SIEMENS

TECHNICAL GUIDELINE | MARCH 2024

Fire Safety for Pre-Charging and Formation Equipment in North America

This document outlines Siemens' fire safety product portfolio for battery production, specifically for pre-charging and formation processes. It is intended to be used as a guide for projects involving original equipment manufacturers (OEMs) in battery cell production, in North America.

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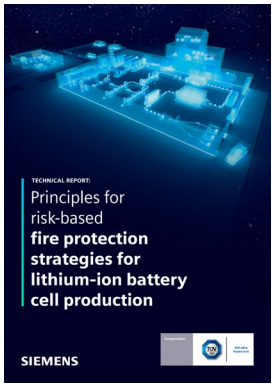
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Introduction

This document outlines Siemens' fire safety concept for pre-charging and formation equipment used in battery production. It provides guidance on best practices for safeguarding a production line, with a special emphasis on risk evaluation and fire protection.

Background reading!

↗ Technical Report: Principles for risk-based fire protection strategies for lithium-ion battery cell production



Summary

The first chapter of this document presents the fire risks associated with lithium-ion battery cells. It starts with the introduction of the fire circle, which shows the correlation to the propagation effect that could cause several cells to catch fire after a thermal runaway is initiated. For a more in-depth understanding of the fire circle, the appendix chapter summarizes knowledge gained from real fire tests conducted at Siemens laboratory in Altenrhein, Switzerland.

Chapter 2 summarizes the normative demarcation for fire safety in production and explains the differences between building protection and machine protection. It also introduces the concepts of process protection and operative fire safety and applies the SFPE Guide to Fire Risk Assessment (2023).

Chapter 3 provides a technical description of the equipment that needs protection. With drawings and texts, the pre-charging and formation chamber, tray, and tower layout are explained, followed by the application of the EN ISO 19353:2019 standard.

Chapter 4 presents a fire safety concept that can be used to protect these chambers and towers. The objective is the earliest fire detection at the off-gassing event, using a multi-criteria point-type detector and an aspirating smoke detector. After the fire is detected, the fire control panel sends a signal to shut down the equipment process, followed by the triggering of the automated suppression system. The purpose of the suppression system is to prevent an explosive atmosphere and limit the thermal runaway to only one cell.

For the suppression system, an inert gas is used. To dissipate the heat generated during loading, the chambers require effective ventilation. For this purpose, the chambers are linked to a mechanical ventilation system. On-site fire dampers, equipped with Siemens fire damper actuators, must be provided for each chamber as a mechanical solution to limit the spread of fire. Additionally, the tower must be equipped with emergency exhaust ventilation featuring an overpressure relief system.

After successful suppression, trays with cells should be left in the chamber until cells have cooled down. Then, they should be removed safely and transported in a fireproof box.

The appendix provides two interface models and a list of products to be used from Siemens.The appendix provides two interface models and a list of products to be used from Siemens.

Restrictions to this document

Please note that the examples given in this document are generic and not related to any specific cell manufacturer. Additionally, no specific cell chemistry or material is considered. For each new project, it is important to conduct an examination and assessment of the fire behavior of the cell design individually by means of fire testing and prepare a specific risk evaluation and fire protection concept based on the guidelines provided in this document.

Background

This chapter discusses the fire risks that can occur during lithium-ion battery cell production. It presents building and machine fire safety, process safety, and operational and organizational fire protection measures. The chapter also introduces the SFPE Guide to Fire Risk Assessment (2023).

During the production process of lithium-ion battery cells, there are several critical production steps in which a fire might occur, such as during pre-charging and formation. However, all fires happen due to some sort of battery abuse.

Examples of abuse can be:

- Electrical (through overcharging or overload)
- Mechanical (e.g., by penetration)
- Thermal (by heating-up a battery beyond its design limits)

Abuses as such might result in an exothermic process known as “thermal runaway.”

Without any fire protection measures, a thermal runaway can lead to a chain reaction with high energy and heat release by means of a fire, an explosion, and toxic gases with a rapid propagation to other cells and/or parts of the production.

A thermal runaway propagation from cell to cell is always to be avoided.

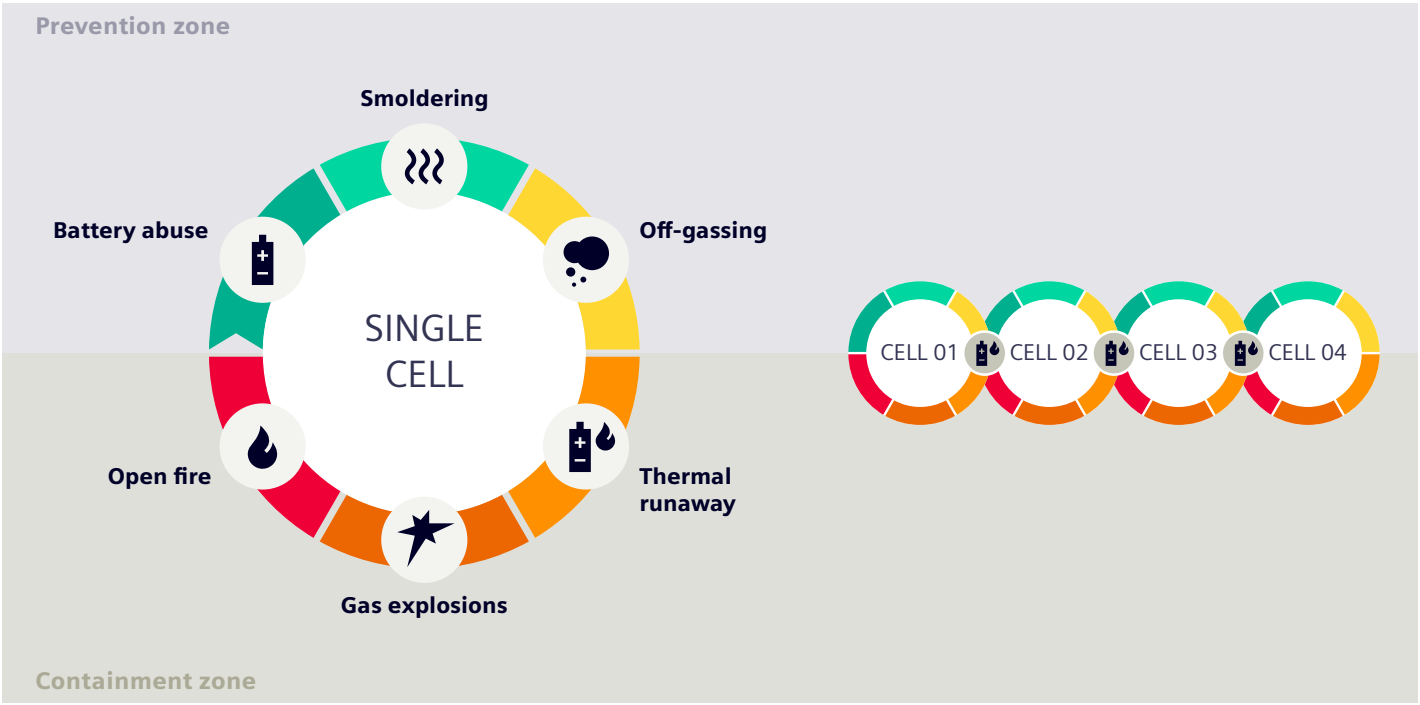


Figure 1:
Fire circle and the possible propagation effect from cell to cell

The fire circle to the left shows the different steps that a cell undergoes from abuse to full fire, and the consequences of propagation from one cell to another.
More information about each step is found in the appendix.

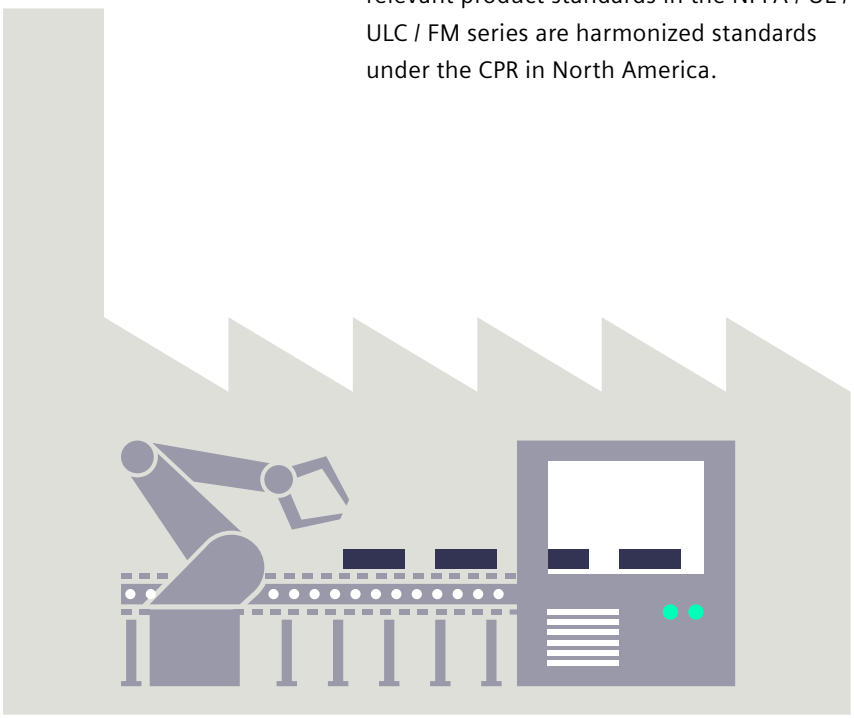
Normative demarcation

When securing a battery production site, it's crucial to consider two primary legal regulations: one for the building's protection and another for the machines used in the production process.

For building safety, fire detection, and suppression products, compliance with the Construction Products Regulation (CPR) is required. Similarly, fire safety products that are built into machines must comply with the North America (USA / Canada) Machinery Directive and are not subject to CPR.

The NFPA / UL / ULC / FM are North American standards for fire alarm systems. These standards define product characteristics, test methods, and performance criteria based on the effectiveness and reliability of the components of fire alarm systems. The most relevant product standards in the NFPA / UL / ULC / FM series are harmonized standards under the CPR in North America.

Figure 2:
The building and machine perspective of the normative demarcation is important.



Building: Construction Products Regulations

Machine: Occupational Safety and Health Standard - 1910 (OSHA 1910 - inc. sub part L Fire Protection)

Process safety, in addition to building and machinery safety

In addition to the building and machinery fire safety, it is important to consider aspects such as business continuity and financial loss in the case of an event by means of process safety.

The objective of process fire safety is to:

- Guarantee maximal uptime and in the case of a fire
- Limit the downtime
- Limit physical damage
- Limit business interruption
- Keep data available
- Limit reputational risk

Operational and organizational fire safety, in addition to building, machine, and process safety

Finally, in addition to process safety, operational and organizational fire protection measures needs to be accounted for. They include all preventive and post-fire measures that are not of a structural or technical nature.

Risk assessment according to the SFPE Guide to Fire Risk Assessment (2023)

Further reading!

↗ Chapter 5 "Risk Analysis" in Technical Report: Principles for risk-based fire protection strategies for lithium-ion battery cell production

For each project, a risk assessment is needed. For battery production, SFPE Guide to Fire Risk Assessment (2023) can be used. In this standard, some elements are detailed and shall be part of the fire risk assessment.

When discussing the project, analyze the following:

1. Is there a presence of flammable materials and/or explosive/toxic products?

2. Is there a likelihood of ignition due to sufficient ignition energy in the production processes and/or electrochemical reactions?

3. If a fire/explosion/release of toxic gases occurs, is it restricted to a controllable part of the factory or not propagated to other parts/cells?

Technical description of cell formation

Battery formation involves the initial charging and discharging of a battery cell, which brings it to life. This process usually starts with a pre-charging step and is followed by multiple charging and discharging cycles, which can take several days or longer to complete. During this process, production errors in previous steps can influence the final product which in the worst case, when powered electrically, can lead to a fire.

Single formation chamber

The formation process takes place in chambers where the battery cells are arranged in trays and then placed inside. Typically, an electrical high-power supply unit and a ventilation duct are located near the formation chamber. These chambers can either be completely open or have a window system. Loading and unloading of trays into the chamber are usually automated using a handling system.

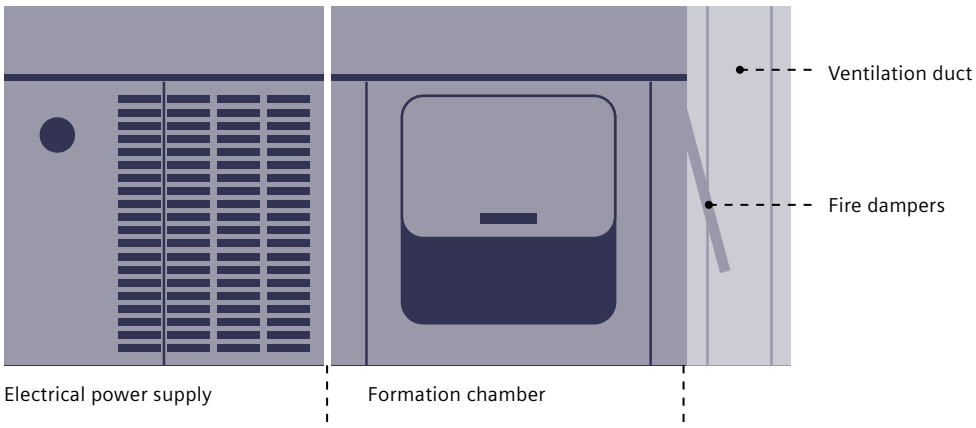


Figure 3:
Example layout of a formation chamber

Questions related to the SFPE Guide to Fire Risk Assessment (2023)

To get a good understanding of the fire risks associated with the pre-charging and formation equipment, the following questions should be addressed in relation to a single chamber:

A) The presence of flammable materials and/or explosive/toxic products

- What kind of cells are produced?
- With what cell chemistry?
- What is the size and design of the chamber?
- What is the operational temperature inside the chamber?
- How large are the chamber openings?
- Are there automatic doors?
- How are the automatic doors triggered?
- Are the cells fire-tested? What is their off-gassing and fire behavior?
- What is the material of the tray? How is the layout of the tray?

B) The likelihood of ignition due to sufficient ignition energy in the production processes and/or electrochemical reactions

- What is the electrical power/risk in the chambers?
- How are the cells charged? With what current?
- How is this controlled? Measured?

C) If a fire/explosion/release of toxic gases occurs, it is restricted to a controllable part of the factory or not propagated to other parts/cells

- In case of a thermal runaway, what toxic gases are released?
- What is the ventilation concept? Air speed in the chamber? How is this controlled?

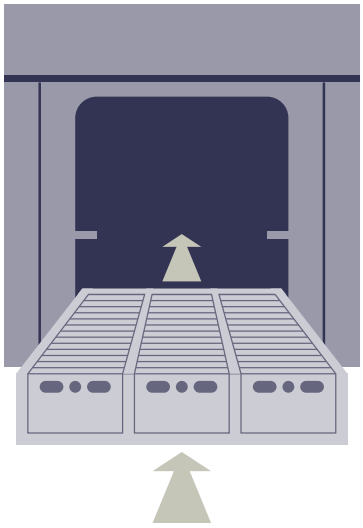


Figure 4:
A tray of cells is placed in a formation chamber

Multiple chambers stacked create a tower

In a giga factory, formation chambers are typically stacked on top of each other to form towers. As thousands of cells are charged and discharged simultaneously, these towers pose an increased risk of fire due to the large quantity of cells and flammable material.

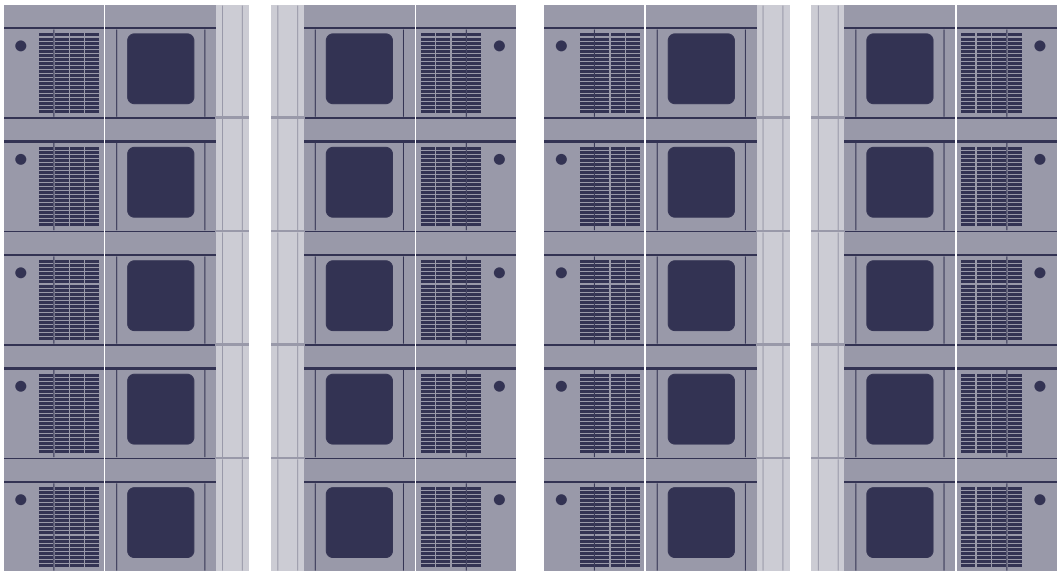


Figure 5:
Example layout of two formation towers, with five chambers stacked on top of each other in each tower

Additional questions related to the tower layout related to the SFPE Guide to Fire Risk Assessment (2023)

A) The presence of flammable materials and/or explosive/toxic products

- How many formation chambers are stacked on top of each other?
- What is the tower height?
- Is there any other flammable material stored close to the tower?

B) The likelihood of ignition due to sufficient ignition energy in the production processes and/or electrochemical reactions

- What is the electrical risk in the complete tower?
- What is the complete fire load in the tower?

C) If a fire/explosion/release of toxic gases occurs, it is restricted to a controllable part of the factory or not propagated to other parts/cells.

- What is the ventilation concept for the tower? How is this controlled?
- How is the tower air-cooled?
- How often is the ventilation system in the tower cleaned? Is there a risk of dust in the channels?
- Does the tower have fire dampers? How do they work?

Checklist

Areas to be discussed to set a proper fire safety concept

- ☑ Chamber layout (size, presence of flammable material, presence of electrical equipment)
- ☑ Tower layout (number of chambers on top of each other / height / air flow / power supply)
- ☑ Air concept (exhaust air / air tightness / air cooling / air duct layout / flaps at front and grilled surfaces)
- ☑ Tray (design / size / material / spacing between cells)
- ☑ Water concept (supply and drainage)
- ☑ Power supply units
- ☑ Stacker crane (purpose, operation, and redundancy)
- ☑ Connection to other systems (danger management, layout, communication standard used, I/O modules)

Fire safety concept

Further reading!

↗ In the appendix, two interface models are shown. One like this one, which has the NFPA/UL/ULC/FM standards, including the NFPA 2001 Clean agent fire extinguishing systems, in mind, and another one where the fire detectors are SIL2-approved and connected directly to the PLC

In this chapter, four aspects of fire safety, which is the building, machinery, process, and operative fire safety are presented. The objective is to respond early to the off-gassing event using a multi-criteria point-type detector in combination with an aspirating smoke detector. Additionally, an inert gas automated suppression system is used to avoid explosive atmospheres and to contain the spread of fire.

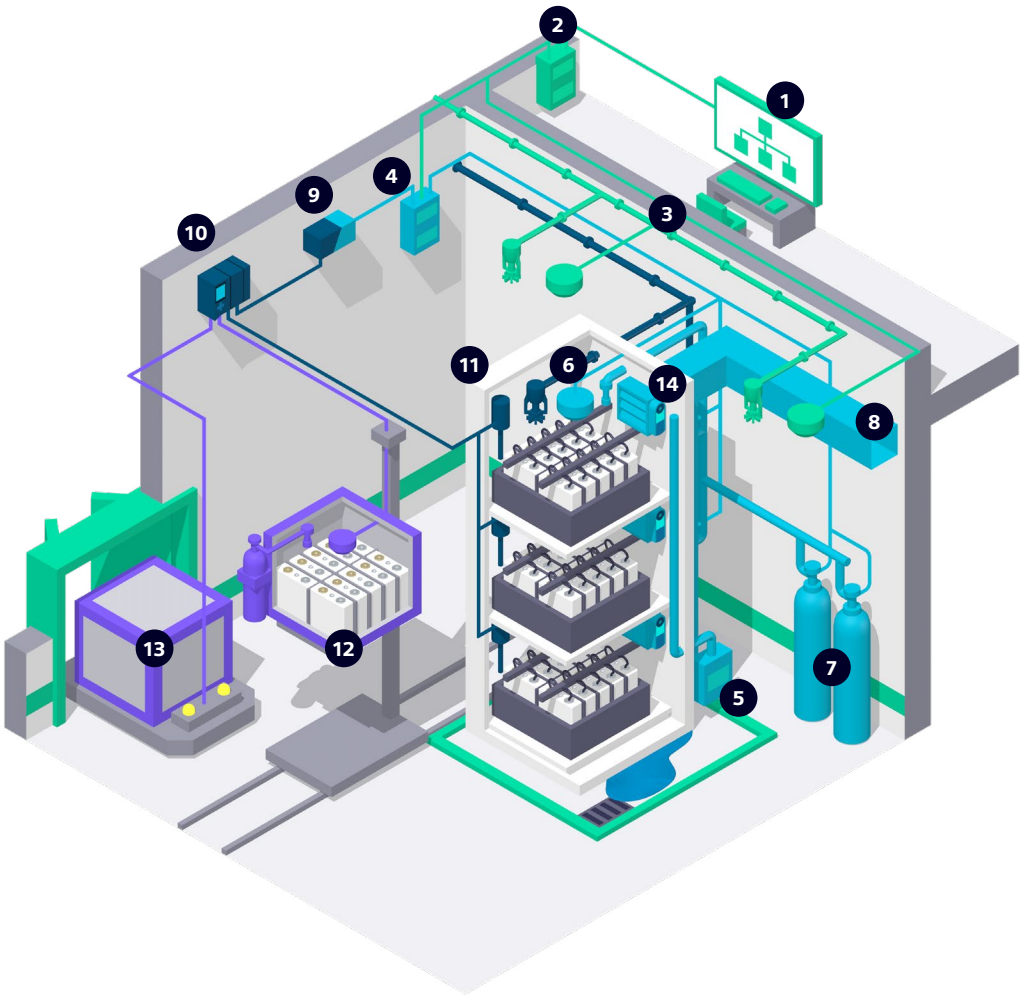


Figure 6
Overview of the four protection categories: building safety, machinery safety, process safety, and operative fire safety

1. Command and control system
2. Building fire alarm panel
3. Building sprinkler and fire detection system
4. Process fire alarm panel
5. Aspirating smoke detection
6. Fire detector and suppression nozzle
7. Suppression cylinders
8. Overpressure flaps and smoke removal
9. Gateway
10. PLC
11. Temperature and voltage measurement, and sprinkler nozzle
12. Stacker crane with fire safety system
13. Safety box
14. Damper actuator / Fire damper actuator

Category	Safety measures
Building safety	Comply with NFPA/UL standards for fire safety products.
Machinery safety	Comply with Occupational Safety and Health Standard - 1910 (OSHA 1910 - inc. sub part L Fire Protection).
Process safety	Strive for maximum uptime in case of a fire event and minimize financial loss.
Operative safety	Implementation of operational and organizational preventive and post-fire measures.

Building safety

Further reading!

↗ Chapter 5 "Elements of the fire protection concept development" in Technical Report: Principles for risk-based fire protection strategies for lithium-ion battery cell production

Building safety involves a combination of structural, technical, and organizational measures to protect against fires, considering the fire load and various factors such as production processes, goods storage, and machines in use. The goal is to minimize the risk of fire outbreak and limit the spread of fire and smoke, ensuring the safety of employees and rescue teams during evacuation and firefighting. The specific design of these measures depends on the building type, size, and purpose, and must comply with local building codes and applicable rules and standards. For North America, the fire alarm system must follow the NFPA/UL standard.

Machinery safety

Machines used in North America must follow the Occupational Safety and Health Standard - 1910 (OSHA 1910 - inc. sub part L Fire Protection). This standard regulates the legal health and safety requirements for machines. In simplified words, the directive says that the machine is to be designed in such a way that it does not pose a danger to the environment.

The potential hazards, including the risk of fire, must be considered in all phases of the machine's life and in all operating modes, which also includes maintenance and repair. Usually, the risk assessment is carried out according to the SFPE Guide to Fire Risk Assessment (2023) / NFPA 79 Electrical Standard of Industrial Machinery. The objective of the risk assessment is to reduce the risks as far as possible and to identify all hazards that may be posed by the machine.

When using water as a fire safety measure for a lithium-ion battery cell machine, it is crucial to ensure that the internal components used in the equipment design for the drainage are resistant to water mixed with hydrogen fluorides (HFs). This is because HFs are highly corrosive and can cause severe damage or leakage in the equipment. It is also advised to monitor the connection between the main drain and the equipment regularly, especially after installation, to ensure that there are no leaks or other issues that could compromise the effectiveness of the fire safety system.

Checklist

Do you have the answers to these questions?

- ☑ Will the machine fulfill the EU Machinery Directive?
- ☑ Will the fire safety system be integrated into a more advanced fire safety system?

Process fire safety

Process fire safety is an additional functional layer, that should be addressed after considering building and machinery safety. The objective is to:

- Ensure maximal uptime in case of a fire
- Limit downtime
- Minimize physical damage
- Reduce business interruption
- Ensure data availability
- Mitigate reputational risk

Fire detection at the off-gassing event

The key is to react quickly with early and precise fire detection of the off-gassing event, using a multi-criteria point-type detector with a carbon monoxide sensor, such as the FDOOTC441 / OOHC941, in combination with an aspirating smoke detector, such as the FDA241. These detectors will react in the prevention zone.

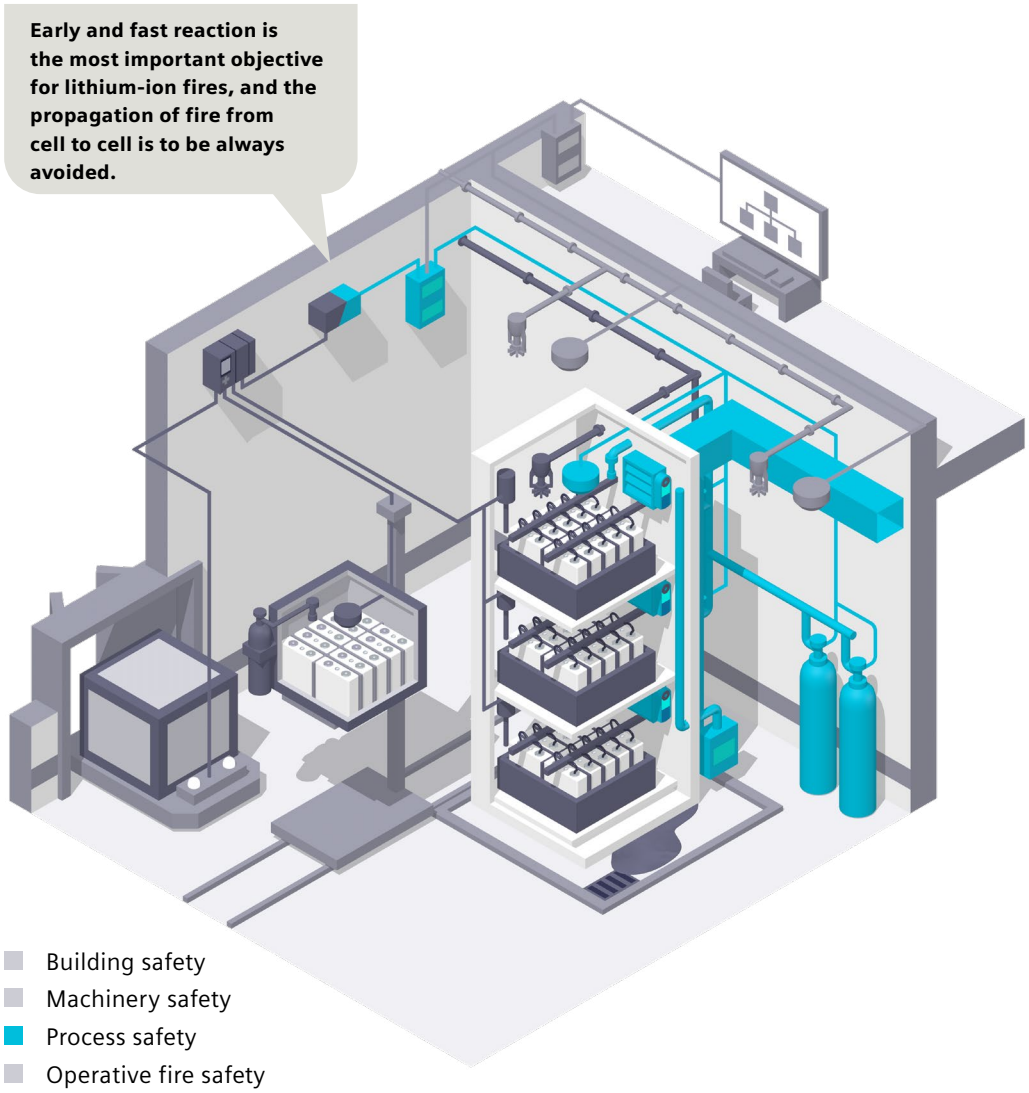


Figure 7:
Components of process protection highlighted

Additional inputs from the equipment process control system

In a pre-charging and formation chamber, each individual cell is connected to the equipment process control system. This system measures the temperature around the cathode area of the cell, and if the cell reaches a certain critical temperature, the probes will disconnect from charging, and the power supply will stop.

This means that two signals can be read out by the equipment process control: temperature level and voltage measurement. Exceeding critical values could result in a request for the suppression agent discharge.

Interface diagram, fire control panel, and PLC

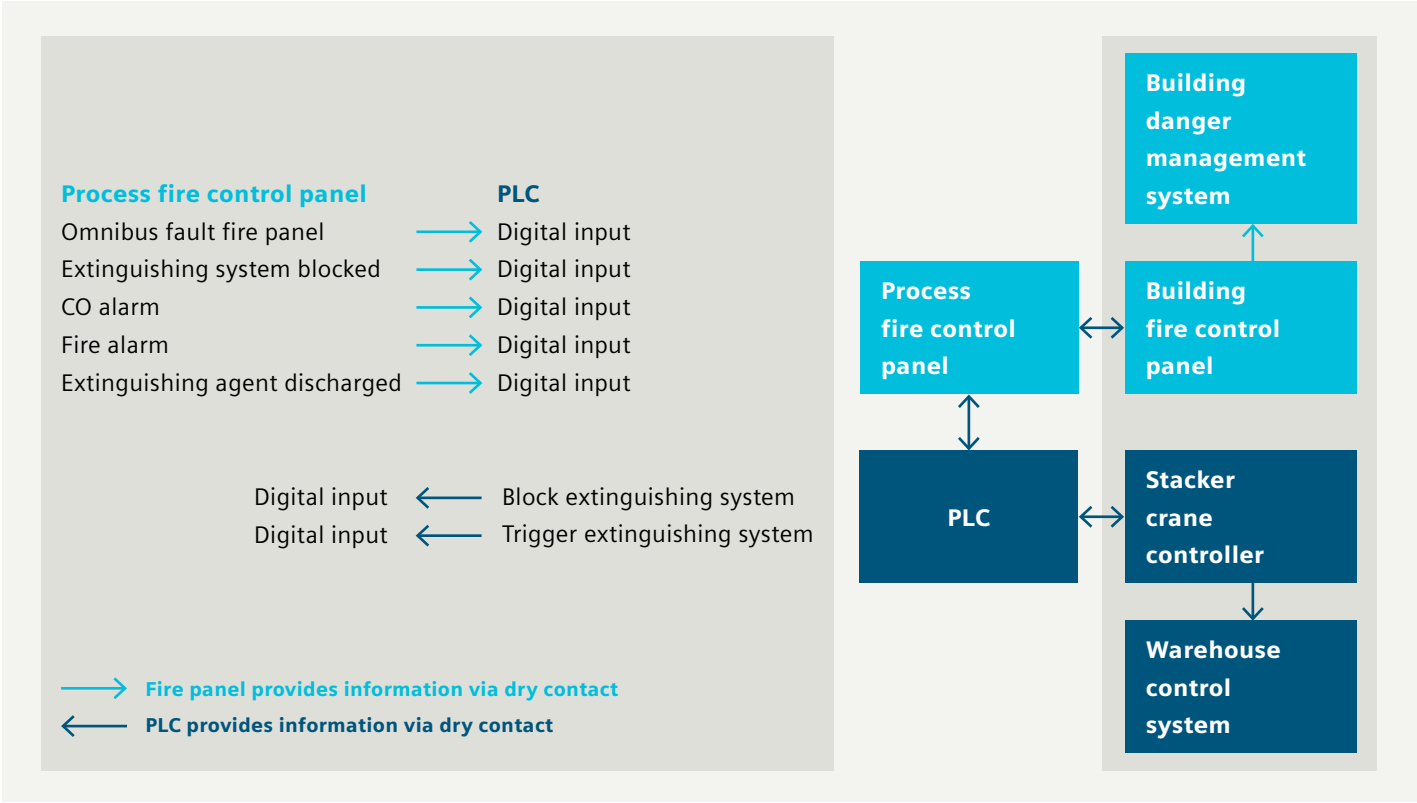


Figure 8:
Example of a diagram of communication between the fire control panel and the process control panel (PLC)

It is equally important for the fire control panel to send a signal to shut down the equipment process (charging) in case the fire detectors detect a fire. Once a fire is detected (either via elevated temperature measured at the cell, or the fast increase in temperature, or via the fire detector), the automated suppression system should be triggered. This is shown in the interface diagram in Figure 8.

Fast reaction using an inert gas automated suppression system

The purpose of the discharge of the suppression agent is to prevent an explosive atmosphere and to limit the thermal runaway to only one cell, so that there is no propagation effect from cell to cell in the tray. The automated suppression system must be UL/ULC/FM-approved, and the activation of the system must be carried out either by an UL/ULC/FM-approved fire alarm control panel or a fail-safe process control unit.

For lithium-ion battery cell fires, nitrogen or carbon dioxide should be used as the suppression agent. When engineering this, attention must be paid to the chamber's airtightness and the airflow within the ventilation system of the complete tower. Both requirements are necessary prerequisites to design an effective system.

If possible, the machine should have a mechanical solution (fire damper) to limit the fire spreading in parallel to the deployment of the suppression agent. The formation equipment must also have an emergency exhaust ventilation with overpressure relief system to remove the toxic gases from off-gassing and fire.

After a successful suppression discharge, care must be taken when removing the trays. This is since when the chamber is opened, the suppression gas atmosphere will mix with ambient air, and the right design concentration cannot be guaranteed. If sufficient ignition energy is still present, there will always be a risk of reignition of the fire.

For this reason, it may be advisable to leave the affected tray in the chamber for a sufficiently long time, until the cells have cooled down to such an extent that reignition can be largely excluded. Finally, the trays should always be removed safely and transported in a fireproof box.

Checklist

- ☑ Chamber layout (size, presence of flammable material, presence of electrical equipment)
- ☑ Tower layout (number of chambers on top of each other / height / air flow / power supply)
- ☑ Air concept (exhaust air / airtightness / air cooling/ air duct layout / flaps at front and grilled surfaces)
- ☑ Tray (design / size / material / spacing between cells)
- ☑ Water concept (supply and drainage)
- ☑ Power-supply units
- ☑ Stacker crane (purpose, operation, and redundancy)
- ☑ Connection to other systems (danger management, layout, communication standard used, I/O modules)

Operative fire safety

The area of operational or organizational fire protection includes all preventive and post-fire measures that are not of a structural or technical nature. These include:

- Education, training, and instruction
- Creation, updating, and issuing of fire protection policies and regulations
- Appointment of fire protection officers and assistants
- Maintenance and servicing of fire protection equipment
- Marking and keeping escape routes clear
- Handling of successfully suppressed materials after the initial fire event

The term operational and/or organizational points out that it can concern both the operation of the building, and the operation of a company.

This means that the definition also includes the safe handling of affected cells. As written in the previous chapter, after the incident, the affected cells are to be picked using an automatic stacker crane and removed from the affected area. By automating this process, the risks of personal injuries can be pared down to a minimum.

Such a stacker crane should itself be fireproof and have its own fire detection and suppression system (e.g. Sinorix al-deco system from Siemens).

Checklist

Have you covered these questions in your risk analysis?

- ☑ How will you prevent fire outbreak?
- ☑ How will you prevent the spread of smoke and fire?
- ☑ How will you enable short and safe escape routes?
- ☑ How will you keep transportation and access routes freely accessible?
- ☑ What is the purpose of the stacker crane? How will it be used? Redundancy?
- ☑ What will be the fire safety concept for the stacker crane?

Appendix

Cause-and-effect matrix

A cause-and-effect matrix is essential for each project. It is a table structured with the outcome of interest in the center and potential causes organized into categories or themes. The matrix helps to identify and prioritize causes to improve problem-solving and decision-making.
A complete system description is necessary, and post-fire management should be addressed in a separate matrix. The cause-and-effect matrix also describes all necessary fire controls, such as ventilation and damper controls and emergency shutdowns.

Examples of possible fire safety system configurations

The following text describes two possible fire safety configurations for pre-charging and formation towers, that can be used in a planning context. The first example includes an UL/ULC/FM-approved fire panel. This panel can automatically detect fires and send signals to the process control via the gateway, and also communicate with the building fire alarm system.
It is CPR-compliant.

The second example is not CPR-compliant. It uses SIL2-approved fire detectors. These detectors are connected directly to the PLC in a fail-safe mode. If wanted, the PLC can communicate with the building fire alarm system, through a gateway.

Both examples rely on early detection of the off-gassing event with the use of an aspirating smoke detector, placed in the ventilation duct. The first example uses additional multi-criteria point-type detectors to detect the off-gassing event inside the chambers and to localize the fire. The second example uses a smoke detector to localize the fire inside the chamber, at the thermal runaway stage.

Both examples use an automated suppression system, but the control of the extinguishing system will differ. The first example will use an UL/ULC/FM-approved fire control panel, while the second example will be controlled directly by the PLC. Both examples will flood the entire tower with the extinguishing agent in case of a fire, and they will use a natural agent to do so.

Both systems are equipped with alarm beacons to show which tower is under alarm, and manual call points for manual triggering of the suppression system.

Example #1 – NFPA/UL fire safety system configuration (CPR-compliant)

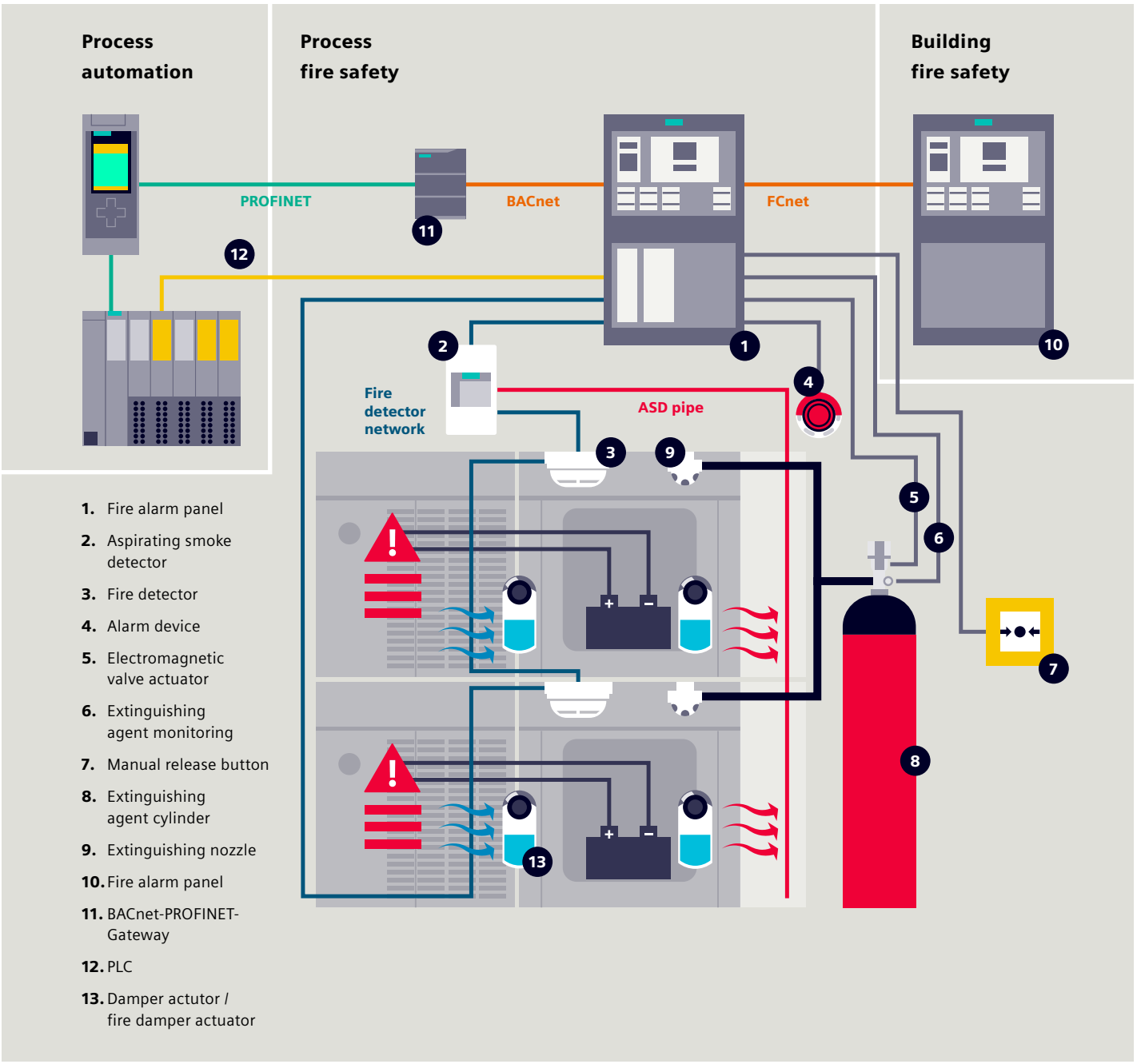


Figure 9:
Example of a possible configuration focusing on fulfilling building safety standards (NFPA/UL/ULC/FM and CPR)

This interface model describes the use of an NFPA/UL-compliant fire panel that automatically detects fires and sends signals through the FDnet. The panel provides safety functions and detailed information about alarms or failures via BACnet and a subsequent gateway to the PLC through PROFINET.

Example #2 – fire safety system configuration (non-CPR-compliant)

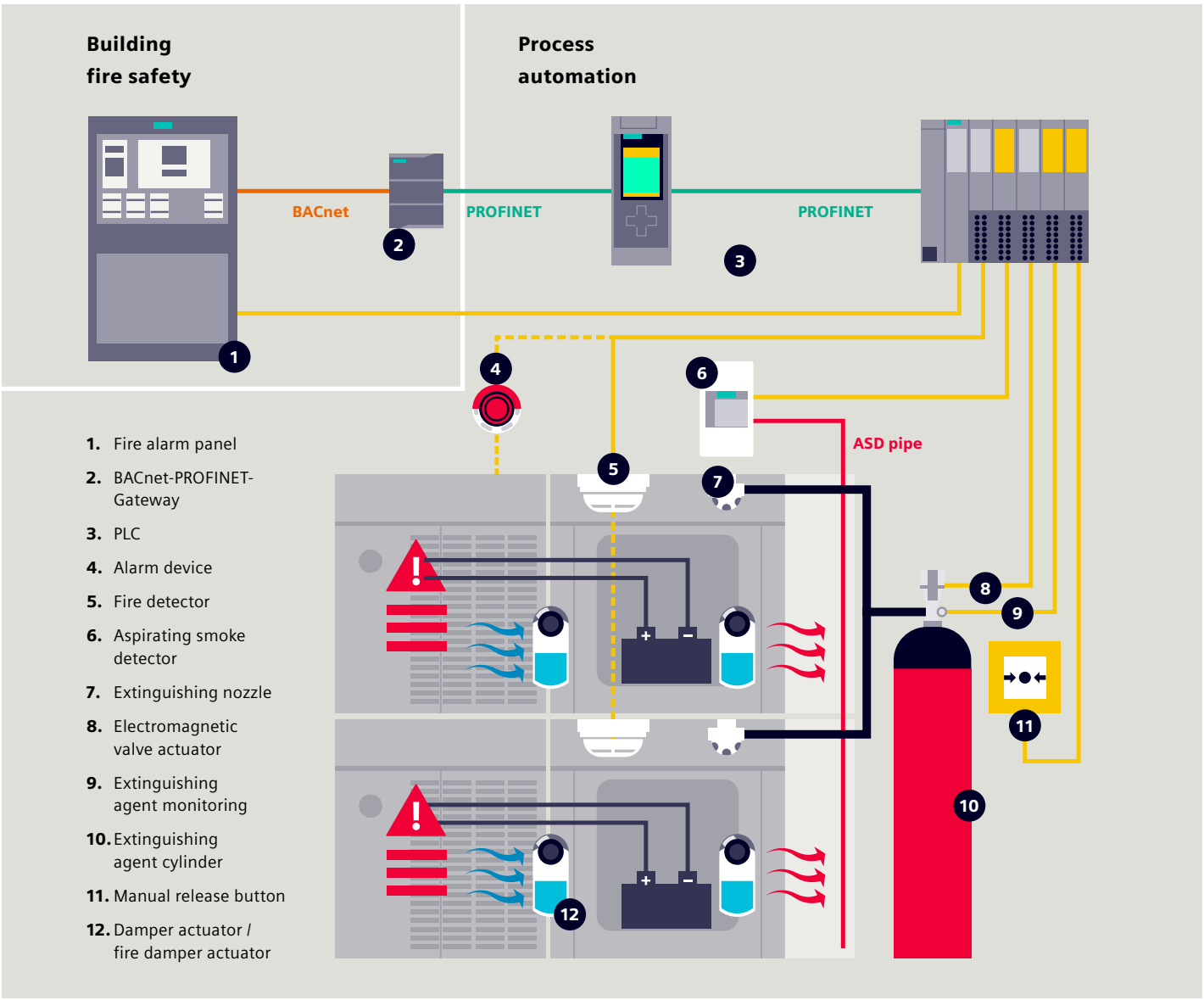


Figure 10:
Example of a possible configuration focusing on fulfilling machinery safety standards such as SIL2

Figure 10 describes the second example of a possible configuration, where the PLC is responsible for providing safety functions and detailed information about alarms or failures through PROFINET, via the SIMATIC PLC, and the gateway to the fire panel.

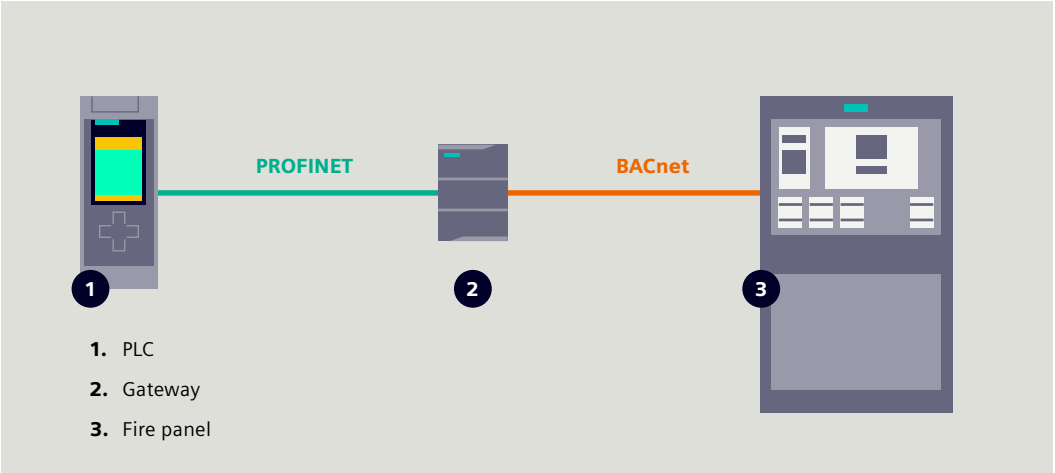
The purpose of this interface model is to use SIL2-approved fire detectors that are connected directly to the PLC in a fail-safe mode. This requires at least two wires to be drawn from each fire detector to the PLC.

For this configuration, FDA221/241, which is SIL2-approved, for early off-gassing detection, in combination with SIL2-approved point-type detectors for the localization of the fire event can be used.

As for the first example, the process control can communicate with the NFPA/UL-approved fire alarm panel via a gateway.

Interface between programmable logic controller and fire panel

Figure 11: Description of how a PLC can communicate via a gateway to a fire control panel



Gateways to connect Fire Panel and PLC

The use of various protocols in industrial environments is common. Gateways ensure interoperability by seamless integration of devices and systems, regardless of their specific communication standards. When systems need to be expanded or updated, and new devices using different protocols are added, gateways enable a gradual migration without the need for a complete replacement of all components for higher fexibility in system updates. Gateways facilitate communication between these different protocols by acting as intermediaries and translating the data accordingly. The use of gateways allows the integration of devices from different manufacturers, bridging the protocol differences. A PLC for process control often uses a specific communication protocol like PROFINET or Modbus for interfacing with external devices, while a fire panel commonly utilizes BACnet.

Specificity for Building Automation, the BACnet (Building Automation and Control Networks) protocol was designed. It provides a standardized method for controlling and monitoring building systems, including fire detection systems. The use of BACnet enables consistent and integrated building automation. By using BACnet in fire panels, the fire detection panel can efficiently communicate and collaborate with other systems.

Modbus is favored in the industry for its simplicity and widespread acceptance, along with its low hardware requirements. It enjoys support from a diverse range of devices and manufacturers. However, it comes with limitations such as a restricted bandwidth and data rate when compared to more modern protocols. Additionally, its origin as a protocol developed for local networks without internet connectivity raises concerns about integrity and security.

PROFINET boasts a high data rate and supports real-time communication. It stands out for its comprehensive diagnostic and monitoring capabilities, as well as flexibility in both topology and network architecture. However, it comes with higher hardware requirements, making it more demanding in terms of configuration complexity. While its superior performance is advantageous, it may not be necessary for all applications.

The choice between Modbus and PROFINET depends on the specific requirements of an application, including speed, flexibility, and diagnostic capabilities. Both protocols have their advantages and disadvantages, making them suitable for different contexts.

Siemens offers gateways for both, BACnet–PROFINET and BACnet–Modbus coupling.

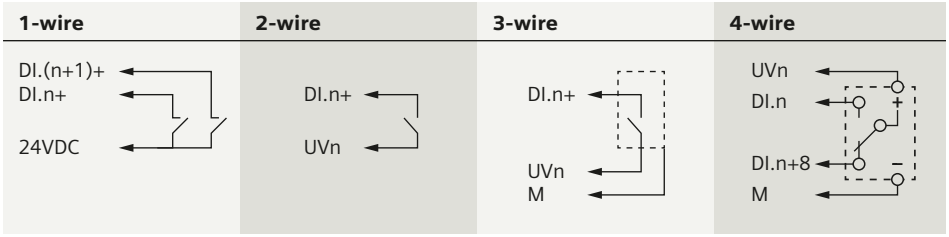


Figure 13:
PLC DI wiring

Figure 13 shows the implementation of digital outputs to achieve increased functional safety in NFPA/UL-certified fire alarm control panels. Digital outputs are used to provide global alarm and fault messages. However, the digital I/Os in fire alarm control panels are not typically certified as fail-safe for machine functional safety. Therefore, the output signals of the fire alarm control panel can be implemented redundantly and antivalent (opposite state signals) depending on the requirements for safety.

Depending on the design of the fire panel outputs and safety requirements, a 2- to 4-wire connection can be made to the PLC (programmable logic controller). Usually, a 2- or 4-wire connection is used.

Short circuit to M: This functionality involves connecting the encoder supply to M (which likely refers to ground or a common reference point), channel by channel. This can help protect against short circuits that might occur in the encoder wiring, again channel by channel.

Further reading!

↗ Talk to a battery expert on our website today!

When using fail-safe F-DI modules, both monitoring for wire breakage and short to ground are realized. Wire-break protection: This is an optional protective circuit that prevents wire-break diagnostics in the case of simple encoder contacts. The circuit has a resistance range of 18 kOhm to 30 kOhm, with a typical value of 26 kOhm. It operates channel by channel, meaning that it can detect wire-break issues in each individual channel of the encoder.

Results of lithium-ion fire tests

Since 2018, extensive testing of lithium-ion battery cells has been conducted at the Siemens International Competence Center in Altenrhein, Switzerland. The purpose of these tests is to provide a foundation for selecting appropriate fire detection and suppression agents for pre-charging and formation equipment.

The testing procedure involves using cells from various international suppliers and abusing them with mechanical breakdown (penetration), external heating, or overcharging.
All three variants of cells (cylindrical, prismatic, and pouch cells) have been tested.

The primary focus of the tests is to evaluate whether Siemens detectors can detect potential off-gassing at an early stage, which is crucial for preventing catastrophic failures. To achieve this, multi-criteria point-type detectors FDOOTC441 / OOHC941 and aspirating smoke detectors (FDA241) are used. During the tests, the test box is flooded with a suppression agent (nitrogen or carbon dioxide) to prevent the formation of explosive oxygen-electrolyte gas mixtures.

The success of the detection test is determined based on whether the off-gassing is detected before the separator breaks down. To evaluate the propagation behavior of thermal runaway, the starting temperature is recorded and documented for later analysis.

Fire behavior of cylindrical, prismatic, and pouch cells

Lithium-ion cells are known to have a potentially dangerous fire behavior. When a lithium-ion cell is exposed to conditions such as physical damage, overcharging, or overheating, it can become thermally unstable and enter a state of thermal runaway, which is a self-sustaining reaction that can cause the temperature of the cell to rapidly rise, leading to a fire or explosion.

Figure 14 below explains the fire circle, and the behavior that all cells go through. However, the time at which each step happens, and for how long it happens, can be influenced by various factors such as the cell chemistry, design, state of charge, and operating conditions. For example, some cell chemistries are more prone to thermal runaway than others, and the size and shape of the cell can also affect its propensity to catch fire.

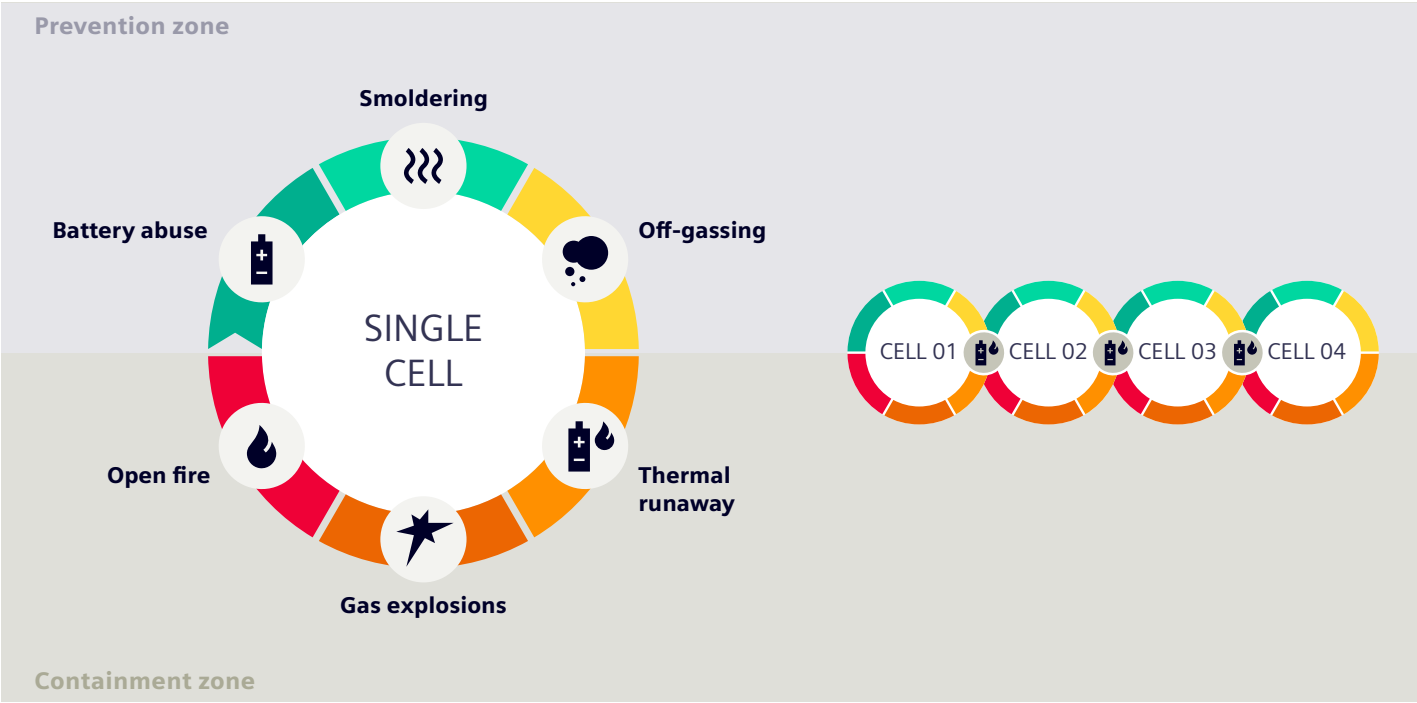


Figure 14:
The fire circle of a lithium-ion battery cell

1. Battery abuse (electrical, mechanical, or thermal)

2. Smoldering (usually only at cells with relevant coating)

In certain cases, smoke may be released before off-gassing occurs, for instance when the battery failure is caused by external heat. In such situations, early detection of smoke can be crucial in initiating timely intervention measures. Conversely, when heat is generated internally due to other failure modes such as overcharging, off-gassing typically occurs before smoke and high external temperatures are observed.

3. Off-gassing

Off-gassing takes place before the separator breaks down, starting with initial venting of the battery cell and increasing during thermal runaway and thereafter. Detecting off-gassing during its initial phase presents the best opportunity for early intervention, if it is detectable.

As the separator breaks down, the temperatures generated by a faulty battery begin to exceed the design limits of the material of construction. This decomposition process leads to the production of smoke due to the high temperatures.

4. Thermal runaway

5. Escalation of the cell temperature

6. Explosion and open fire

With rising temperatures, clouds of flammable gases and larger volumes of smoke, it is highly likely for the situation to escalate into a fire condition, especially when thermal runaway spreads to nearby cells, causing an exponential increase in temperature.

Typical fire behavior for cylindrical cells

Cylindrical cells typically have a smaller fire load compared to prismatic and pouch cells due to their smaller size. When cylindrical cells are packed together to form a module, the contact surfaces between cell to cell are smaller, which limits heat transfer between cells and reduces the risk of propagation from cell to cell. Additionally, cylindrical cells typically have a good safety function for overcharging.

In terms of fire behavior, when a faulty cylindrical cell reaches a critical temperature, it will begin to release potentially flammable gases and smoke. However, the smaller size of the cell means that the volume of released gases and smoke is also smaller compared to larger cells, and the risk of thermal runaway and propagation to adjacent cells is reduced.

Furthermore, cylindrical cells usually exhibit a well-constructed off-gassing behavior, which provides a time buffer between off-gassing and the collapse of the separator, giving an opportunity for early intervention.

Typical fire behavior for prismatic cells

Prismatic cells are typically designed with a well-constructed venting opening to release gas during off-gassing. This feature enables the detection of initial signs of failure with a good safety margin. However, due to their cuboid shape, modules made of prismatic cells are more prone to propagation risks, as the individual cells have potentially larger contact areas.

Typical fire behavior for pouch cells

Pouch cells are a type of lithium-ion battery cell that differ from cylindrical and prismatic cells in that they lack a dedicated vent opening. Instead, these cells can expand to a certain extent to allow for some degree of off-gassing but are designed to burst (often along a seam or deliberate weak spot) to relieve overpressure in a predictable manner and location. However, this design means that the safety margin between off-gassing and separator collapses is generally smaller compared to cylindrical and prismatic cells.

Additionally, the lack of housing in pouch cells results in very high heat transfer in battery modules, making it difficult to prevent thermal runaway propagation within tightly packed cells. The suitability of off-gassing detectors for detecting potential issues depends primarily on the size of the battery cells, the volume of the room being monitored, and the air flow present in that space.

Product selection



Fire detection, for detection in the prevention zone

Multi-sensor fire detector, FDOOTC441 / OOHC941
For early and reliable detection of emerging fire, due to analysis of the three criteria smoke, heat, and gas. Fast response to all carbon monoxide (CO) which is important in detecting lithium-ion battery cell fires and makes it ideal for this application.

Siemens ASD, FDA241
The detector works by continually drawing air into sampling holes in a pipe network. The air is passed into a uniquely designed detection chamber where light scattering technology detects the presence of small amounts of smoke.

Fire detection, for detection in the containment zone

Multi-sensor fire detector, OOH941 / FDOOT441
For the detection of flaming fires caused by the combustion of liquid and solid matters, as well as smoldering fires. For reliable fire detection in environments with deceptive phenomena.

Fire suppression

Sinorix™ NXN
Selecting sustainable products that protect the environment is a vital concern for all of us. Sinorix™ solutions suppress fires almost immediately, minimizing any potential damage. It uses a range of naturally occurring inert agents that are environmentally friendly, offer outstanding properties against all types of fires, and do not leave any residue behind when activated.

Fire control panels

Desigo™ Modular and Cerberus™ Modular fire control systems
The Desigo Modular and Cerberus PRO Modular systems have flexible and scalable panels with integrated operating units that can process signals from up to 2500 intelligent initiating devices (detectors, manual stations, etc.). Each system can support a network of up to 64 panels and can be cloud connecting with Building X for real-time and remote status of all events or alarms.

Damper actuators

OpenAir™ is a comprehensive portfolio of damper actuators tailored to suit different requirements. You will benefit from a wide selection of positioning forces, control signals, communications standards and add-on options. In our Siemens HVAC Integration Tool (HIT), the correct damper actuator can be determined for you based on the damper area and torque as well as other factors.

Damper actuator for HVAC applications
With the self-centering shaft adapter, you will not only minimize installation outlay, but also eliminate mounting errors entirely. Even in challenging locations where space is tight, for example, in false floors, ease of mounting is guaranteed.

The actuators with Modbus RTU offer you even more advantages. They reduce wiring costs and can be easily integrated into existing systems. To determine the correct damper actuator type, we recommend that you use the specification in our Siemens HVAC Integrated Tool (HIT) tool.

Damper actuator for fire and smoke protection dampers
The OpenAir actuators function with reassuring reliability at a sensitive interface between humans and safety systems. After all, in an emergency it's extremely important to keep escape routes and emergency exits free from smoke as long as possible, even if there's a power outage or in special applications.

Powerful and safe opening and closing
Three powerful torque levels from 4 to 18 Nm ensure that the dampers open and close rapidly and reliably. Two integrated auxiliary switches provide maximum safety in reporting the damper position. To determine the correct fire damper actuator type, we recommend that you use the specification in our Siemens HIT tool.

SIMATIC

SIMATIC IOT2050 for PROFINET-Modbus connection
The SIMATIC IOT2050 is the reliable and open platform for the collection, processing, and transmission of data directly in the manufacturing environment. It is ideally suited for use as a gateway between the cloud or the company's IT layer and production.

The openness of the system regarding the support of diverse communication protocols and programming in high-level languages enables customized solutions. Openness for industrial IoT applications includes:

- Diverse possibilities for programming in high-level languages.
- Implementation of flexible communication solutions with various protocols, from Modbus RTU, OPC UA to cloud protocols like MQTT/AMQP.

SIMATIC PROFINET BACnet LINK
The SIMATIC PROFINET BACnet LINK is a gateway that enables communication between PROFINET and BACnet devices, allowing the integration of fire alarm systems into industrial automation systems.

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