CLEANROOMS

INTRODUCTION

Some of today's manufacturing processes now require a work environment far cleaner than those found in yesterday's manufacturing facility. Many operations in laboratories, semiconductor fabs, pharmaceutical facilities and aerospace plants must be carried out in areas where the concentration of airborne particles is strictly controlled.

Because of their high level of cleanliness, cleanrooms are easily contaminated by the products of combustion from a fire, as well as from other sources. The inherent use of plastics for process cleanliness creates a greater source of potential contamination under fire conditions. The potential for contamination is minimized by isolating cleanrooms from other areas, using noncombustible materials of construction, installing well designed air handling and smoke removal systems, and providing high sensitivity fire detection and extinguishing systems.

Cleanrooms may be highly automated and sometimes unattended. Process control systems for equipment in these rooms must operate and shut down processes safely and notify operators of upsets.

Pre-emergency planning is critical in minimizing damage from contamination in cleanrooms. Cleanup must begin immediately and must include all areas that could have possibly been exposed. To enable restoring production as soon as possible after a loss, the pre-emergency plan must be responsibility specific and be kept up-to-date.

POSITION

This section addresses only cleanrooms that do not handle biological or radiological materials. Equipment and techniques beyond the scope of this section are required when biological or radiological contamination must be considered.

Management Programs

Develop and implement written management programs covering the areas described in AXA XL Risk Consulting's *OVERVIEW*. Include the following features in these programs.

Maintenance

Set up preventive maintenance schedules assuming maximum wear and maximum exposure to the corrosive fumes generated under normal operating conditions. Schedule increased maintenance for automated processes or processes which are not as frequently observed.

Use lockout/tagout procedures when working in a cleanroom. Be sure to shut down all interrelated processes and their utilities. Pay special attention to manifolded supply and exhaust systems. Take precautions against contaminating any equipment or systems as a result of maintenance work.

Train maintenance personnel in the procedures appropriate for cleanroom maintenance and in the level of cleanliness necessary both during and after maintenance. Carefully check the status of all equipment in the cleanroom before restoring the utilities and restarting the process.

Employee Training

Make sure all employees understand the susceptibility of cleanroom operations to contamination and can identify potential sources of contamination. Train employees with formal, written training programs. Include procedures for setting up and running automated processes safely in these programs. Do not permit deviations from standard operating procedures.

Pre-emergency Planning

Establish written pre-emergency plans that deal with all conceivable incidents in cleanrooms and clean areas. Include in these plans how to determine when each process should be shut down, how to shut it down, and how to control the ventilation system. Also include the equipment and training necessary to conduct effective cleanup and salvage operations. Empower employees to responsibly implement emergency shut down procedures without fear of criticism.

Pre-emergency plans could vary for each process or piece of equipment. Incorporate information from the pre-emergency plans into the operator training programs for each case. Keep safety and Pre-emergency plans as uniform as practical. Provide periodic refresher training and cross-training between operators in adjacent processes.

Appoint a Fire Department Coordinator. Invite fire departments and other emergency response organizations to tour the facility. Familiarize them with the best way to enter each cleanroom or clean area to minimize contamination in an emergency. Arrange a staging area to facilitate cleanroom entrance by the fire department in case of an emergency and allow for any last minute instruction.

Hazardous Materials

Analyze all materials used in cleanroom operations. Check incoming materials for consistency in physical and chemical properties, including purity. Check all possible combinations of materials that could occur in the cleanroom for degree of hazard the combinations could present. Use a central purchasing/supply program to avoid excess storage or staging within a building. Wherever possible use bulk transfer systems with storage outside the cleanroom.

Hot Work

Take the same precautions as those for maintenance work. In addition, protect all cleanroom chemicals, equipment and finishes from the heat and sparks generated by cutting and welding operations.

Process Hazards Evaluation

Evaluate the hazards presented by all cleanroom processes and chemical distribution systems. Pay particular attention to automated processes. Include in the evaluation all conceivable process upsets, all sources of contamination and the possible consequences of an incident to equipment and processes. Emergency action should result in a safe mode for the specific piece of equipment. Total shutdown does not always result in a safe condition. Emergency systems (such as fume exhaust) must remain operational.

Use the results of the process hazards evaluation to set up, run and maintain existing processes safely and to mitigate the consequences of an upset. Also conduct a process hazards evaluation when designing new processes and modifying existing ones.

Management of Change

Re-evaluate each process whenever changes are proposed in operating parameters, such as temperature settings, chemical concentrations, substitute chemicals or run times. Also re-evaluate each process when equipment is replaced, even if it is the same as the older equipment.

When a different material will be used, evaluate its compatibility with all aspects of the process and the process equipment. Check the need for new interlocks or process set points. Reevaluate the need for additional exhaust or the source of exhaust.

Update Pre-emergency plans before returning modified processes to operation.

Arrangement and Protection

Arrange and protect cleanrooms in accordance with NFPA 318 and PRC.17.11.1.

DISCUSSION

General

Cleanrooms are classed by their level of airborne particles within a given volume of air. The class rating of cleanliness of the room are defined in Federal Standard 209E and ISO 14644 and indicate the number of particles of a given size allowed in 1 ft^3 (0.03 m^3) of air. Table 1 lists the particle counts allowed for various size particles in each class. The particle counts shown only define the class; they do not represent a particle size distribution.

To put the numbers in Table 1 in perspective, an average human hair is about 3×10^{-3} in. (75 μm) in diameter.

TABLE 1
Allowed Particle Counts In 1 ft^3 (0.03 m^3) Of Air

Class	Measured Particle Size (μm)				
	0.1	0.2	0.3	0.5	5.0
1	35	7.5	3	1	0
10	350	75	30	10	0
100	N/A	750	300	100	0
1,000	N/A	N/A	N/A	1,000	7
10,000	N/A	N/A	N/A	10,000	70
100,000	N/A	N/A	N/A	100,000	700

N/A-Not Applicable

Design and Layout

To achieve the necessary level of cleanliness, cleanroom construction materials and finishes are selected that minimize particle shedding and clean easily. Horizontal surfaces need to be minimized. Equally important is using only construction materials that are noncombustible. If combustible, select materials listed for use in cleanrooms. They should have minimal flame spread and smoke contribution characteristics and be tested in accordance with a test equivalent to ANSI/UL 2360 and/or FM 4910. Metal composite panels have been found to provide the necessary noncombustibility, conductivity and ease of cleaning. Combustible insulation and honeycomb spacers within these panels must be avoided.

The cleanroom is seldom a stand alone building with exterior walls. It is typically a partitioned area within a building. Not only the cleanroom, but also the exterior building shell needs to be of noncombustible construction.

There is often a desire to use expanded plastic panels and/or an Exterior Insulation Finishing System (EIFS). The excellent thermal insulation properties of the plastics make these systems appear ideal for wall systems of semiconductor fabrication buildings (FABS). Listed systems in these categories are treated as noncombustible. Care should be taken in evaluating these systems in construction of FABS. Do not exposure these wall systems with gas houses, silane distribution centers or similar hazards. Involvement of expanded plastic panels or EIFS can create large amounts of contaminating products of combustion. Since the make up air systems could ingest these contaminants and treatment would be beyond the capabilities of the filters a seemingly harmless fire could shut down the entire cleanroom. Where these wall systems are necessary, consult PRC.2.0.2 for additional guidance. A non-combustible wall located between the exposure and the EIFS may be required.

The quantity of airborne particles in a cleanroom is controlled by filtering both the makeup and re-circulating air. Every cleanroom has a sophisticated air handling system. There will be multiple levels of filtration. When fire occurs, this arrangement of the system must be able to limit the spread of combustion products throughout the facility. Also arrange the system to remove any products of combustion from the room. In some cases, a separate smoke removal system is necessary.

Layout of cleanrooms is a function of the process and its work flow. Some cleanrooms have floor areas of 100,000 ft^2 (9300 m^2) or more. As the level of cleanliness increases, the number of high efficiency particulate air (HEPA) and ultra low air penetration (ULPA) filters will increase. The arrangement of return service corridors and utility chases will vary. These areas usually have a lower level of cleanliness and often contain maintenance and operating sections of process equipment. The equipment, as well as piping, electrical wiring and parts staging and transfer systems, will protrude through the cleanroom wall. As much maintenance as possible is carried out in these areas to minimize contamination of the cleanroom. This also allows employees to work in these areas without as much cumbersome protective clothing in some cases.

Isolating a cleanroom from the remainder of the facility is necessary to maintain the cleanliness of the room. Walls, airlocks, separate air handling systems and positive air pressure in the cleanroom all help prevent infiltration of contaminants. Under normal conditions, positive pressure is a benefit. However, under fire conditions, positive pressure aids in the spread of the products of combustion to other areas. When fire is detected, the cleanroom air handling system should quickly discontinue air re-circulation and switch to 100% exhaust. Make-up air must be provided to allow the exhaust mode to be effective. This changes the pressure differential to allow the products of combustion to be quickly exhausted and not forced into other areas. In all cases the cleanroom should still remain at a slight positive pressure relative to the surrounding areas.

Cleanroom isolation under fire conditions should also consider methods of preventing the products of combustion from escaping through wall, floor and ceiling penetrations, such as electrical conduit and clean tunnels, which may connect two or more cleanrooms. Adequate fire and smoke seals are critical for these penetrations.

Occupancy

Cleanrooms contain a wide range of occupancies, wafer patterning, photolithography, layering, chemical vapor deposition, etching, planarization, and cleaning. Wet benches or other workstations are used for many cleanroom processes. These stations are designed to handle a variety of liquids of which some are corrosive, combustible or flammable.

Wet stations and other work stations are commonly made of ordinary plastics such as polypropylene, fire retardant polypropylene and PVC. High -end units are made of stainless steel, or plastics specifically listed for use in cleanrooms. The inherent safety of less hazardous plastics makes these units a better choice for cleanroom use. They reduce the normal, probable and maximum foreseeable loss estimates, since they would deter the spread of fire in a cleanroom. These plastics are tested in accordance with UL 2360 or FM 4910. Designs include simple, flat benches or benches with solution tanks formed into the surface. Provide detection and automatic shut down to all plastic work stations regardless of the plastic used. Wet workstations usually connect to either an acid fume exhaust or an organics exhaust system, to remove vapors produced by the process. Many stations have interior compartments and ventilation passages that form a portion of the exhaust system. A typical arrangement is shown in Figure 1.

Solutions in tanks may be heated with steam or hot water heat exchangers, inline electric, infrared, hot plates, quartz lined baths or electric immersion heaters. Electric immersion heaters and their controllers have been a common ignition source in combustible wet workstations. This type of fire produces large amounts of corrosive smoke in a cleanroom filled with expensive equipment that is easily damaged by contamination. Even a small incident can easily result in a multi-million dollar loss. There has been similar loss experience with hot plates and quartz lined bath heaters, but to a lesser extent.

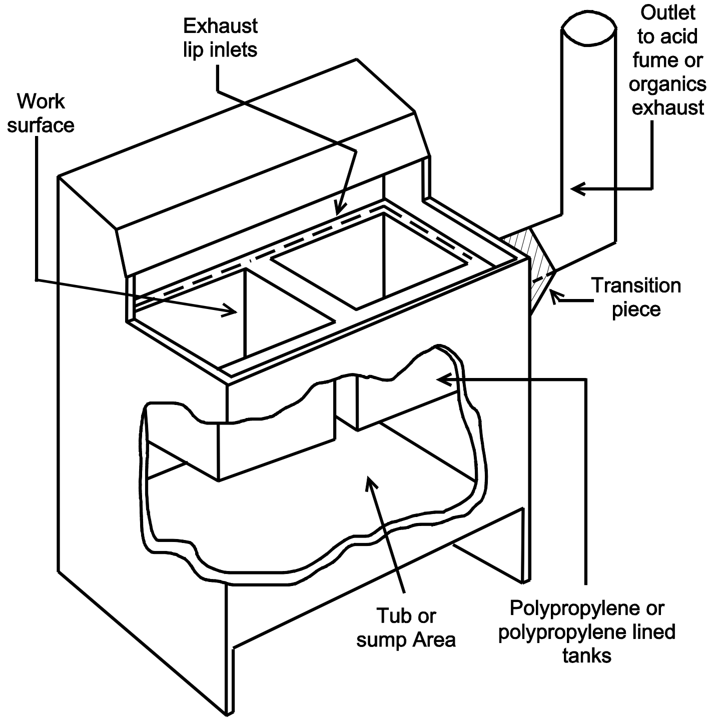

Figure 1. Typical Arrangement Of A Wet Work Station.

Laminar Flow Cleanroom

As the demand for even cleaner cleanrooms grew, designers switched from laminar flow hoods to laminar flow rooms. In this cleanroom design, fresh air is brought to the cleanroom through fresh air intake (A) and passed through pre-filters (B). The air is then brought to a desired temperature and humidity (C) and distributed via flexible ducts (D) to numerous filters (E). The air enters the cleanroom (F) and is drawn down either the crawl space utility area (G) or the work stations (H). Air in the crawl space is drawn back through chase areas (J) to a common return plenum (K) and recycled back to the cleanrooms. Work station exhaust is drawn away from the cleanroom via the fume exhaust system (L) and then cleaned in a fume scrubber system (M) before exhausting to the outside. In the event of a contamination emergency, such as a smoky fire or spill, the recycling system can be switched to 100% exhaust by opening exhaust damper (N) and closing re-circulating air dampers (P).

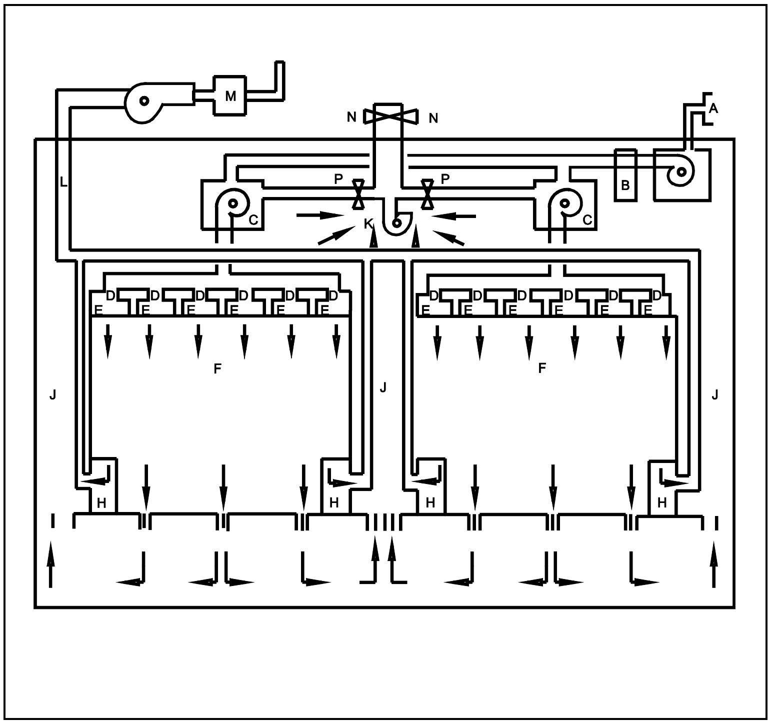

Figure 2. Raised Floor Laminar Flow Cleanroom.

As the name implies, electric immersion heaters are designed for the heating element to be immersed at all times. Loss of solution due to process usage or evaporation results in the exposure of the heating element to air, allowing its surface temperature to rise. Radiated heat can warm the solution tank wall to the auto-ignition temperature. This type of fire not only destroys the plastic tank but have historically involved the bench and plastic ductwork associated with the workstation. Low energy electric immersion heaters can provide fire safety by limiting the heater surface temperature. Performance of quartz lined bath heaters has been improved over that of ordinary electric immersion heaters. Electric immersion heaters are now commonly replaced with circulation heaters and infra-red heaters remote from combustible work stations. Additional information about heating solutions in tanks is available in PRC.9.5.1*.*

Air Handling Systems

Cleanrooms may have as many as five different types of air handling systems. These are the normal heating, ventilating and air conditioning (HVAC) system, heat removal from equipment, acid fume exhaust system, organics exhaust system and emergency smoke removal system. In some cases the smoke removal capability is incorporated in the design of the normal HVAC system.

Normal HVAC systems have a variety of configurations. A common arrangement is called a vertical laminar flow system. In this system, air enters the cleanroom at the ceiling level, flows uniformly (without turbulence) from the ceiling to the floor and exhausts at or through the floor. The air exhaust may be through either a wall or raised floor.

Figure 2 shows a typical raised floor room and its air handling systems. Fire extinguishment is difficult in the sizable concealed spaces containing ducts, overhead and underfloor plenums and filters. Sound loss prevention dictates using noncombustible construction in these areas. Since the concealed areas are inaccessible for fire fighting, automatic sprinkler protection is also necessary.

Cleanroom air is filtered by HEPA or ULPA filters. These filters are designed to remove 99.97% and 99.997%, respectively, of 0.3 μm diameter particles from the air. They consist of a filter medium of glass fiber or other equivalent inorganic material. The frame is normally constructed of metal, other inorganic material or wood treated by pressure impregnation to reduce combustibility. Even though filters are principally noncombustible, other system parts, such as flexible connectors and sealant, might not be. If not, the concealed spaces containing them require automatic sprinkler protection. Diffusers installed beneath the filters may also be combustible and require automatic sprinkler protection above and below the diffusers.

Design of the HVAC system should consider air intake and exhaust locations. It also needs to consider locations for makeup air intakes. The potential for drawing contaminated air into the system from fume or smoke exhaust discharges should be minimized. Installation of smoke detection and dampers in the intake can be an added source of contamination prevention. Contamination within the cleanroom can also be limited by the use of multiple HVAC systems arranged in zones.

Wet benches are often constructed as small laminar flow areas that exhaust fumes without any air re-circulation. Wet bench fume exhausts should go directly to the outside through a scrubber or other fume treatment system. Provide automatic sprinkler protection for the scrubbers where they are of ordinary plastic construction or handle flammable liquids capable of reaching the lower flammable limit (LFL). For solvent recovery refer to PRC.9.6.2.2. These exhaust systems should not be connected to the normal HVAC system to allow re-circulation.

Metal ducts are preferred over plastic. NFPA 91 allows the use of plastic ducts where necessary for corrosion protection. Plastic ducts and plastic lined ducts should be specifically listed in the FM Approval Guide for use without sprinklers in cleanrooms and should be installed in accordance with PRC.17.11.1. Ducts should be tested in accordance with FM 4922 and not merely use plastics that pass FM 4910. Even with sprinkler protection, other types of plastic ducts are less desirable because contamination potential from products of combustion increases when ducts burn.

NFPA 318 allows the use of ordinary plastic ducting with sprinkler protection, although this should only be used as a last resort. It should only be used where listed or noncombustible ducting will not hold up when exposed to the corrosive chemical exposure. Some plastic ducts, such as ordinary PVC, should not be used even with sprinklers. This type of duct will restrict under fire conditions and cut off all exhaust. Similarly, dampers and other devices, which could obstruct ducts, should not be installed in any fume removal ducts. Additional guidance for protection of plastic ducts is provided in PRC.2.3.2.

Use only unlined metal ducting for removal of combustible and flammable liquids. Provide automatic sprinkler protection in all ducting 10 in. (250 mm) or larger unless the exhaust flow is designed to prevent the solvents from reaching the lower flammable limit. Provide detection to sound an alarm at 25% of the LFL and initiate process shutdown and emergency exhaust at 50% of the LFL where sprinkler protection is not provided.

Smoke removal systems should be capable of exhausting at least 3 cfm (0.08 m^3/min) for each ft^2 (0.093 m^2) of floor area throughout the cleanroom. Increase the exhaust rate in higher hazard areas such as around wet benches and other plastic tools. Smoke removal systems that use the HVAC system for exhaust should have the return air ducts equipped with high sensitivity, sampling type smoke detectors arranged to stop the re-circulation air fans and divert all air to exhaust. The air sampling ports are generally located near the return air intake filters before dilution with the make-up air fans. Make-up air must be maintained to prevent the cleanroom from going negative. The smoke removal system should be designed and installed in accordance with the powered exhaust ventilation section of PRC.2.1.4.

Loss Prevention and Control

NFPA 318 and PRC.17.11.1 specify the construction and fire protection features needed for loss prevention and control in cleanrooms. This discussion briefly explains these features.

Wet benches of noncombustible construction, such as stainless steel, are preferred over polypropylene or other ordinary plastic benches, even those with stainless steel or quartz lined baths. These liners cannot prevent a malfunctioning electric immersion heater from overheating and igniting the polypropylene. In addition, heated solution tanks should have controls to monitor temperature and solution level and remove the heat source on high temperature or low liquid level.

At a minimum, the fire protection system must cover the interior compartment surface area and below the laminar flow hoods of all wet benches constructed of ordinary plastics. If a wet bench or other work station uses combustible or flammable liquids the wet bench should also be protected regardless of construction. Protection of plastic wet benches is not a suitable alternative to noncombustible construction. A massive quantity of fuel exists under adverse conditions. Where plastics tested to UL 2360 or FM 4910 or noncombustible benches can not be used protection should be designed using water mist, a tested halon alternative or carbon dioxide system. The system should include proven detection and include an emergency power off system (EPO).

Recently less hazardous plastics have been introduced. They are tested in accordance with UL 2360 or FM 4910. While still combustible they are more inherently safe for cleanroom use. They have exhibited the tendency to not allow a fire to progress beyond the ignition source. Regardless, EPO actuated by flame detection needs to be provided. There is no information on the performance of even the best materials with a sustained ignition source.

Where wet benches use combustible or flammable liquids, carbon dioxide systems should be installed. These CO_2 systems should be activated with optical (flame) detectors. In older benches a sprinkler should also be installed in the transition piece and over the work surface. This is to protect the bench and is regardless of the construction of the duct. In a modern facility the benches containing combustible or flammable liquids should never be constructed of plastic and should never release into the acid fume exhaust system.

Flammable and combustible liquids handling in cleanrooms must be controlled. Quantities of liquids stored in the cleanroom should be kept as small as possible. This can be accomplished by having regular deliveries throughout the day. Carts or trucks for delivery should be designed to contain spills. These carts should be dedicated to one type of liquid, to prevent accidental mixing. Pass-through type cabinets should be of noncombustible construction and be designed to contain a spill of the largest container.

Metal containers are preferred for holding flammable and combustible liquids. Glass containers should be avoided and used only when other methods of preventing contamination are not available. Plastic bottles or bags should never be used within the cleanroom.

Pre-emergency planning is essential to minimize contamination from fire and to ensure prompt, effective cleanup. An Emergency Response Team (ERT) should be trained in the proper techniques of controlling water damage. An emergency supply of cleaning materials should be stored on site. Plans and lists of sources of cleaning supplies and cleaning experts should be compiled and regularly updated. Equipment files should contain the manufacturers’ instructions for cleaning procedures.