# BULLETIN

JUNE, 2000

A PUBLICATION OF MUNICH REINSURANCE COMPANY OF CANADA, SPECIAL RISKS DEPARTMENT

## Protecting Clean Rooms in Semiconductor Manufacturing Facilities

The March, 2000 luncheon meeting of the Southern Ontario Chapter of the Society of Fire Protection Engineers featured the fire protection challenges of clean room operations in semiconductor manufacturers. The guest speaker was Harvey Eng, P.Eng., of FM Global in Toronto (formerly Factory Mutual Engineering).

This bulletin is a general overview (not a complete guide) of how to reduce the loss exposures in clean rooms. It is based on Mr. Eng's presentation, FM Global loss prevention data sheet 7-7 Semiconductor Fabrication Facilities, Munich Re references and other material.

### Incredible air quality - and high vulnerability to smoke and fire damage

Clean room environments are essential for the reliable, cost-effective manufacture of highly complex integrated circuits (ICs) or computer chips. Even a single dust particle landing on an IC during the manufacturing process steps can short circuit the tightly spaced pathways, rendering the chip useless.

In a clean room, temperature, humidity and especially air quality are strictly controlled to ensure superior quality control. Clean rooms are classified by how few particles are found in a cubic foot of air, down to less than one micron in size (one micron is equal to one thousandth of a millimetre or 39 millionths of an inch).

For example, a Class 1,000 clean room contains on average no more than 1,000 particles of 0.5 micron size or larger per cubic foot of air. (A normal office environment in an urban area would contain about 5 million particles of 0.5 micron size or larger per cubic foot of air.) A Class 10 clean room contains on average no more than 10 particles of 0.3 micron size or larger per cubic foot of air.

The near-perfect air quality in clean rooms is achieved using high efficiency particulate air (HEPA) filters to remove contaminants from the air supply to the room. However, it is this need for incredible air purity that makes clean rooms vulnerable to smoke and fire damage.

### Hazard analysis: Thermal and non-thermal damage potential

Clean rooms present several challenges for protection against fire. They contain high-value equipment and work-in-process that are very sensitive to damage. This damage can be thermal (from flame/heat) and non-thermal (smoke contamination and corrosion). Non-thermal damage resulting from a fire can be far greater than the thermal damage.

There usually is high business interruption potential because clean rooms are so critical to the manufacturing process and often are not duplicated. Even a small fire with relatively low physical damage can result in significant loss of production while the room is being decontaminated. For example, a fire that occurred in a 5,000 sq. ft. (465 $m^2$) clean room was extinguished by a single sprinkler, but it took 74 days to clean up and resume operations.

Clean rooms frequently employ hazardous materials, including toxic, corrosive materials, flammable liquids

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and pyrophoric gases. A pyrophoric gas will ignite spontaneously in air at temperatures below 130°F (54°C).

Large quantities of plastic materials can be found in clean rooms because of the corrosive environment. This adds greatly to the combustible loading in the event of a fire.

## Loss statistics

FM Global loss statistics indicate an increasing trend in both the number and amount of losses in the semiconductor industry. There were 265 losses reported from 1986 to 1998. However, the losses that occurred in the last five years of this period accounted for 49% of the total number of losses and about 77% of the total loss amount.

A Munich Re study completed in 1995 of 21 semiconductor plants in Asia revealed 12 known losses in the previous ten years. Business interruption was not insured or reported in six of these losses. In the other six losses where both property damage (PD) and business interruption (BI) were insured, the average loss was DM 35 million (Deutschemarks), or about C$27.5 million in today's dollars. The average breakdown between property damage and business interruption was DM 21 million for PD and DM 14 million for BI.

Electrical faults or defects are the leading cause of fires in semiconductor manufacturing facilities. Six of the 12 losses in the Munich Re study were caused by short circuits or electrical defects. The FM Global study found that electrical ignition was the cause in 41% of the losses. This is typical of the overall experience of general industrial facilities where electrical ignition is the leading cause of fires.

## Loss prevention strategies

The four main ways to reduce the loss potential from clean rooms are Construction, Passive Control, Smoke Control and Fire Protection.

**Construction** of the clean room should be noncombustible. Interior subdivision walls should be provided to limit the spread of smoke and contaminants in the event of a fire in one area. Interior subdivision is highly recommended between two parallel production lines. The clean room itself should be located in a noncombustible building.

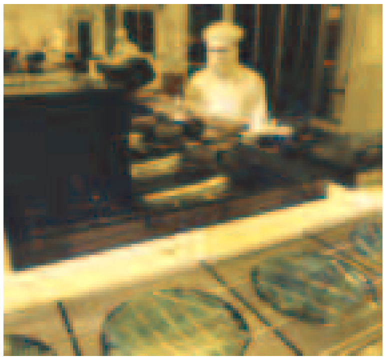
It is not always possible to use noncombustible materials due to the corrosive environment. A possible alternative is to use ceiling, wall and floor panels that are FM approved for use in clean rooms, based on testing in accordance with an FM protocol specifically designed for clean room materials. Approved materials are difficult to ignite, will not propagate the fire beyond the ignition area, and will generate reduced amounts of smoke and corrosive products.

Significant sources of combustible material in clean rooms include plastic tools and wet benches, the work stations used for chemical etching in the fabrication of integrated circuits. Wet bench construction should be noncombustible, if possible, or constructed of approved plastic materials per the above flammability test protocol.

Fume exhaust ducts are another possible source of plastic material. Exhaust ducts should be noncombustible or approved for use without

sprinklers. The alternative is to provide sprinklers in the exhaust ducts to prevent a fire from propagating back to the clean room.

This hazard was underlined by a major fire in 1997 at a semiconductor plant in Taiwan. Workers were repairing the polypropylene exhaust duct between the clean room and roof-mounted scrubbers, using a hot air gun. Heat from the repair work ignited powder residue in the ducts, which, in turn, ignited the plastic duct. The duct fire burned all the way up to the roof-mounted



scrubbers - destroying them completely - and burned back to the unsprinklered clean room, causing extensive smoke and corrosion damage. Direct fire damage in the clean room was limited, but the clean room was a total loss. Physical damage to the clean room and plant was DM 600 million (about C$450 million). Fortunately for the insurers, there was no business interruption coverage.

**Passive control** refers to safe delivery and use of liquids and gases in the clean room. Flammable and corrosive liquids should be stored and dispensed outside the clean room. Flammable liquids should be dispensed into safety cans for transport into fabrication areas. If flammable liquid storage in the clean room is unavoidable, it should be in an approved flammable liquid cabinet.

Flammable, pyrophoric and corrosive process gases should be supplied to clean rooms from gas cylinders located in a remote location, such as a 2-hour rated cut-off room. Gas cylinder rooms should be sprinklered and equipped with Class 1, Division 2 electrical equipment for hazardous locations.

Cylinders containing hazardous process gases should be located inside metal gas cabinets within the above gas cylinder room. These gas cabinets should be equipped with continuous internal ventilation and a gas monitoring system interlocked to automatically shut off the flow of gas at the cylinder upon detection of a leak.

Automatic shut-off of gas flow should be by automated cylinder valves (ACVs) located on the cylinders. The gas cylinders should also be equipped with excess flow valves or switches and a restrictive flow orifice (RFO). The RFO is provided to limit the flow of gas out of the cylinder should the pressure regulator fail.

**Smoke detection and control** are essential to maintaining clean room integrity in the event of a fire. Prompt detection of smoke at very low concentrations, and its subsequent removal, is needed to minimize contamination. Highly sensitive air sampling or linear beam-type smoke detectors are needed as conventional photoelectric and ionization-type smoke detectors are not sensitive enough for clean rooms. Clean room ventilation, normally from the ceiling down to the floor, can also affect the performance of smoke detectors in conventional ceiling locations.

The smoke detection system should be an integral part of the air handling system for the clean room. The sensitive air sampling or beam-type smoke detectors should be provided in the return air path (the air drawn from the clean room). Conventional smoke detectors should be provided in the make-up air path (the fresh air supplied from outside the room) to prevent the intake of contaminated air.

The clean room should have a dedicated smoke control system arranged for automatic activation by the smoke detection system. Several permutations are possible, depending on the clean room design. The smoke control system can be integrated with the main air handling system, when the room exhaust is returned to the recirculating air fan in enclosed ducts. This arrangement requires the automatic operation of dampers to stop the flow of contaminated air back to the clean room and divert the clean room exhaust to outside. Another possibility is to use the fume exhaust system(s) from work stations for smoke control if it has been designed for this purpose.

**Fire protection** for clean rooms should consist of ceiling sprinklers and special extinguishing systems for certain apparatus such as wet benches.

Sprinklers are required to protect the clean room itself from a major fire loss. NFPA and FM Global recommend a density of 0.2 gpm/sq. ft. over 3,000 sq. ft. (8 mm/min over

279 m$^2$), using low temperature, quick response sprinklers. Unfortunately, significant smoke damage will have occurred to the room, equipment and work-in-process by the time sprinklers activate and control a fire. This does not negate the need for sprinklers. It simply means that sprinklers should be considered the last line of defence in a layered fire protection scheme that also includes special extinguishing systems, smoke detection and control. The Munich Re study of Asian semiconductor plants found that 80% of the plants were sprinklered, but only 65% had sprinklers in the clean rooms.

Wet benches are a serious fire hazard because they are typically constructed from plastic, commonly use flammable liquids and contain electrical equipment that represent a potential ignition source. This fire exposure is supported by loss statistics: 40 wet bench fires have been reported to FM Global in the past 10 years.

Wet benches should be protected by an automatic, fixed extinguishing system if they are of combustible construction or handle flammable liquids. Three extinguishing agents have proven to be successful in full-scale fire testing and are recommended by FM Global: water mist, carbon dioxide and FM-200 (halon replacement gas). Actuation should be by optical flame detectors for the working surface and subsurface plenum (area below the working surface where the different bath tanks are located). Electrical power to the equipment should be interlocked to shut down upon activation of the extinguishing system.

## Clean room losses can be minimized

Clean rooms present unique property loss prevention exposures because of high value equipment and work-in-process that is very susceptible to fire and smoke damage, often with very high business interruption values. Combine these threats with the extensive use of plastics plus corrosive and flammable liquids and gases and you have the potential for substantial loss in the event of a fire.

However, the potential for clean room losses can be minimized with noncombustible or approved plastic materials, safe delivery and use of flammable liquids and gases, early detection and removal of smoke, and full fire protection for the clean room and work stations.

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