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Fire protection in cleanroom laboratories

Protection of people, assets and reputation

Cleanrooms in universities and commercial research establishments fulfill a key role, as research work in many widely diverse fields would be virtually impossible without them. Cleanrooms, however, are high risk areas, which is mainly due to the high cost of replacing any loss due to fire damage and the consequential loss of revenue during the ensuing reconstruction period. Providing adequate fire protection is essential, as a fire in a cleanroom could have devastating financial consequences.

Aspirating Smoke Detection (ASD) systems are capable of reliably detecting even the smallest aerosol concentrations, which could have been generated by the malfunction of an individual electrical or electronic component. The risk of such an incident developing into a damaging fire can be effectively eliminated by immediately removing power from the faulty unit. If ASD sampling pipes are installed in the air intake vents, any harmful pollutants can also be detected and appropriate measures taken to prevent these from entering the cleanroom atmosphere.

Should a fire occur, the highest priority is the prompt activation of the predefined countermeasures. A fire protection system is therefore required that ensures a fast and reliable response. In addition to the warning and evacuation of all persons in the danger area, smoke must be prevented from spreading to any neighboring cleanrooms. In cases where a fire occurs outside the cleanrooms, smoke must be prevented from entering and the fire must be extinguished as soon as possible.

Content

Introduction

Highlights

- Many university research projects cannot be conducted without cleanrooms.
- Cleanrooms represent a significant fire risk.
- Electrical installations, electronic equipment and a variety of processes represent a constant threat as potential ignition sources.
- The smallest of fires can cause considerable damage and prevent a return to normal operation for many months.

Cleanrooms are enclosed areas where dust or smoke particles, airborne microbes, aerosol particles and chemical vapors (that are normally present in the environment) cannot be tolerated, as they may cause unwanted contamination. The procedures and processes being carried out in such rooms demand strictly controlled environmental conditions. The highest priority is maintaining the air quality, which is defined by the number and size of the particles suspended in the air per unit volume. In addition to controlling air quality, the environmental parameters (temperature, humidity and air pressure) must also be kept constant to guarantee comparable conditions at all times.

Typically cleanrooms have been used in the semi-conductor, pharmaceutical, food and beverage industries, as well as in hospitals. Increasingly, however, such facilities can be found in universities, where they serve in such fields as research into nanostructures, which play an important role in solid state and semiconductor physics. A cleanroom separates the research processes from the "contaminated" environment, enabling the procedures to be carried out under carefully controlled environmental conditions.

The main objectives of a cleanroom are:

- To protect processes and products from contamination
- To protect persons from health-threatening substances and organisms (e.g. micro-organisms)
- To protect the environment from dangerous and unwanted emissions

Frequently cleanrooms play a central role in the research activities of a university and are consequently a critical area, which must fulfill a higher security level.

Cleanrooms are designed in such a way that:

- The specified air quality level can be guaranteed
- The climatic conditions remain within specified tolerance limits
- Only authorized persons are permitted access; to prevent any adverse effects on the environmental conditions that might be caused by untrained persons
- Each cleanroom is a separate fire compartment and is therefore in no immediate danger from a fire in a neighboring fire compartment
- A fire can be detected and dealt with at the earliest possible stage, thus preventing any impact on neighboring cleanroom

Basic conditions

This section describes the fire protection objectives, typical fire risks and possible fire development scenarios in cleanrooms. It also lists a number of critical points regarding fire risks, fire detection and appropriate countermeasures.

Objectives

- Recognition of abnormal fire-related aerosol concentrations and transmission of this information to a technician. The situation can then be quickly evaluated and appropriate countermeasures taken (e.g. removing power from the relevant equipment).
- Minimizing damage by suppressing an incipient fire at the earliest possible stage using a reliable residue-free extinguishing system.
- Prevent smoke and fire spreading to other areas.
- Timely alerting and safe evacuation of all endangered persons.

Typical fire hazards

- Overload or short-circuit of electrical or electronic equipment and installations.
- Careless handling of heat sources such as hot air guns or Bunsen burners.
- Leakages of highly inflammable or pyrophoric liquids (i.e. those liquids that can ignite spontaneously on contact with air or moisture).
- Explosive concentrations of gases or solvent vapors.

Typical development of a fire

In a cleanroom we cannot talk about a typical fire development. To a great extent, this will depend on the infrastructure, materials and substances inside the cleanroom, together with the procedures being carried out.

- When electrical or electronic components overheat they generate increasing quantities of visible aerosols. If appropriate countermeasures are not taken at this stage, such as removing power from the devices concerned, then the smoldering fire can develop into an open fire. This can cause immense damage and create a significant threat to any persons in the area.
- Careless handling of heat sources, spontaneous ignition of dust deposits in the ventilation ducts, or self-igniting liquids can lead directly to an open fire, which (depending on the fire load) may spread very rapidly.
- An explosion (a rapid increase in volume and uncontrolled release of energy) can occur, if an explosive concentration of gases is allowed to build up.

Critical Points

- Even the smallest of fires can cause enormous damage.
- High air circulation rates dilute the aerosol concentration, making it more difficult to detect incipient fires at an early stage.
- Very little heat will be created by a smoldering fire and consequently the fire aerosols generated will not spread throughout the entire room.
- To minimize fire damage, the consequences of a fire must be restricted to the cleanroom itself.
- Fire aerosols from a neighboring room must be prevented from entering.
- An explosive mixture of gases must not be allowed to develop.
- The extinguishing process itself must not cause any additional damage (e.g. the ruining of electronic equipment, water damage or other types of residue).

Solution

Depending on the area of application, cleanroom requirements can differ significantly. In the pharmaceutical industry topics such as particle emission, chemical stability or cleanability play an important role. Such topics, however, would not have the same importance in, for example, the photovoltaic sector. Demands on the air purity can also vary considerably as they can be influenced by the outside air, contamination caused by personnel, process-dependent contamination and inappropriate production facilities.

Although cleanroom requirements may vary considerably, this has only a limited influence on the design of a suitable fire protection system. What is important, however, is that the ventilation conditions in the room are taken into consideration when selecting and positioning the appropriate fire detectors. During an extinguishing incident the agent itself should not cause any additional damage. Consequently, the type of equipment and materials used in the room will largely determine the most appropriate extinguishing agent to be used.

Cleanrooms are at the core of many diverse research projects and any contamination caused by dust, micro-organisms or smoke particles can severely disrupt the research work. On the other hand, health and safety considerations also present their own particular challenges. Active substances (in pharmaceutical research projects), dangerous pathogenic bacteria (in a high security laboratory), flammable cleaning solvents and toxic chemicals all pose significant health risks for research personnel and for the environment.

The objective of the solution presented here is to minimize the damage that could result from the greatest single risk – FIRE. Achieving this objective requires a combination of organizational, structural and technical measures

Organizational measures

On the organizational side the two most important factors are access control and training. It is important to ensure that only authorized persons who have received the necessary training are able to enter the cleanroom. As the research in universities is mainly carried out by the students themselves, it is essential that they receive adequate training, where the importance of the appropriate behavior is impressed upon them.

In addition to training regarding the correct use of the equipment, topics such as technical cleanliness, the correct handling and safe disposal of the various materials (solids, liquids and gases) must also be dealt with. In this context special attention should be paid to the prevention of fire. It is also important, however, to be fully acquainted with the automated extinguishing system and how (and when) fire extinguishers should be used to deal with minor incidents.

Structural measures

Both cleanroom-specific and fire protection aspects must be taken into consideration when designing and implementing the appropriate structural measures.
As overpressure in a cleanroom can prevent pollutants from entering the room through the air, the room-in-room construction is often the preferred design concept. The air inlet and exhaust take place via air vents, whereby the air inlet is equipped with a filter system which purifies the air before it enters the cleanroom.

Fire protection considerations require that the cleanroom be designed as an independent fire compartment with appropriate smoke seals and fire doors. In the event of a fire, it would also be desirable if the smoke could be vented directly into the open air, however, this would be inconsistent with the room-in-room concept. For this reason the experts responsible for the cleanroom system design must be consulted to help provide a suitable smoke extraction solution.

Technical measures

Fire protection incorporates a wide range of technical disciplines and dedicated systems including access control, gas warning, fire detection and extinguishing. The access control system should ensure that only authorized persons (who have received the appropriate training) are permitted entry into the cleanroom. The gas warning system must be able to prevent the development of any dangerous gas mixtures by controlling the ventilation in the individual areas. In case of a dangerous situation arising (e.g. due to the malfunction of the ventilation system) it must also generate a warning signal, and an alarm if the danger becomes imminent.

The fire protection system must detect an incipient fire at the earliest possible stage and activate the acoustic and optical warning devices. In addition it must activate the pre-programmed functions that control the ventilation and smoke extraction systems. If an automated extinguishing system is present, this must also be activated.

Research facilities can be very diverse and depend greatly on the specialization of the individual university.

An ASD system is designed to detect the smallest quantities of fire-related aerosols and is the ideal smoke detection system for cleanrooms. This is due to the requirement that a fire in a cleanroom must be detected as early as possible in its incipient stage and that no deceptive phenomena whatsoever should be anticipated in a cleanroom environment. Modern ASD systems are capable of generating different warning and alarm signals. These signals can be used to control the ventilation and smoke control systems as well as activating the automated extinguishing system. In the "gray areas" (i.e. those areas immediately outside the cleanroom itself) multi-criteria fire detectors or special detectors such as flame detectors may be employed, depending on the fire load and the local processes. In addition to the automatic fire detectors, manual call points are also installed to enable fire alarms to be triggered manually.

Where an automated extinguishing system has been installed and local regulations require multiple zone dependency (independent alarm signals across two zones in the same room) before the extinguishing system can be activated, then either an additional high sensitivity smoke detector or a second ASD system must be installed.

Example: Cleanroom for nanotechnology

The following paragraph describes a solution for a cleanroom that may typically be found at a university offering courses in the highly interdisciplinary field of nanotechnology. The example is based on a room-in-room construction with a surface area of 440 m^2 (20 x 22 m).

In the cleanroom and yellow light areas (working areas) the tempered and humidified air enters the working areas through ceiling filters. These filters are designed to achieve the ISO air quality class 5. The air from these areas then passes through air vents into the "gray areas" (service zone, corridor, changing room and storeroom). The air in these areas is purer than the outside environment (e.g. ISO 7) but is contaminated with particles that were generated in the cleanroom. The air from these areas is extracted through the ceiling.

Details	Comments/Notes
Automatic fire detectors Aspirating Smoke Detection system	ASD systems ensure early detection of incipient fires and recognition of air pollutants ▪ Parameter set selected for high sensitivity ▪ Evaluation of fine dust particle concentration ▪ The quantity and size of the sampling holes can be determined with the aid of the calculation software provided ▪ By using a combination of the ASD signals, information on the location can be determined (e.g. Cleanroom 1/Cleanroom 2 or Yellow Light Area 1/ Cleanroom 3 or Yellow Light Area 2)
ASA neural detectors	Early and reliable fire detection of all types of fire ▪ Parameter set selected for high sensitivity
Smoke detector	Reliable fire detection ▪ Parameter set selected for high sensitivity
Manual call points MCPs	Manual activation of a fire alarm (via the fire detection panel) ▪ Single or double action (depending on local regulations)
Warning devices Sounder-beacons	Sounders with supplementary optical indication to alert any persons in the room so they have time to react
Manual suppression Hand-held fire extinguisher	Hand-held fire extinguisher; for the manual suppression of minor fires ▪ Recommended type: CO_2
Positioning of the system elements (see Figure 1)	**ASD system** ▪ ASD evaluation unit in the technical room ▪ 1 sampling pipe in the floor of the area to be protected ▪ Air recirculation to the cleanroom **ASA neural fire detectors and smoke detectors** ▪ On the ceiling ▪ Minimum distance from air outlet vent 1 m **Manual call point** ▪ Next to the exit door (inside the cleanroom) ▪ At a height of 1.4 m ± 0.2 m **Sounder-beacon** ▪ In a central location that is clearly visible from anywhere in the room **Hand-held fire extinguisher** ▪ In all cleanrooms ▪ Handle height 1.0 m ± 0.2m above the ground

Further Comments/Notes

Air flow considerations

- When selecting the best positions for the sampling pipes and detectors, all possible air flow scenarios must be taken into consideration. Only in this way can we be sure that (in the event of a fire) the smoke can reach the sampling pipes and detectors.

Furthermore

- Fume cupboards and processes where a higher risk of fire exists, should be monitored with automatic detectors (e.g. flame detectors) and an automated extinguishing system (e.g. CO_2).

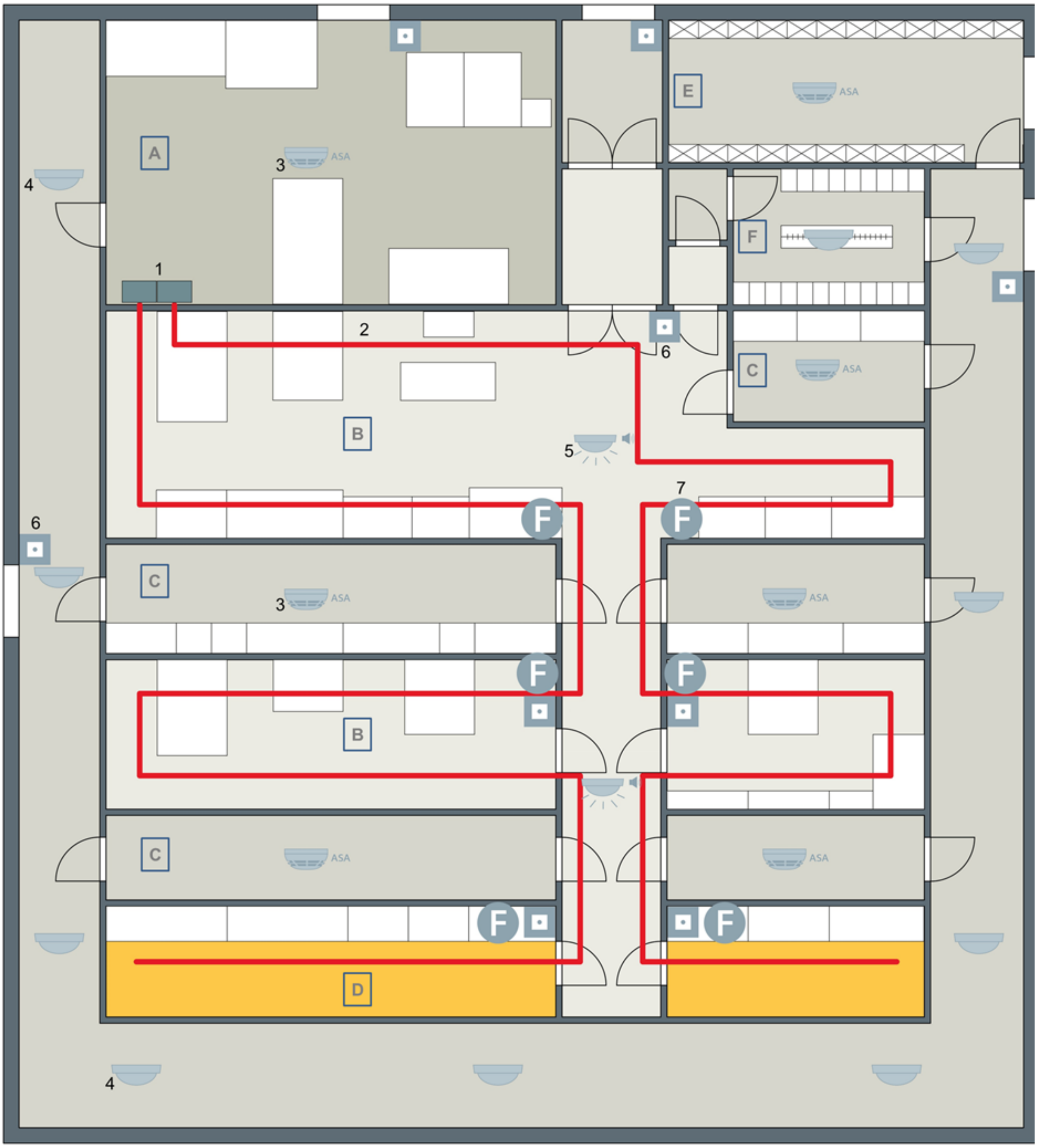

Figure 1 Positioning of system elements

System elements

1. ASD evaluation unit
2. ASD sampling pipes
3. ASA neural fire detector
4. Optical smoke detector
5. Sounder-beacon
6. Manual call point
7. Hand-held fire extinguisher

Rooms

A. Technical room
B. Cleanroom
C. Service zone
D. Yellow light area
E. Storeroom
F. Changing room

Practical experience

There is no standard solution for cleanroom laboratories and the example described above should be regarded as a “basic solution”. Frequently additional fire protection measures are required to further reduce the fire risk to the “accepted” level. The fire risk is the product of the probability of a fire occurring and the consequential damage from that fire. Hence the risk can be lowered either by reducing the probability of fire occurring or by reducing the possible damage. The probability of a fire occurring can be significantly reduced by observing the following recommendations:

Personnel training

The greatest source of risk stems from the people working in the cleanrooms. Practice shows that many fires could have been avoided if instructions and safety procedures had been followed. It is therefore absolutely essential that all persons who work in the laboratories are not only trained in self-protection topics, but also in how to prevent fires from starting and how to combat a fire if an incident should occur. Careful handling of easily flammable materials and careful attention to possible ignition sources such as flames, hot objects, chemical reactions or spontaneous combustion are topics that must be dealt with in user training sessions. Regular monitoring also helps to maintain the awareness level for fire protection issues and make improvements where necessary.

Testing electrical equipment and installations

A wide variety of electrical equipment can be found in a cleanroom. Most of these pieces of equipment consist of a power supply and electronic components and are therefore potential ignition sources. Defective electrical appliances, extension cables or overloaded multi-way power sockets are further potential ignition sources. To minimize the potential danger from electrical equipment and installations, they must be tested regularly. Defective equipment and installations that do not comply with the specified safety standards must be repaired immediately or taken out of service.

Prevention of explosive atmospheres

Gases and solvent vapors can create an explosive atmosphere. Consequently activities involving gases and solvent vapors should only be permitted in fume cupboards with appropriately designed ventilation. If for some reason this is not possible, then the area must be monitored with a gas detection system. This system should control the ventilation according to the gas concentration and trigger a warning before a critical concentration can develop.

The consequences (incurred damage) resulting from a fire can be kept to a minimum through a combination of early fire detection and targeted fire-fighting.

University research projects are often supported by local high-tech industries.

Early fire detection

The earlier a fire can be detected, the sooner the corresponding countermeasures can be initiated (e.g. removal of power, ventilation control, extinguishing). In this way, any resulting damage can be kept to an absolute minimum.

All persons responsible for supervising the processes must be trained in how to react correctly to any fire-related situation that might arise.

A timely warning from an automatic fire detector can only be guaranteed if the detector reacts to the fire phenomena generated (smoke, temperature, heat radiation, gas) and these reach the detector with sufficient intensity. As airflow rates in a cleanroom are high, optimal positioning of the ASD sampling pipes is crucial. Even at the highest airflow rates it must be ensured that the developing smoke is delivered to the ASD evaluation unit in adequate quantities. The most appropriate positions can only be determined in close cooperation with ventilation experts. Experience has shown that although suitable positions can be determined on the basis of theoretical consideration alone, these are not always the optimal positions. For this reason and before the final cleaning of the installation, the response behavior of the ASD system should be verified with a "test fire" and appropriate modifications made if necessary.

Targeted extinguishing

Targeted extinguishing means that the fire should be dealt with quickly and with the most appropriate means.

The majority of cleanrooms require that a sprinkler system is installed. Such systems help to keep the escape routes accessible for a sufficiently long period of time to allow evacuation and can help prevent a total loss. However sprinkler activation in a cleanroom can often lead to considerable water damage. In order to limit this damage, additional forms of extinguishing must be considered for the more critical areas.

Practice shows that fires only cause limited damage when processes are supervised by people, assuming that they react quickly and are fully conversant with the usage of the available extinguishing equipment (e.g. fire blanket or hand-held CO_2 fire extinguisher).

Objects with a heightened fire risk and without permanent supervision should be equipped with an automated extinguishing system. Of course it must be ensured that the ventilation in the affected areas is switched off and the ventilation flaps are closed before the extinguishing agent is released. The preferred extinguishing agent in cleanroom applications is carbon dioxide.

- CO_2 is very reliable and is completely residue-free. After an extinguishing event has occurred it is only necessary to ensure that the affected area is well ventilated. Care must be taken as the CO_2 concentration required for the extinguishing process is toxic. A special case, however, is the extinguishing of very hot materials such as burning magnesium. The very high temperatures split the CO_2 into carbon (C) and oxygen (O_2), which then supplies the fire with additional oxygen.
- In applications where the use of CO_2 would create a heightened risk to personnel, argon may be used as the extinguishing agent. The non-toxic inert gas argon also provides residue-free extinguishing and is electrically non-conducting. In comparison with CO_2 more attention must be paid to ensure that the required concentration is maintained over a sufficient period of time, especially in cases where the room is not air-tight.
- Powder is also a very efficient extinguishing agent and would guarantee rapid extinguishing. However, it would create excessive, large scale contamination and is consequently not at all suitable for cleanroom applications.

The choice of extinguishing agent must be based on the process that needs to be protected and the associated risk to personnel. When calculating the required quantity of the extinguishing agent, the volume of the room(s) to be protected and the expected leakage must be taken into account.

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