERV Filters) – high efficiency (high velocity, low pressure drop).
 - HEPA or ULPA
 - Carbon Filtering / Gas-Phase air Filtration – Airborne Molecular contamination (AMC)

- Isolation / segregation

- Cleanroom are isolated by walls ceiling and floor from other room.
 - Entry and exiting of material and personnel is controlled through room of lower cleanliness zones
 - Utilize independent HVAC systems
 - Isolate particulate generating operations and personnel (garments/suits)

- Positive Pressure

- Clean air flow out to lower pressure areas

- Laminar Flow

- Moves particles to the air returns efficiently and quickly
 - Suppress contaminants

- Cleaning & Maintenance

- Daily, Weekly, Monthly
 - HVAC and Filter maintenance

- Materials & Equipment

- Approved materials and equipment design

- Protocols

- Rules for personnel conduct in the cleanrooms

Introduction

- **What cleanroom is right for your application?**

Where do you start?

- Product - Product Quality (clean , sterile, other)
- Cost (ISO 5 = \$900 - \$1200 / ft²)
- Work / Process Flow (Product Mix, volume, change-over, key/critical steps)
- Regulation (FDA/USP, OSHA, EPA, DOD, Industry, Customer)

- **Jlab SRF**

- Test Lab Addition classified space: ISO 4-9 = ~6100 ft²
- Main Cleanroom and associated Chemistry rooms
Cleanroom Contractor (DAW): ~2.5M
Other CR specific construction: 4.0M+

Contamination - Particles

- **Cleanroom Classification** – Cleanrooms are designated by ISO 14644-1 for particulate levels.

Class	maximum particles/m ³						FED STD 209E equivalent
	≥0.1 µm	≥0.2 µm	≥0.3 µm	≥0.5 µm	≥1 µm	≥5 µm	
ISO 1	10	2.37	1.02	0.35	0.083	0.0029	
ISO 2	100	23.7	10.2	3.5	0.83	0.029	
ISO 3	1,000	237	102	35	8.3	0.29	Class 1
ISO 4	10,000	2,370	1,020	352	83	2.9	Class 10
ISO 5	100,000	23,700	10,200	3,520	832	29	Class 100
ISO 6	1.0×10 ⁶	237,000	102,000	35,200	8,320	293	Class 1,000
ISO 7	1.0×10 ⁷	2.37×10 ⁶	1,020,000	352,000	83,200	2,930	Class 10,000
ISO 8	1.0×10 ⁸	2.37×10 ⁷	1.02×10 ⁷	3,520,000	832,000	29,300	Class 100,000
ISO 9	1.0×10 ⁹	2.37×10 ⁸	1.02×10 ⁸	35,200,000	8,320,000	293,000	Room air

Occupancy States – “As-Built”, “At-Rest”, “Operational”

- As-Built: building complete and operational, but no equipment, materials, or personnel.
- At-Rest: no personnel, no work.
- Operational: specified number of personnel and process working.
- Cleanrooms are tested (certified) when built, then recertified annual or semiannually.
- Re-Certification can be performed “at-rest” or “operational”.

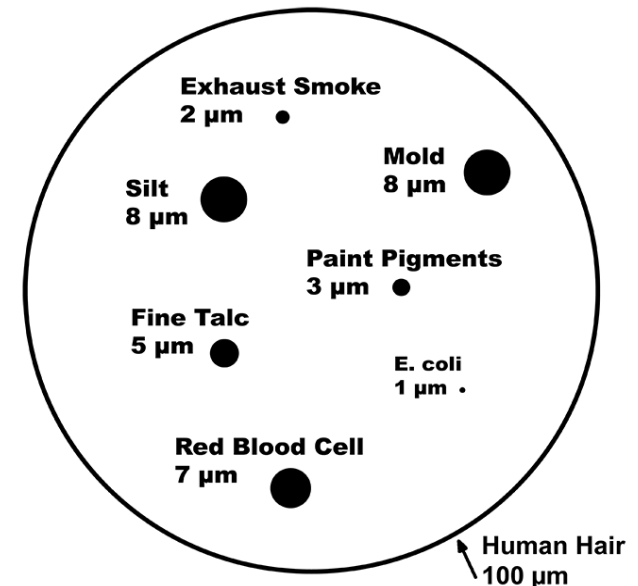
Contamination - Particles

- **Particles movement through the cleanroom air**

- Gravity
- Ballistic force: particles ejected and move against prevailing air flow.
- Diffusion: thermal variation, Brownian motion.
- Currents: laminar or turbulent.

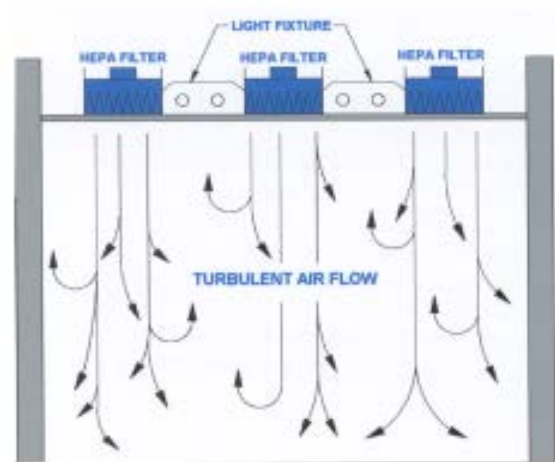
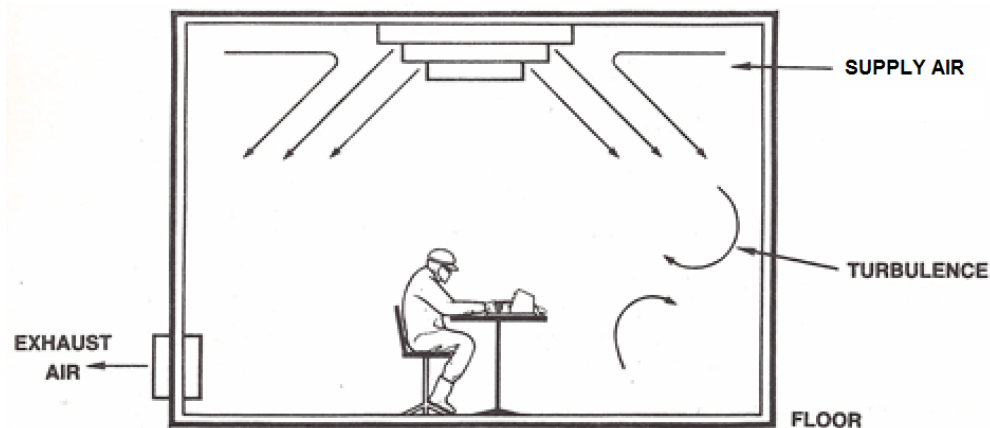
- **Particles Adherence**

- Friction
- Electrostatic adhesion
- Capillary adhesion
- Accretion – particles sticking to other particles
- Van der Waals force

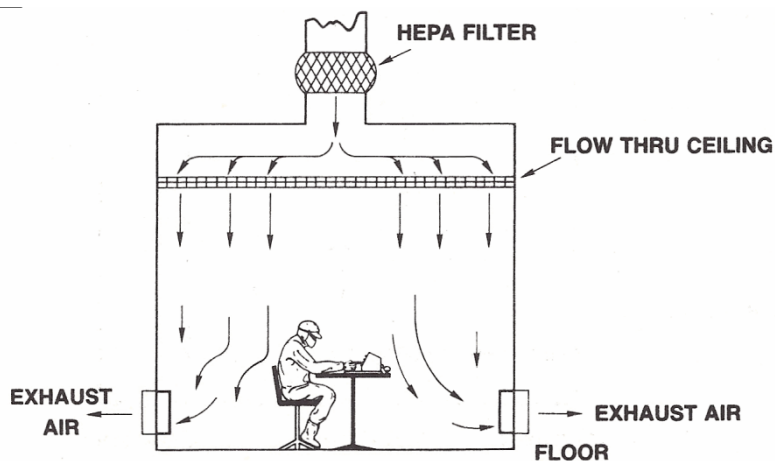


Design - Airflow

- Conventional

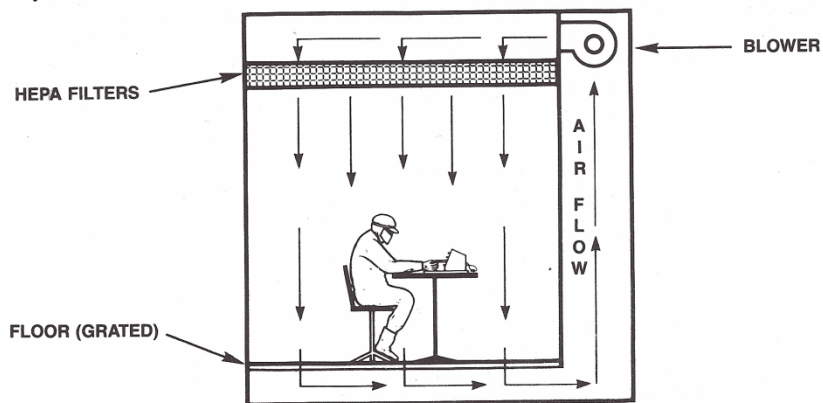


- Semi-Laminar

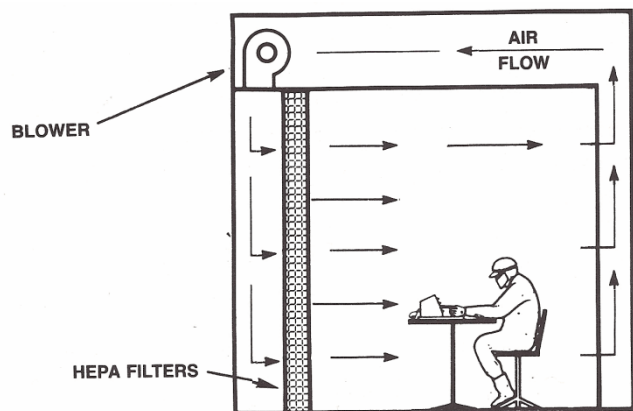


Design - Airflow

- **Vertical Uni-directional**



- **Horizontal Uni-directional**

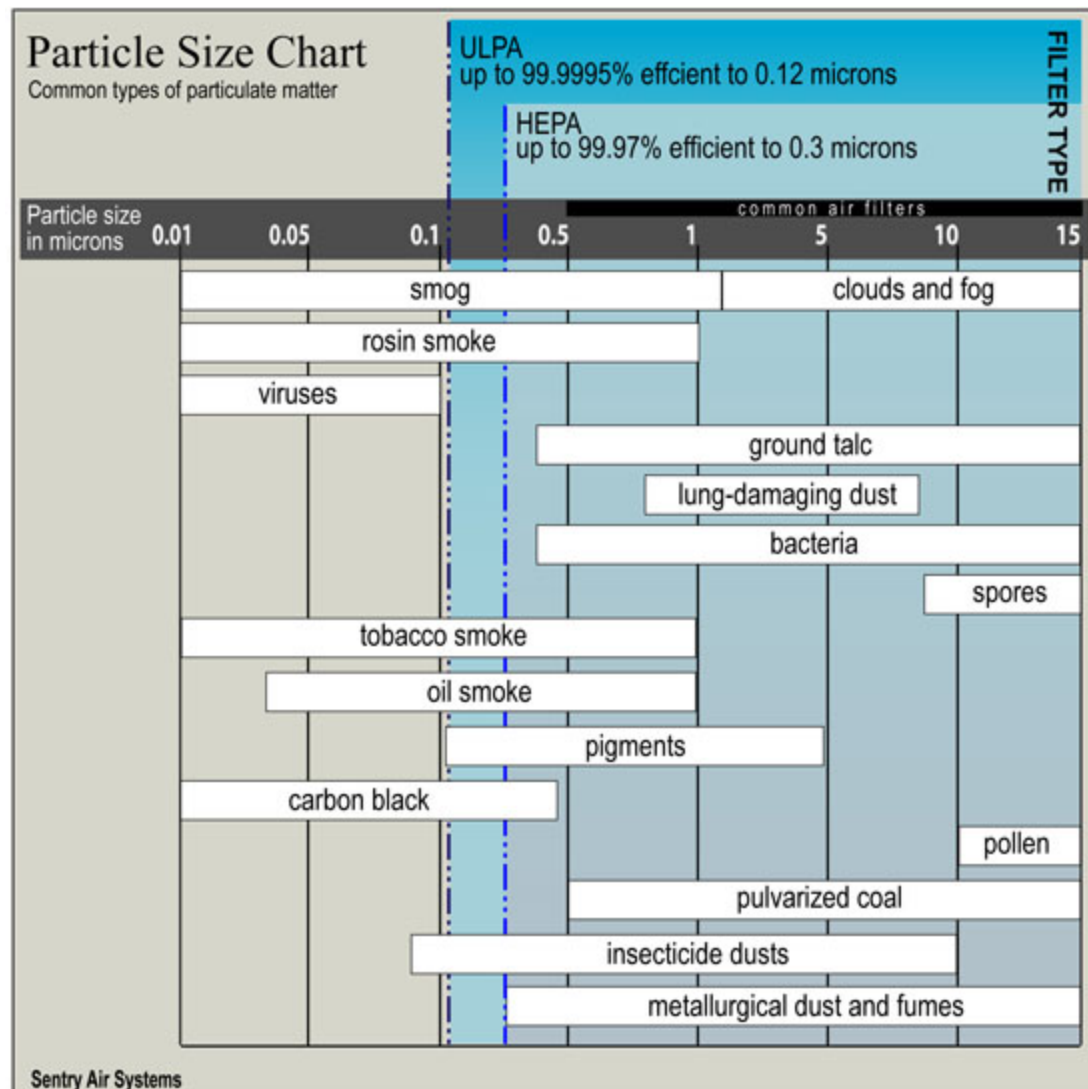
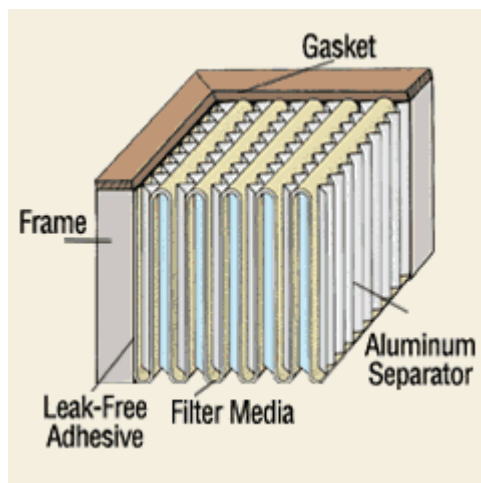


Design - Filtering

• HEPA vs ULPA

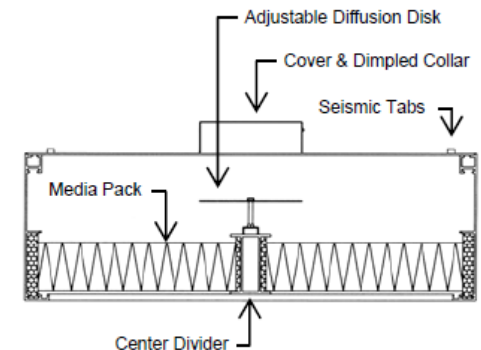
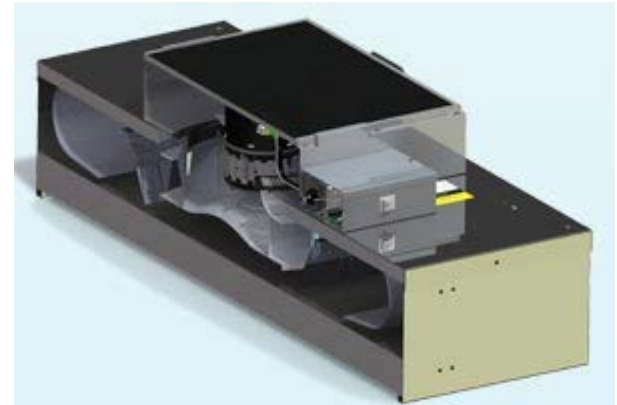
- High efficiency particulate arrestance or air (HEPA)
- Ultra-Low Particulate Air (ULPA)
- EN 1822, and IEST-RP-CC001

Filter	
HEPA	99.97% @ $\geq 0.3\mu\text{m}$
ULPA	99.999% @ $\geq 0.12\mu\text{m}$



Design – HEPA/ULPA

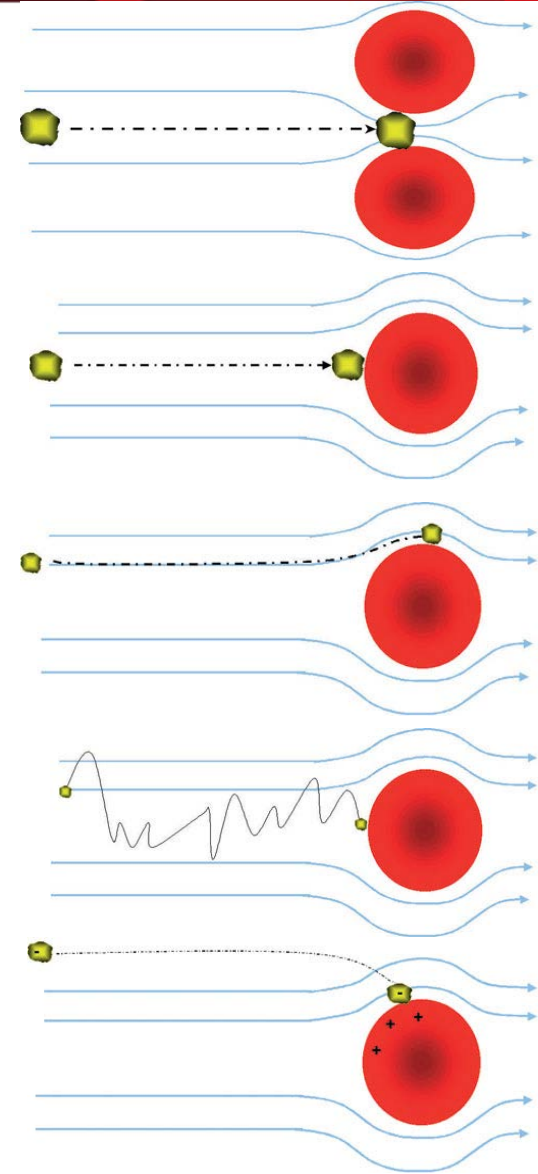
- **Fan Filter Unit** – Typically used in soft-wall and small modular cleanrooms.
- **Ducted Filter Unit** – Typically used for modular or conventional cleanrooms.
- **Gasket or Gel Sealed Filters** - Found in open plenum conventional cleanrooms.



Design-HEPA/ULPA

- **How the HEPA/ULPA filter works:**

- **Straining / Sieving:** particle diameter is simply too large for the space for it to flow through.
- **Impaction / Impingement:** particle hits a filter fibers and embeds into its surface. (particles $> 0.1 \mu\text{m}$)
- **Interception:** particles are attracted and bonded via intermolecular adhesion (van der Waals force). (particles $< 0.1 \mu\text{m}$)
- **Diffusion:** Brownian motion on small particles increasing likelihood of particle coming into contact with fibers. (particles $< 0.1 \mu\text{m}$)
- **Electrostatic Attraction:** Uses large diameter charged fibers to attract much smaller particle with the opposite charge. (Special Filters Only)



Design-HEPA/ULPA

- **Air Velocity**

- Carry particles faster to the return. Suppress particles on surfaces.
- Too High – turbulence, operating cost, filter efficiency.
- Too Low – no laminar flow, migration of particles, etc...
- Test method used for unidirectional rooms per ISO 14644.

- **Air Changes**

- Dilution of air.
- Test method recommended by ISO 14644 for non-unidirectional rooms.

- **Ceiling Design**

- **Ducted Filter Unit** - used for modular or conventional cleanrooms.
- **Gasket or Gel Sealed Filters** - typical of open plenum and some FFU or ducted filter units.

DESIGN GUIDE FOR CLEANROOMS

Cleanroom Design¹

CLEANLINESS CLASSIFICATION ²	AIRFLOW PATTERN ³	AVERAGE AIR VELOCITY	AIR CHANGES PER HOUR
ISO CLASS 8 (100,000)	Nonunidirectional / Mixed	1 – 8 fpm	5 – 30
ISO CLASS 7 (10,000)	Nonunidirectional / Mixed	10 – 15 fpm	30 – 60
ISO CLASS 6 (1,000)	Nonunidirectional / Mixed	25 – 40 fpm	125 – 240
ISO CLASS 5 (100)	Unidirectional	40 – 80 fpm	240 – 480
ISO CLASS 4 (10)	Unidirectional	50 – 90 fpm	300 – 540
ISO CLASS 3 (1)	Unidirectional	60 – 90 fpm	360 – 540
ISO CLASS 2	Unidirectional	60 – 100 fpm	360 – 600

FILTER EFFICIENCIES

Cleanliness Class	Filter Efficiency
Class 2	99.9999% @ 0.12µm
Class 3	99.9995% @ 0.12µm
Class 4	99.999% @ 0.12µm
Class 5	99.99% @ 0.30µm
Class 6	99.99% @ 0.30µm
Class 7	99.99% @ 0.30µm
Class 8	99.99% @ 0.30µm

AIR RETURNS

Cleanliness Class	Air Return Design
Class 2	Raised Floor
Class 3	Raised Floor
Class 4	Raised Floor
Class 5	Low Wall Long Axis
Class 6	Low Wall
Class 7	Low Wall or Ceiling
Class 8	Low Wall or Ceiling

CEILING DESIGN

Cleanliness Class	Ceiling Grid Type
Class 2	Gel Grid
Class 3	Gel Grid
Class 4	Gel Grid
Class 5	1-1/2" T Bar Gasket
Class 6	1-1/2" T Bar Gasket
Class 7	1-1/2" T Bar Gasket
Class 8	Side Access HEPA Hsg.

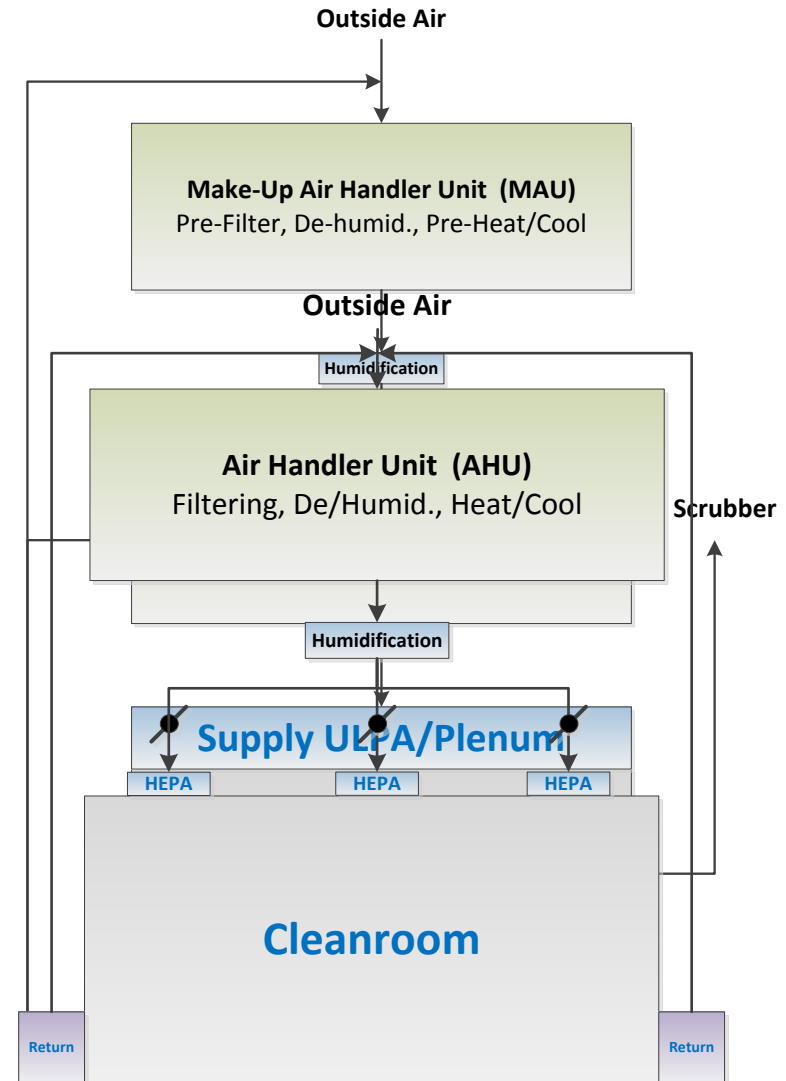
FILTERED CEILING COVERAGE

Cleanliness Class	Amount of Filters
Class 2	100% Ceiling Coverage
Class 3	100% Ceiling Coverage
Class 4	100% Ceiling Coverage
Class 5	100% Ceiling Coverage
Class 6	20-60% Ceiling Coverage
Class 7	5-40% Ceiling Coverage
Class 8	5% Remote Filter Bank

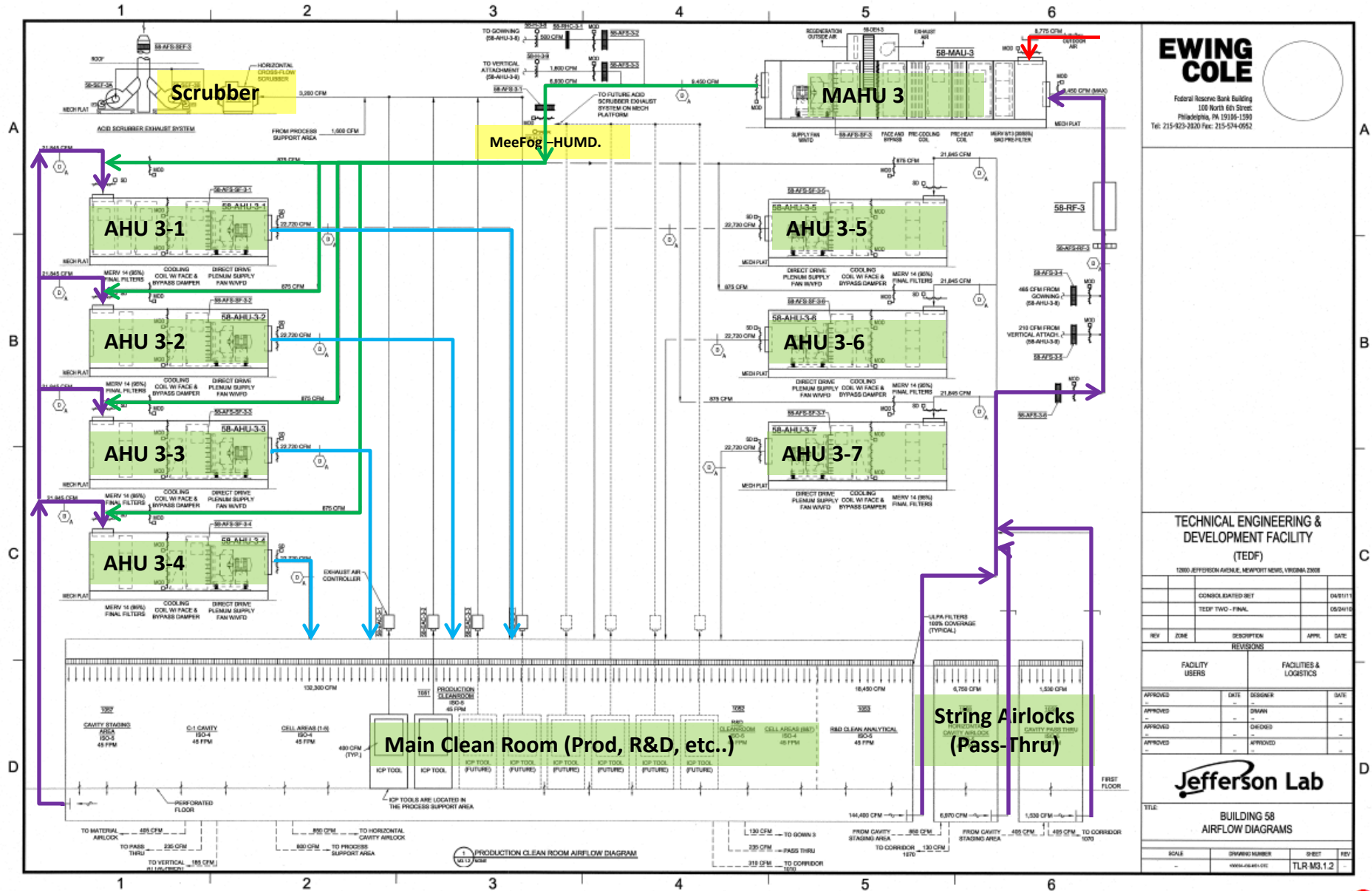
http://www.flanderscorp.com/files/Technical_Data/DESIGN+GUIDE+FOR+CLEANROOMS.pdf

Design – Cleanroom HVAC Block Diagram

- **Make-up Air Units (MAU)**
 - Used to supply fresh air
 - Keeps cleanroom pressurized
 - Work-horse for dehumidification
 - Pre-heat and Pre-cool
 - Pre-filtering
- **Humidification**
 - Uses high pressure spray of RO or DI to humidify air.
 - Located in supply duct
- **Supply Air Handler Units (AHU)**
 - Filtering
 - Cooling
- **Supply Plenum**
 - HEPA/ULPA Filters
 - Diffusion Grids
 - Lighting, Fire, etc...
- **Controls / Dampers/ Fans**



Design - System Diagram



EWING COLE

Federal Reserve Bank Building
100 North 6th Street
Philadelphia, PA 19106-1590
Tel: 215-423-2820 Fax: 215-574-0552

TECHNICAL ENGINEERING & DEVELOPMENT FACILITY (TEDF)

1200 JEFFERSON AVENUE, NEWPORT NEWS, VIRGINIA 23606

CONSOLIDATED SET	DATE/TITLE
TEEP TWO - FINAL	05/24/10

REV	ZONE	DESCRIPTION	APPL.	DATE
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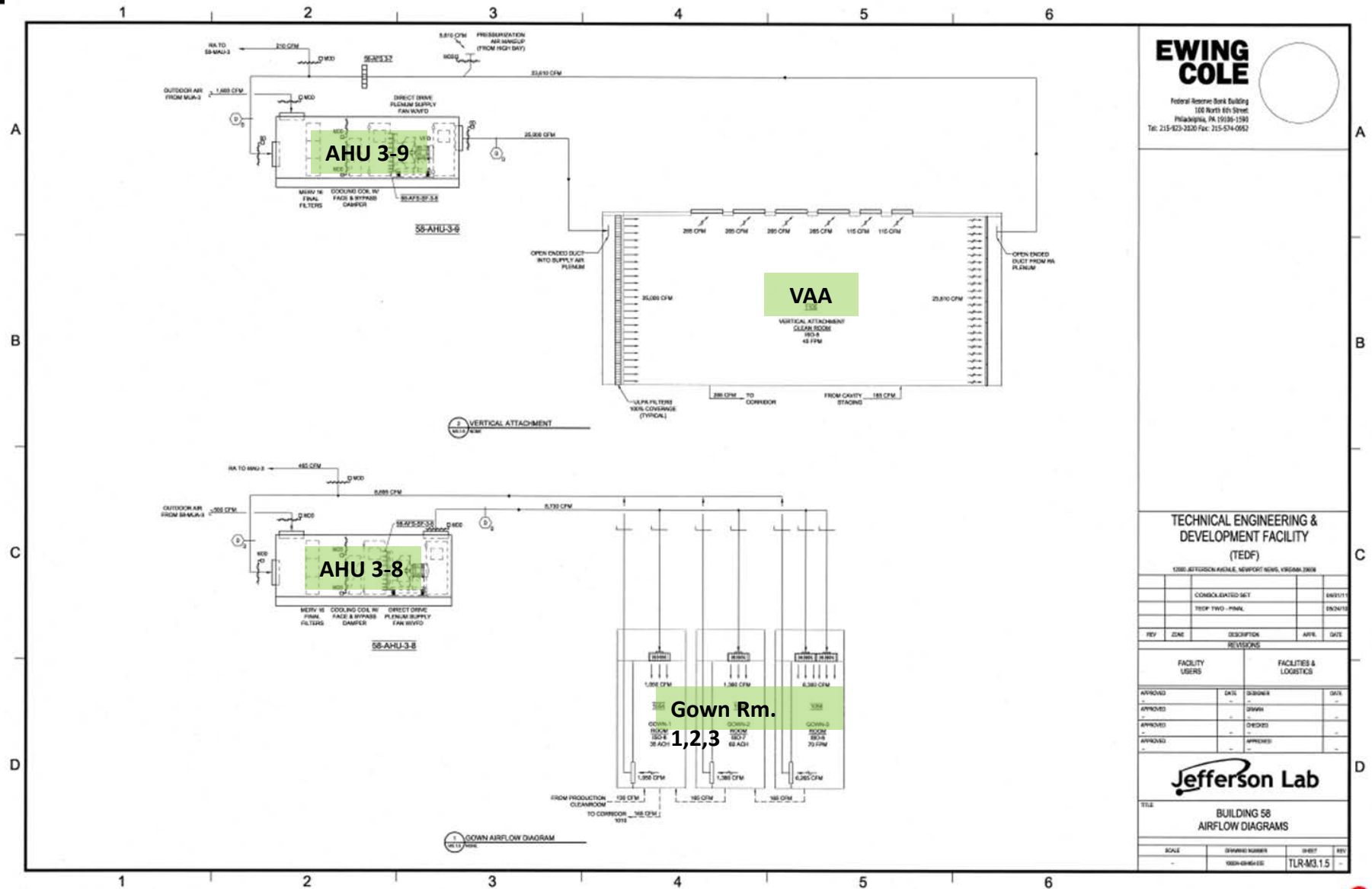
FACILITY USERS		FACILITIES & LOGISTICS	
APPROVED	DATE	DESIGNER	DATE
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Jefferson Lab

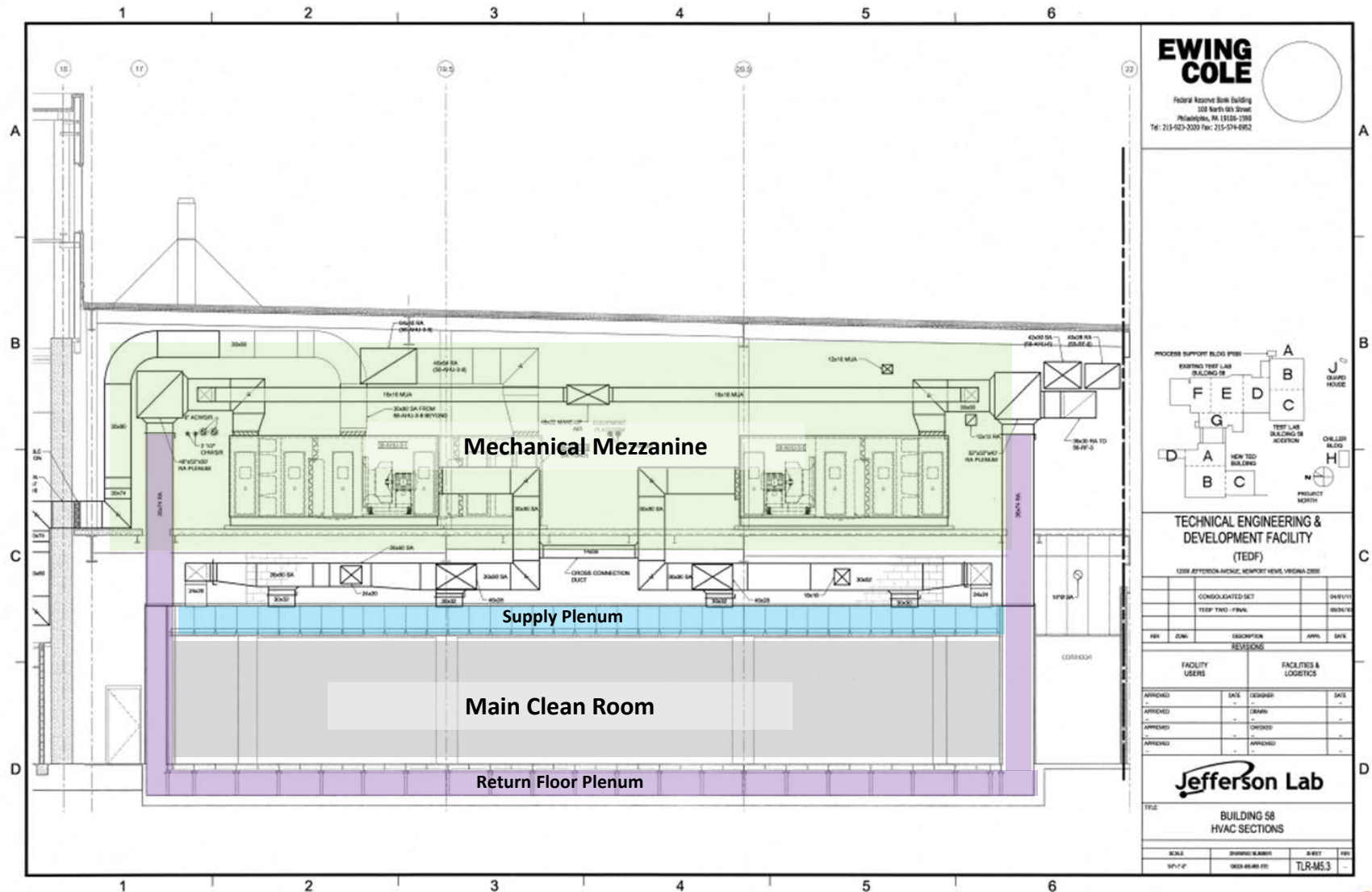
BUILDING 58 AIRFLOW DIAGRAMS

SCALE	DRAWING NUMBER	SHEET	REV
	58-001-001	1	TLR M3.1.2

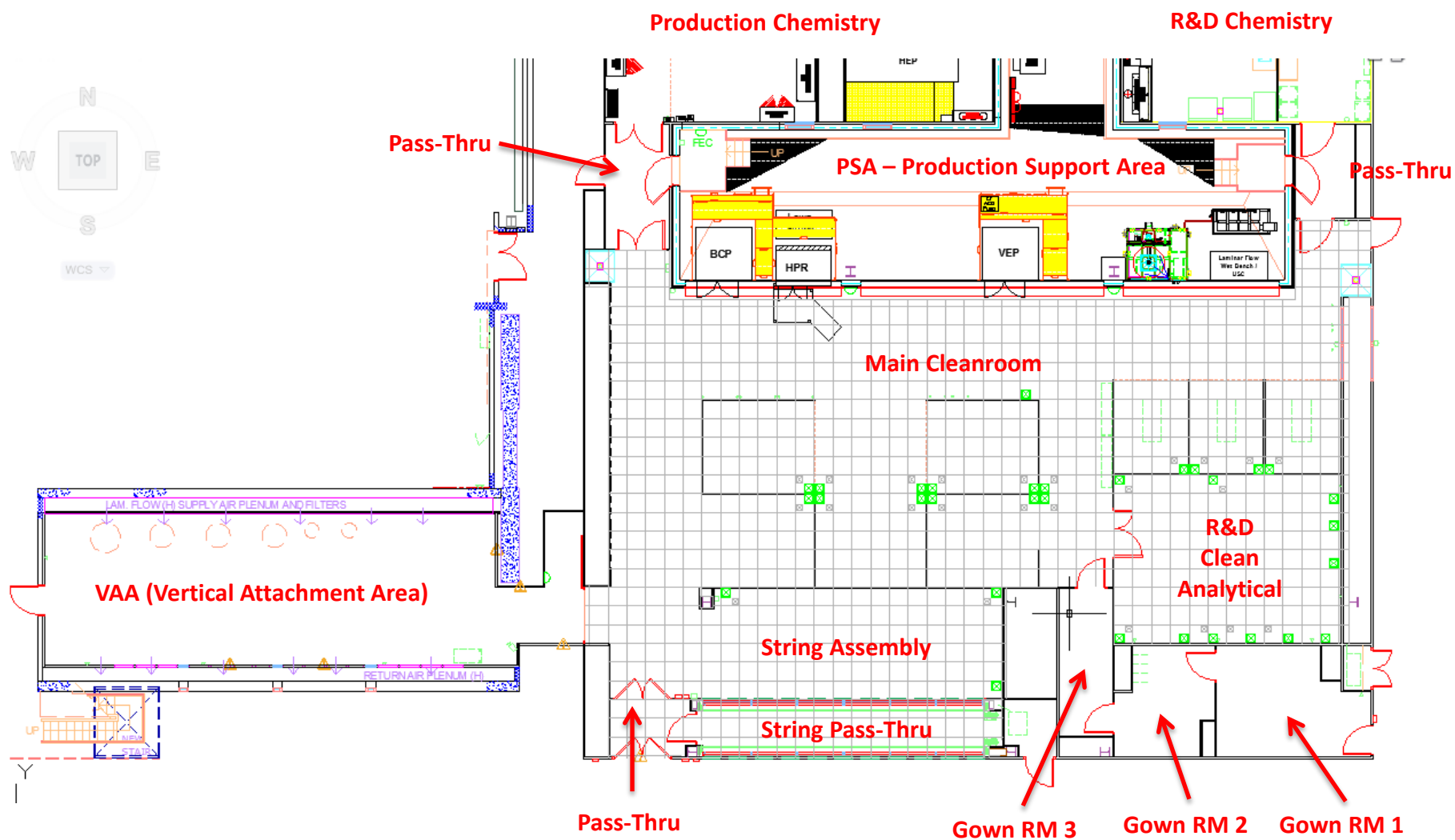
Design - VAA & Gowning Diagram



Design – Building Cross-Section

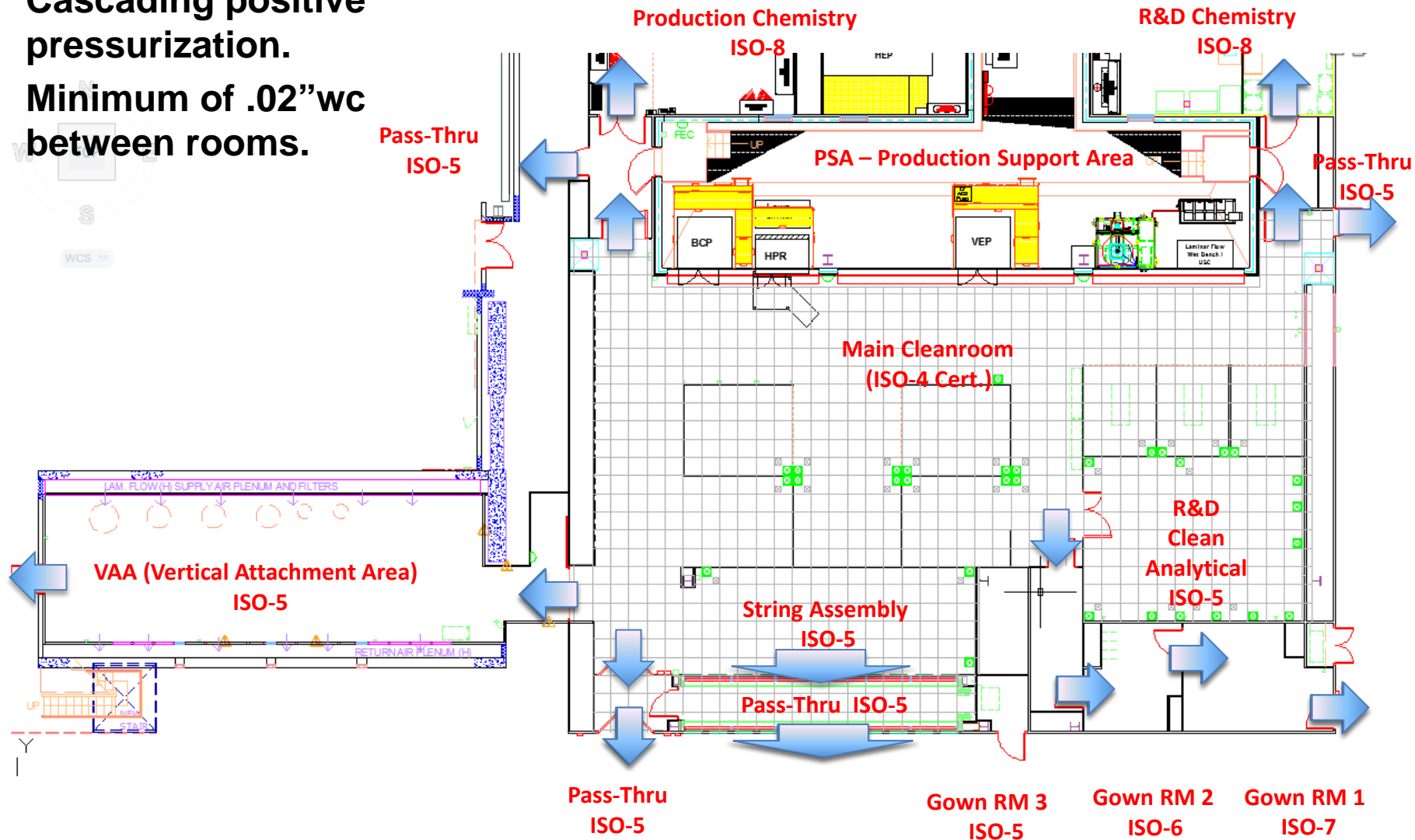


Design - Cleanroom Layout

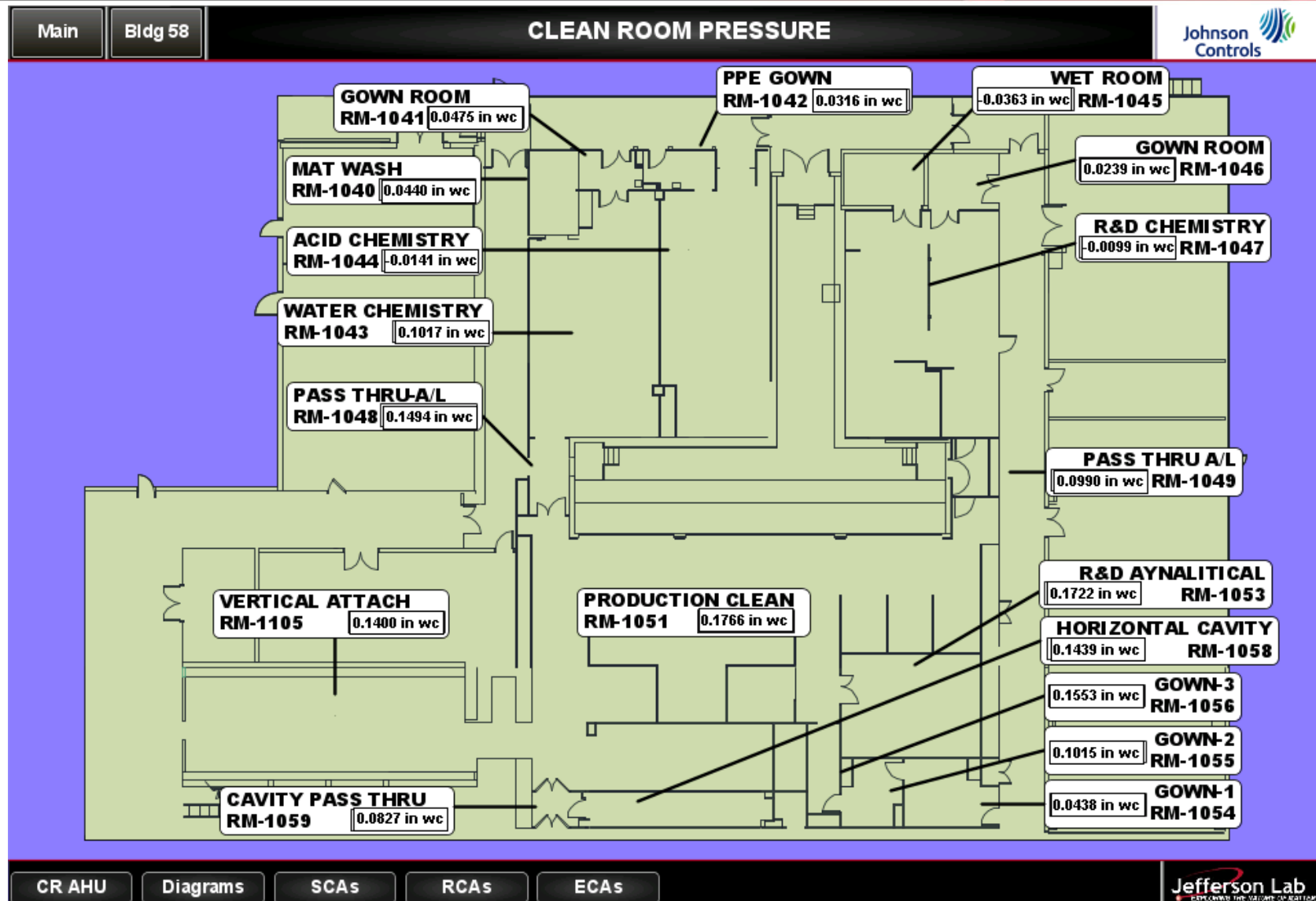


Design - Pressure/Flow

- Cascading positive pressurization.
- Minimum of .02"wc between rooms.



Design – Pressure/Flow



Operations – Process/Systems Monitoring

- **Systems Monitoring**

- Real-time monitoring for maintaining cleanroom systems.
 - Particles
 - Temperature, Humidity
 - Pressure
 - HVAC Status
 - Other- AMC, Air Velocity, Gases

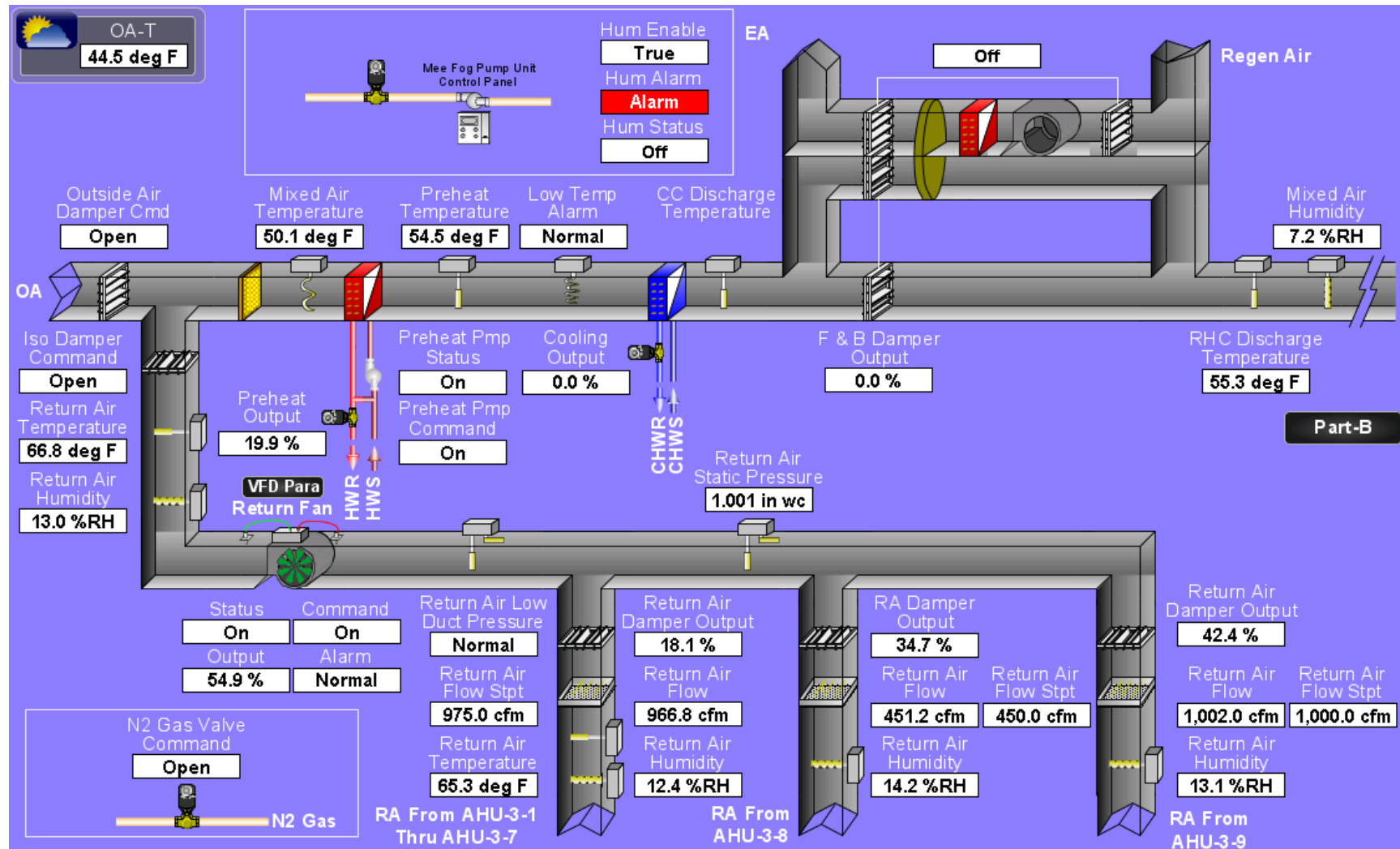
- **Process Monitoring**

- Local Particle measurements
- Other.....

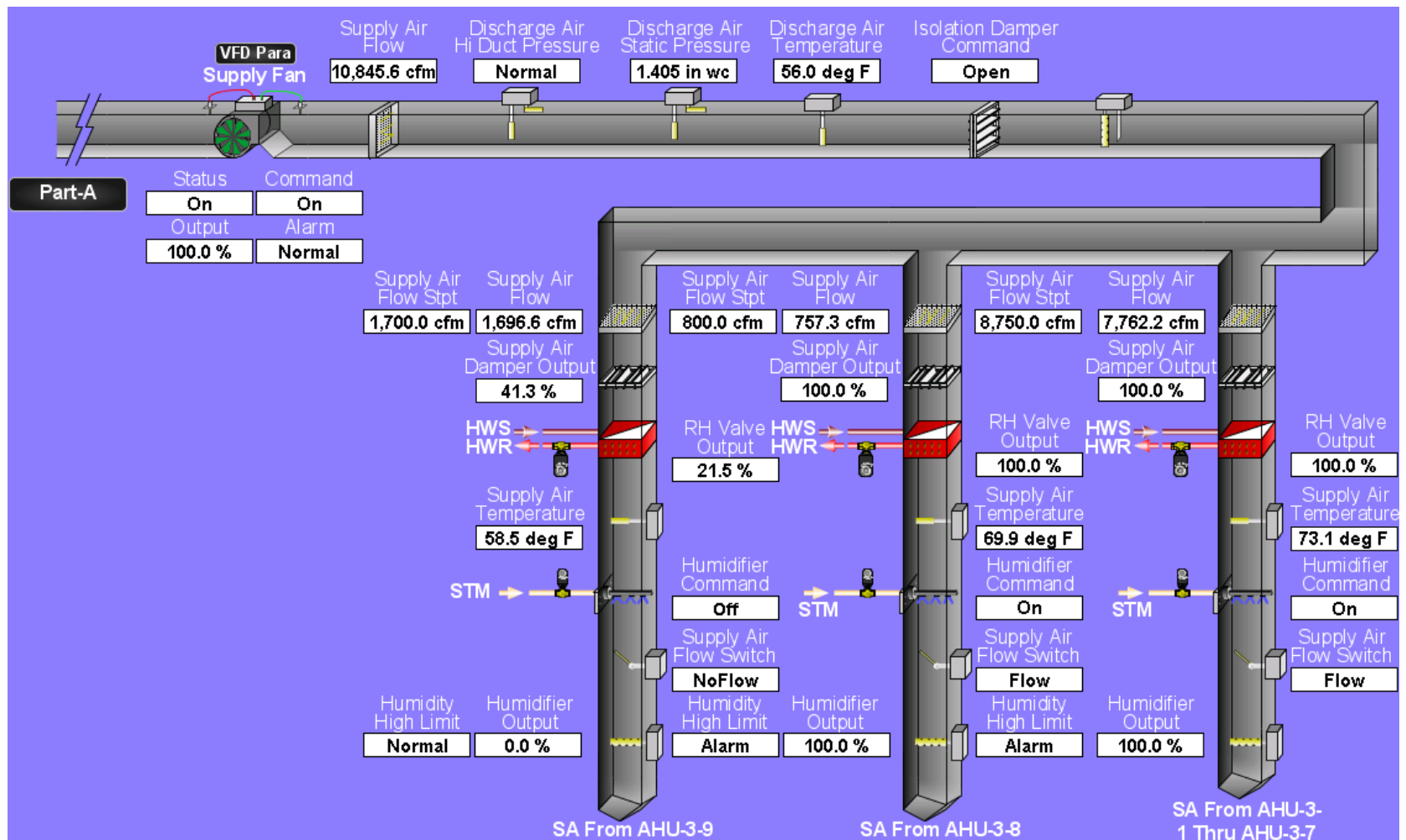
- **Systems Certification**

- Air velocity, leaks particles, etc.....

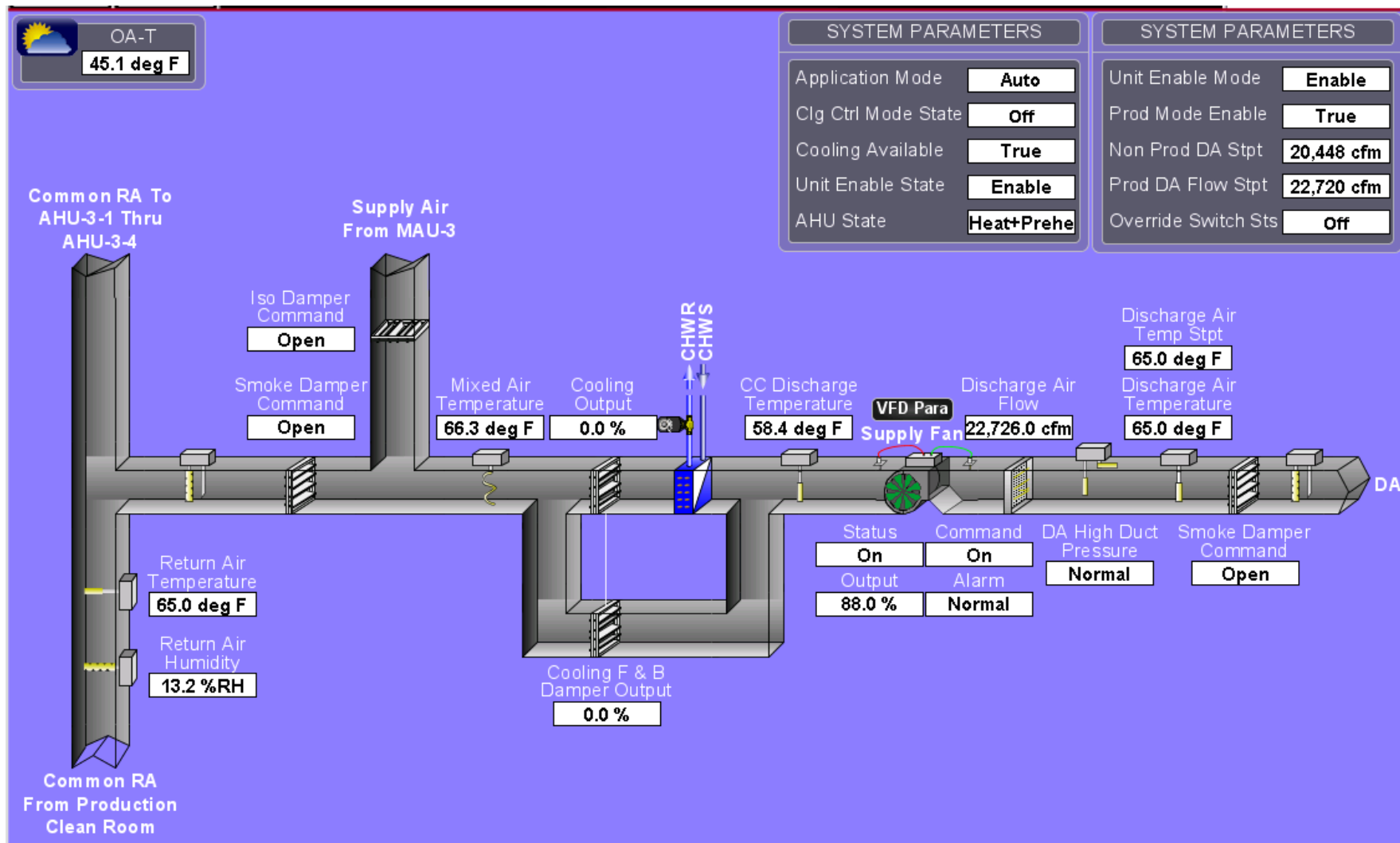
Operations – JCI Control



Operations – JCI Control



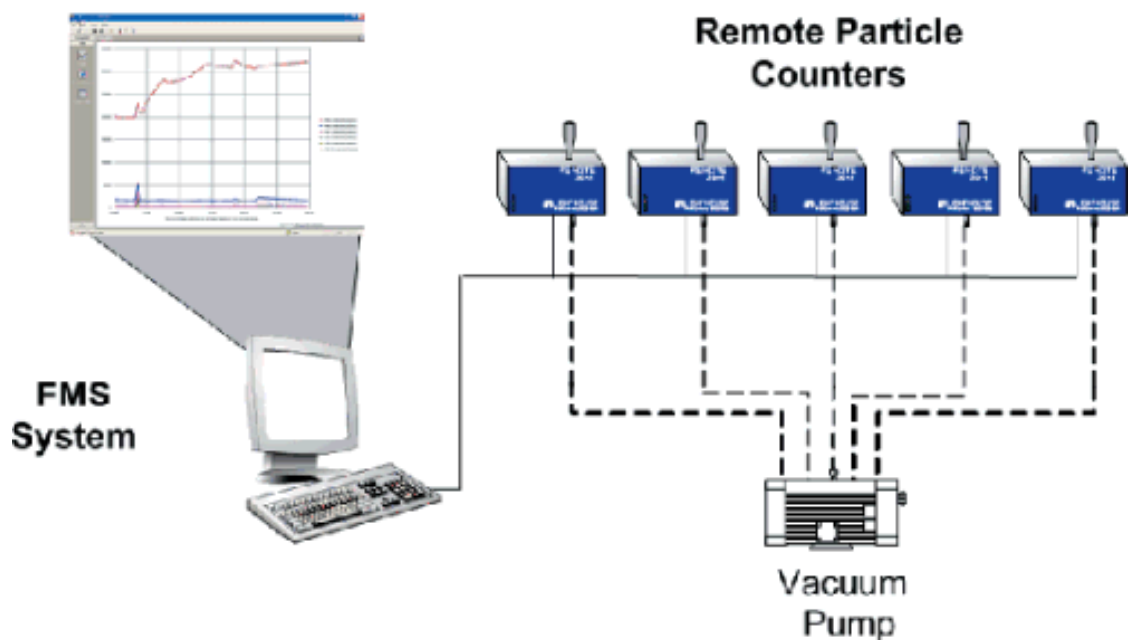
Operations – JCI Control



Operations - Monitoring Particles

- **Airborne Particle Counters**

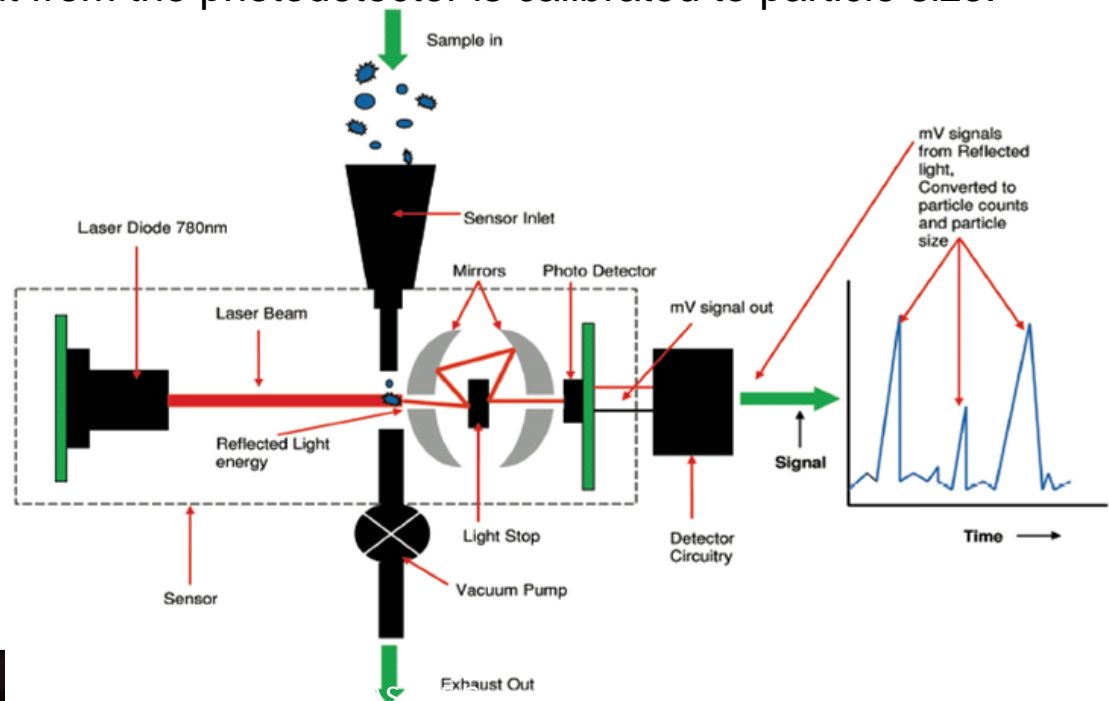
- Types: Handhelds , Desktop, Remote
- Networkable and Software: Real-time, Historical, SPC, Alarms
- Typically 2-4 channels, from 0.3 to 10 μ m
- Additionally temperature, humidity, air velocity, etc.....



Operations – Monitoring Particles

Cleanroom particle counter operation:

- A vacuum pump pulls cleanroom air through an isokinetic probe at a known flow rate.
- The air sample is channeled through glass tube where the laser is targeted.
- Laser light reflected from the sample is collect and reflected by mirrors to a photo-detector.
- The photo detector turns light energy into electrical energy proportional with the light intensity.
- The amplitude electrical current from the photodetector is calibrated to particle size.
- The counter has further circuitry, programing, and algorithms that ensure calibration and filter out noise.
- Output is normalized to usable data such as cts/m3 or cts /dl.



Operations - Protocols

General Cleanroom Regulations/Practices

1. Store all personal items before entering gown room. I.E. keys, watches, rings, matches, lighters and cigarettes.
2. Valuable personal items such as wallets & cell phones are permitted, but they are NEVER removed from beneath the cleanroom garments.
3. NO eating, smoking, or gum chewing.
4. Only garments approved for the cleanroom should be worn.
5. Only approved cleanroom paper and pens shall be allowed in the cleanroom. NO PENCILS
6. No paper towels. Only cleanroom approved and rated wipes per cleanroom level.
7. Only approved and rated gloves allowed in cleanroom.
8. Gloves should not be allowed to touch any item or surface that has not been thoroughly cleaned.
9. Solvent contact with the bare skin should be avoided. They can remove skin oils and increase skin flaking. Approved skin lotions or lanolin based soaps are sometimes allowed. These can reduce skin flaking.
10. All items need for use in cleanroom shall be cleaned in Chemistry rooms and delivered via the pass-thru. No items shall enter the cleanroom through the gowning areas.
11. All tools, containers and fixtures used in the cleaning process should be cleaned to the same degree as the cleanroom surfaces.
12. NO tool should be allowed to rest on the surface of a bench or table. It should be placed on a cleanroom wiper.

Personal

1. Shower morning of or day of entering cleanroom.
2. Shorts and skirts are not recommended. And some fuzzy or high lint or static inducing fabrics.
3. If a smoker wait 30min before entering cleanroom and drink a minimum of 8oz of water.
4. No one who is physically ill may enter cleanroom. Including open sores, respiratory infections, and skin irritations should not work in the cleanroom.
5. NO cosmetics shall be worn in the cleanrooms. No make-up, mascara, powder, perfumes, or hair sprays.

Personal Actions Typically 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.

Operations - Materials

- **Prohibited Materials**

- Paper Items

- paper towels, bags
 - Tissues or unapproved wipes
 - masking tape
 - cardboard
 - newsprint

- Natural fibers: cotton, wool

- Metals

- cold rolled steel (unfinished)
 - galvanized steel
 - zinc
 - lead
 - mercury
 - cadmium and cadmium plated
 - steel wool
 - unfinished aluminum

- Other materials

- Mica, chalk, powders
 - fiberglass, unsealed
 - Sandpaper, pumice
 - lapping compounds
 - emery cloth, Scotch-brite
 - lead pencils and erasers
 - carbon typewriter and printer ribbons
 - cloth tapes, e.g. duct tape
 - wood products
 - Aerosols, unconfined lubricants
 - Books, notebooks, magazines
 - Cotton Q-tips
 - Open cell foam
 - Velcro
 - Bubble wrap
 - Plastics bags
 - Grease, oil, lubricants, dry lubricants
 - Leather

Operations - Processes

- **PROHIBITED Processes**

- Sawing
- Grinding, filing
- Lapping, polishing
- Thread cutting, tapping
- Scraping, deburing
- Drilling, reaming
- Welding, soldering
- Painting, coating
- Gluing, unapproved adhesives
- All actions that remove material
- Generation of fumes

Operations - Equipment

- **A note on clean room equipment and furniture**

- Moving Parts: Muffin Fans, Belts, hinges, slides, motors, gears, etc
- Non Volatile lubricants(No dry powder, silicone), Low VOC
- Fabricated or assembled in a cleanroom, bagged for shipping.
- Laminar Flow
- Decontamination
- Hand Tools – Stainless
- Exhaust Vacuum

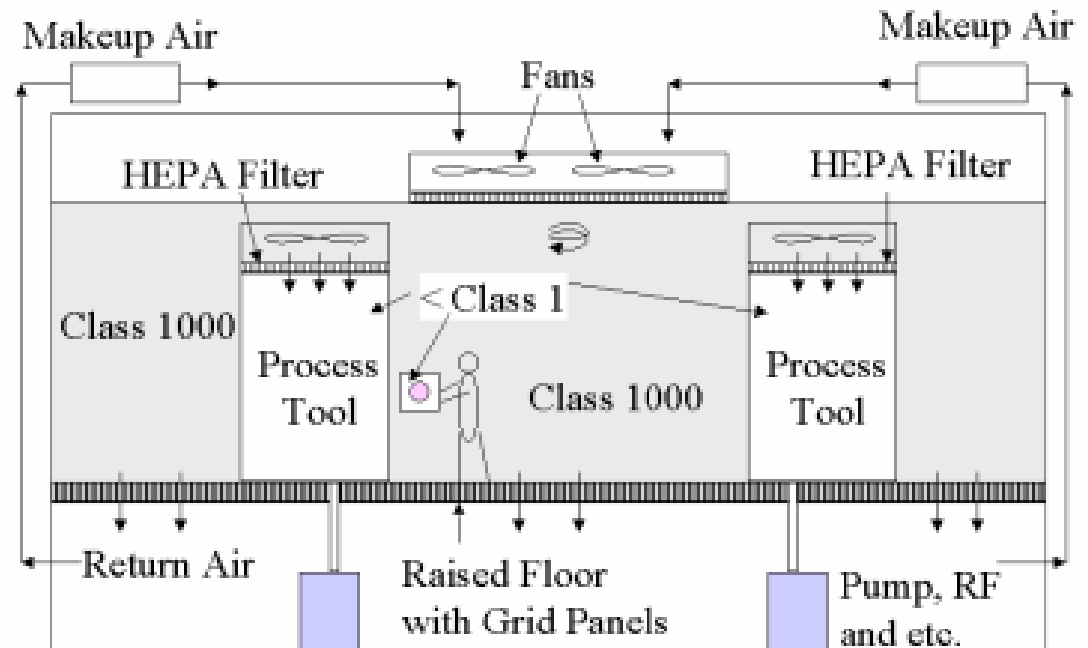


- **Approved materials –**

- FM Global 4910 Approved Materials – Cleanroom Materials Flammability Test Protocol
- Materials Example: Polypropylene, Stainless* (304/316), Polypropylene, PVC, CPVC, PEEK, Aluminum*
- *Coatings/ Surface: Anodized Aluminum, Polished or Electro-polished SS, Powder Coat (25-60μm)

Operations – Equipment

- **Mini-Environment – Cleanroom within a cleanroom**
 - Designed for a unique process
 - Airflow (Laminar, Velocities)
 - Computational-Fluid Dynamics (CFD)
 - Positive Pressure
 - FFU
 - Cost Savings
 - IEST (RP) CC 028.1



Resources

- **Clean Room Standards – ISO 14644**

- ISO 14644-1 Classification of Air Cleanliness
- ISO 14644-2 Specification for testing and monitoring.....
- ISO 14644-3 Test Methods
- ISO 14644-4 Design, Construction, and Start-up
- ISO 14644-5...12
- www.iso.org/iso/home/standards.htm

- **SEMI - Semiconductor Equipment and Materials International**

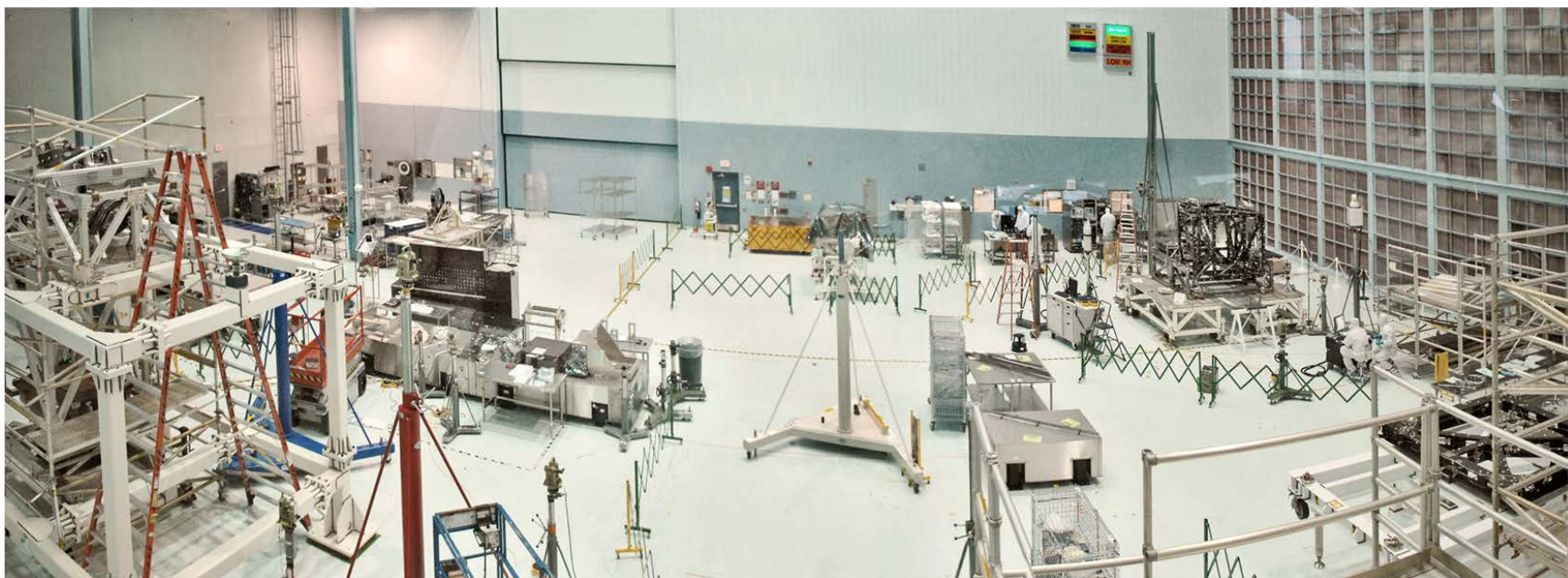
- Source for Standards and methods (especially equipment /systems , installation, design and materials)
- www.SEMI.org

- **IEST – Institute of Environmental Sciences and Technology**

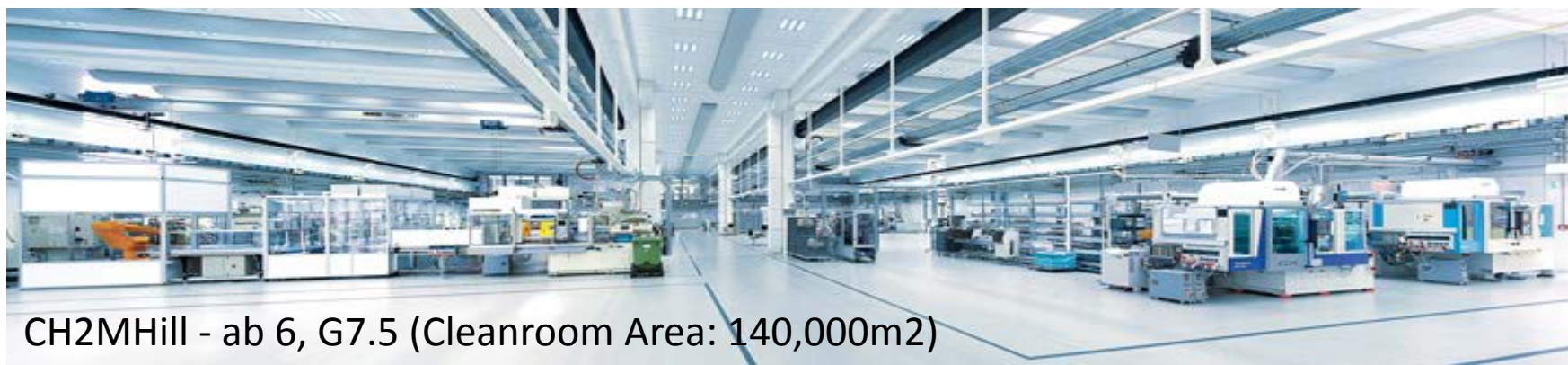
- IEST.org
- Cleanroom training / education
- Standards for contamination control, equipment design, etc.... (www.iest.org/Standards-RPs/Recommended-Practices#TableCC)

- **Cleanroom Suppliers and Consultants**

- Balancers / Certifiers National Environmental Balancing Bureau (www.nebb.org)
- Cleanroom Construction Companies
- Cleanroom suppliers (equipment and consumables) Example: <http://www.terrauniversal.com/>
- Tradeshows, Papers, etc...



Worlds largest ISO 7 HB Cleanroom Goddard 1.3m ft³



CH2MHill - ab 6, G7.5 (Cleanroom Area: 140,000m²)