IMPLEMENTATION OF THE SAFETY FUNCTION FOR EXPLOSION RISK MANAGEMENT IN BATTERY ROOMS AT PIC BUILDINGS 44–45

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For the past 15 years, Empresarios Agrupados has been part of the ENGAGE consortium, Architect Engineer for Fusion for Energy (F4E), the European Domestic Agency of the ITER project. Within this framework, design, supply, installation, and commissioning activities have been carried out for safety functions associated with the PBS 43 emergency power distribution system. This emergency system incorporates energy sources (diesel generators, UPS systems, DC batteries, etc.) to supply relevant components required to bring the plant to a safe shutdown condition in the event of a power supply failure or blackout. However, these highly safety-significant systems involve the use of battery rooms installed in the redundant Buildings 44 (Train A) and 45 (Train B), which introduces a hydrogen emission explosion risk that must be properly managed.

This article presents a **comprehensive overview of the technical implementation of the safety I&C function** "Ventilation / Prevention of H_2 Accumulation," classified as PIC/SIC-2 Category C and developed at ITER within the scope of F4E under the TB13 contract (a consortium formed by Ansaldo and Monsud).

The purpose of this safety function is to provide the necessary means to mitigate the accidental H_2 explosion scenario. The principle adopted to prevent event initiation consists of maintaining the H_2 concentration in air below the flammability threshold (4% vol.). To achieve this, automatic battery charging disconnection measures are implemented when a concentration of 1% vol. is reached.

This article presents the **regulatory framework, ITER design requirements**, the architecture, and the key systems involved (HVAC, H_2 detectors, and battery charge disconnection circuits), highlighting the importance of the full-loop qualification process that confirms installation reliability and personnel safety.

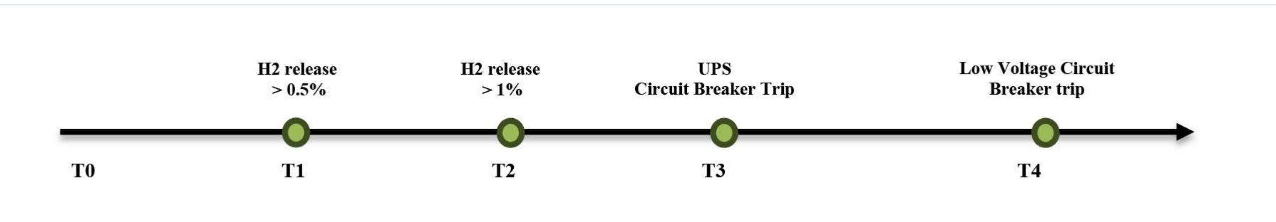

Figure 1. Example of accident scenario – SIC-2 Category C safety function implemented at ITER in the battery rooms of Buildings 44–45.

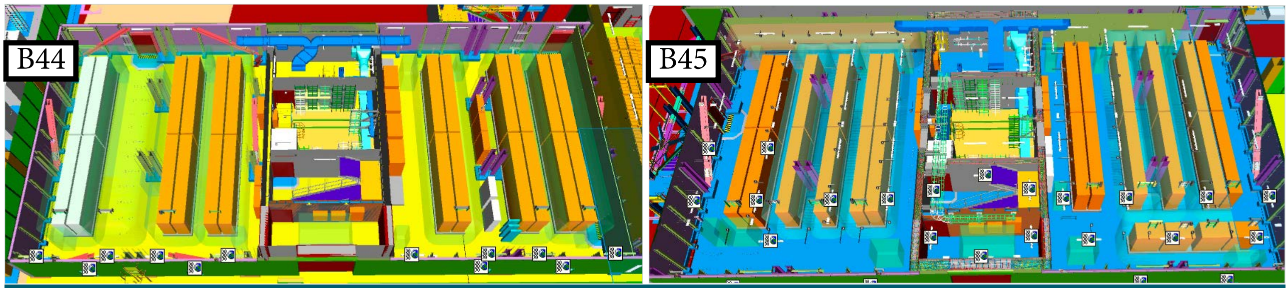

Figure 2. Preliminary view of the battery rooms in Buildings 44–45.

INTRODUCTION

The battery rooms located in Buildings 44 and 45 represent areas of special concern due to hydrogen generation as a by-product of the battery charging process. During normal operation, batteries convert chemical energy into electrical energy, progressively depleting the sulfuric acid electrolyte. To ensure continuous operation, they require charging processes that produce electrolysis, releasing hydrogen and oxygen. When hydrogen concentration in air exceeds 4% by volume, the mixture becomes flammable and therefore constitutes a significant risk to both facility and personnel safety.

In this context, it is essential to implement specific measures to prevent gas accumulation and explosion hazards. The TB13 project includes the implementation of a **safety function for H_2 mitigation** based on technical and regulatory requirements and supported by a global strategy integrating redundant ventilation, hydrogen detectors, battery chargers, fire protection systems, safety controllers, and low-voltage distribution boards.

The objective of this article is to explain how automatic responses to different risk scenarios have been defined and coordinated within the project, including total ventilation loss, detection of critical hydrogen concentrations, and fire events in associated areas. Each situation triggers specific actions, such as immediate interruption of battery charging, with the aim of maintaining risk at acceptable levels and ensuring equipment integrity and personnel safety.

Furthermore, the implemented mitigation solution must also ensure continuous power supply to SIC components for one hour, a safety function classified as SIC-1.

BATTERY CHARACTERISTICS AND APPLIED DESIGN REQUIREMENTS

The ventilation design of the battery rooms must ensure prevention of hazards associated with hydrogen generation during the charging process. Requirements are based on **national regulations, project requirements, applicable industrial codes, and standards**, all converging toward the same objective: maintaining hydrogen concentration at safe levels. The following sections identify mandatory regulatory requirements as well as those defined by the client, the nuclear operator.

The batteries installed in this project are **vented lead-acid batteries**. Each room houses **three banks of 192 cells**, for a total of 576 cells, and includes a **gas recombination system** intended to significantly reduce hydrogen emissions during charging.

Applicable Regulations, Codes, and Industrial Standards

The French Order dated 29/05/2000 concerning classified installations for environmental protection and **NF C15-100** (specifically section 554.2.3) are mandatory requirements. Additional standards such as EN 50272-2, IEEE 484, NUREG-1805, and API-505 establish common criteria. These standards require:

- Installation of hydrogen sensors in affected areas.
- Maximum allowable threshold: **1% H_2 concentration in air (25% of the lower flammability limit)**. Exceeding this threshold must automatically stop battery charging and activate an alarm.
- Ventilation capacity defined as a function of the number of cells, charging current, and battery capacity. In case of insufficient airflow, immediate charger disconnection is required.

Specific Requirements for ITER Proyect

- **System Requirements Document, Preliminary Safety Report & Project Requirements:**

Battery rooms shall be adequately ventilated to limit H_2 concentration. This ventilation system must ensure sufficient air renewal to prevent dangerous H_2 accumulation, incorporating safety devices and guaranteeing the minimum fresh air supply required by applicable codes and good engineering practices.

- **Applicable Nuclear Safety Requirements**

QD0617b: PIC 1-PBS 43-Class II – Safety Distribution. The PBS 43 Class II safety power distribution system shall be capable of supplying uninterrupted, reliable, and regulated AC power to various SIC-1 and SIC-2 plant system equipment requiring uninterrupted AC supply for reliable operation.

QD0618A: Explosions in battery rooms shall be prevented under all design conditions (normal operation, incidents, accidents, including all external hazards), including application of the **single failure criterion**. The battery charging circuit and its control shall be designed such that battery charging can be interrupted to avoid hydrogen production when a concentration above 1% is detected by PBS 63.

- **I&C Safety Function definition.** The requirements can be summarized in the **Table 1**.

Safety Class of the I&C function	Action	Actuating function or signals	Systems generating the function	System performing the function	Safety Class of the I&C function	Comments
PIC/SIC-2 Cat C	Alarm	HVAC not operating	PBS63	PBS43	PIC/SIC-1	The status of HVAC is continuously monitored in these rooms (on/off)
PIC/SIC-2 Cat C	Stop battery charging	1% hydrogen in the room Ventilation stopped	PBS63	PBS43	PIC/SIC-1	Monitoring : - State of H2 detectors (detected/ non detected), - State of charging circuit disconnection means (closed/open), - Activation state of the function for each room (activated/not activated).

Table 1. Building ventilation/prevention of Hydrogen accumulation N-133.

SYSTEMS, EQUIPMENT, AND RESPONSE SCENARIOS

In compliance with the requirements defined in Section 2, the overall strategy for implementation of the safety function is established using the following equipment and response scenarios.

Systems, Equipment, and Architecture

The coordinated integration of various systems enables detection, control, and response to hazardous conditions:

- **HVAC System:** Includes fully redundant extraction fans in each battery room. In addition, two redundant RTUs ensure air supply.
- **Hydrogen Detectors:** Redundant sensor installation in each room, wired to the SIC-2 PSS-N.
- **UPS Chargers:** Essential components of the backup power infrastructure, whose operation must be controlled according to detected safety conditions.
- **Fire Detection System:** Responsible for identifying fire scenarios that could compromise personnel and equipment safety.
- **PSS-N SIC-2:** Safety control system based on a failsafe programmable logic controller managing detection signals and executing required interruption actions, while collecting all SIC-2 classified signals for remote monitoring.
- **Low-Voltage** Distribution Board: Ensures power supply to ventilation, battery, detection, and control systems.

Figure 3 presents a simplified architecture diagram including systems, involved equipment, and interconnections.

Response Scenarios

The hydrogen accumulation mitigation strategy considers several possible scenarios. Depending on the condition, **alarms are generated for operators** and, in more severe cases, battery **charging interruption** of the process.

Ventilation System Failure (HVAC/RTU)

Each room is equipped with **100% redundant extraction fans** monitored through differential pressure supervision. In

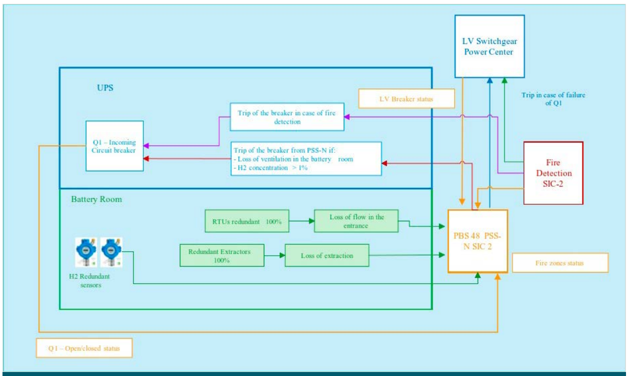

Figure 3. Simplified flow diagram of the implemented architecture.

the event of **abnormal high or low differential pressure**, the system automatically switches to the standby fan and generates an alarm.

If the anomaly persists and also affects the redundant fan, total extraction loss is assumed. In this case, the common air supply to the rooms is interrupted to prevent overpressure, and a ventilation failure alarm is generated. If service is not restored within **2.5 hours***, the system **stops battery charging** by tripping the main UPS breaker and, if necessary, the upstream low-voltage distribution breaker. Logic and execution are performed by the SIC-2 PSS-N PLC. Restart is only possible **manually and locally** after resolving the anomaly.

**2.5 hours corresponds to the time required to reach 1% vol. H_2 concentration without ventilation. This value is implemented as a delay in the PSS-N PLC. This duration is considered safe based on battery float operation conditions and the effect of the Aquagen hydrogen recombination system.*

H_2 Detection at 0.5% (High Alarm)

The rooms are equipped with redundant detectors (1oo2 logic, SIC-2 Cat C classification) continuously monitoring hydrogen concentration. If one detector reaches **0.5% vol. H_2, a high-level alarm** is generated to alert personnel. However, charging is not immediately interrupted, since accumulation studies demonstrate a margin greater than 2.5 hours before reaching 1%. This delay allows preventive operational intervention.

H_2 Detection at 1% (High-High Alarm)

When a detector registers **1% vol. H_2**, the situation is classified as critical. The system emits a **high-high alarm** and immediately commands **interruption of charging in the affected room**. A first trip command is sent to the UPS incoming breaker, followed by a second trip command to the upstream low-voltage distribution board breaker if the first trip fails. Logic and execution are performed by the **SIC-2 PSS-N PLC.**

Subsequently, investigation of the anomaly and restoration of safe conditions are required. Restarting charging requires **manual and local reset** within the building.

Fire Detection

In the event of fire detection, besides immediate alarm transmission to the central system and fire brigade, a command is issued to **interrupt charging of batteries** in the affected room.

The fire protection system acts by opening the UPS main breakers and, if they fail to respond, a second trip command is sent to the upstream low-voltage distribution breaker. The command is executed directly by **the fire alarm control panel.**

As in previous scenarios, charging restart must be performed **manually** once safe conditions are restored.

SAFETY I&C ARCHITECTURE

The architecture of this safety function is based on robust design criteria focused on **maximizing the safety, reliability, and availability** of critical functions. The key principles applied are described below.

Single Failure Criterion

To ensure compliance with the **single failure criterion** established in QD 0618-A, a **redundant architecture** has been implemented in the equipment tripping system. In particular, **two independent signal paths** are defined: one directed to the UPS for opening the main breaker and another directed to the upstream low-voltage distribution board for opening the outgoing breaker.

Failsafe Principle

The **failsafe principle** is applied while ensuring that the architecture prioritizes the SIC-1 safety function (safe emergency power supply from batteries) under any condition in order to comply with QD 0617b. This translates into:

- Normally open contacts.
- Signal energization only when the safety command is activated.

In addition, this configuration, based on the use of shunt trip coils instead of undervoltage coils, avoids the need for permanent energization of the auxiliary relay and also includes auxiliary contacts ensuring feedback information regarding the status of the main breaker.

Defense in Depth

The system applies a two-layer protection scheme:

First layer: direct opening of the UPS main breaker in the event of fire or ventilation loss in the battery room.

Second layer (backup): if opening of the main breaker fails, the PSS-N PLC or the fire detection system also commands the opening of the upstream breaker in the distribution board. This ensures interruption of battery charging even if the first protection barrier fails.

Hardwired Architecture

A hardwired architecture has been selected, avoiding dependence on communication networks for critical safety functions. The core of the system is implemented using **Siemens S7-400 F/FH safety PLCs**, recognized for their robustness in nuclear and safety applications and capable of operating in fault-tolerant and high-availability modes.

Environmental Conditions and Qualification

All equipment involved in the control loop has undergone

Scenario	Detection / Event	Automatic Action	Operator Action	Recovery
Ventilation Failure (HVAC/ RTU)	Extraction fan anomaly or failure of both RTUs	- Activation of standby fan (if applicable) - After 2.5 h without recovery → interruption of battery charging	Investigation and correction of the ventilation failure	Manual local reconnection of battery charging
High H_2 Alarm	0.5% concentration detected by one sensor (1oo2)	- Hydrogen alarm issued (High). - Charging is not interrupted	Immediate investigation of the cause and corrective action	No action required: normal operation maintained
High-High H_2 Alarm	1% concentration detected by one sensor (1oo2)	- H_2 alarm issued (High-High). - Automatic interruption of battery charging	Investigation and resolution of the anomaly	Manual local reconnection after concentration normalization
Fire Detection	Detection inside the battery room	- Alarm transmission to CSS and fire brigade. - Automatic interruption of battery charging	Investigation and resolution of the incident	Manual local reconnection after restoration of safe conditions

Table 2. Summary of Scenarios and Planned Actions.

a complete qualification process in accordance with **IEC 61513 and RCC-E 2016**, ensuring system operation under specific environmental conditions, including temperature, humidity, seismic events, and EMC. This guarantees that the **system is fully qualified and certified for safe operation**.

CONCLUSIONS

- The implementation of the **"ventilation and hydrogen accumulation prevention"** safety function in the battery rooms of Buildings 44 and 45 constitutes an essential element for explosion risk management within the ITER project framework.
- The adopted strategy integrates early detection, redundant ventilation, and automatic battery charging disconnection, complying with international regulations and nuclear safety criteria in a highly sensitive and regulated environment such as ITER.
- The design follows the principles of defense in depth, redundancy, and environmental qualification, ensuring that the system responds safely even under single failure scenarios or extreme conditions.
- Interface management is essential. Coordination among subsystems (HVAC, H_2 detectors, UPS chargers, PSS-N, fire protection systems, and low-voltage distribution boards) ensures the robustness of the safety function and minimizes risks to facilities and personnel.
- The hardwired architecture, based on safety PLCs and failsafe protocols, provides a reliable and highly available solution suitable for long-term operation in a nuclear environment.

Overall, the developed system establishes a replicable reference framework for critical facilities exposed to hydrogen generation risks, providing lessons learned applicable to other industrial and energy sectors.

ACRONYMS

[1] **CSS** → Central Safety System

[2] **F4E** → Fusion for Energy

[3] **HVAC** → Heating, Ventilation and Air Conditioning

[4] **ITER** → International Thermonuclear Experimental Reactor

[5] **PBS** → Plant Breakdown Structure

[6] **PIC** → Protection Important Component

[7] **PLC** → Programmable Logic Controller

[8] **PSS-N** → Plant Safety System – Nuclear

[9] **RTU** → Remote Terminal Unit

[10] **SIC*** → Safety Important Component

[11] **SSC** → Structures, Systems and Components

[12] **UPS** → Uninterruptible Power Supply

**Clarification note:*

SIC-1 SSCs *are those required to bring ITER to and maintain it in a safe state.*

SIC-2 SSCs *are those used to prevent, detect, or mitigate incidents or accidents, but are not classified as SIC-1 (they are not required for ITER to reach a safe state).*

Category C *according to IEC 61226 denotes functions that perform an auxiliary or indirect role in achieving or maintaining nuclear plant safety.*

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ACKNOWLEDGEMENTS

Special thanks are extended to the **Sociedad Nuclear Española (SNE)** for the opportunity to present this work within the framework of its technical conferences.

Acknowledgement is also given to **Fusion for Energy (F4E)** and **ITER** for the opportunity and trust placed in the activities developed by **Empresarios Agrupados** within the scope of the presented safety function activities.

Special thanks to **my family**, my children **Isabel and Francisco**, and my husband **Francisco**, for their constant encouragement and support.