Dipartimento dei Vigili del Fuoco, del Soccorso Pubblico e della Difesa Civile
CORPO NAZIONALE DEI VIGILI DEL FUOCO
Central Directorate for Fire Prevention and Technical Safety

ANALYSIS AND COMPARISON OF HYDROGEN GENERATORS SAFETY MEASURES ACCORDING TO INTERNATIONAL REGULATIONS, CODES AND STANDARDS (RCS)

ID 235

Mazzaro M., Moretti J., Ceccherini C. , Russo P., Lucci A.

Eng. Eros Mannino

Chief of Central Directorate for Fire Prevention and Technical Safety

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Overview of the Italian National Fire and Rescue Service

Assure Urgent Techinal Rescue

National Fire and Rescue Service

Technical Fire Prevention Regulation

- **The National Fire and Rescue Service** ***(Corpo Nazionale dei Vigili del Fuoco - CNVVF)*** is the Ministry of the Interior arm to:
  - **provide emergency technical rescue** and assistance to the public
  - **protect the safety and integrity of all the living and precious non living things present in the territory**

- **Fire prevention technical regulation** is the overriding public interest function intended to:
  - achieve the safety of human life, protect property and environment
  - promote study, tests, standards, devices and modes of action aiming at preventing or limiting the occurrence of a fire and its connected consequences

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Paper submitted introduction

- Climate change has prompted the international community to invest heavily in renewable energy sources in order to gradually replace fossil fuels. Whilst energy systems will be increasingly based on non-programmable renewable sources, **hydrogen is the main player when it comes to the role of energy reserve.**

- This change has triggered a fast development of hydrogen production technologies, with **increasing use and installation of hydrogen generators (electrolyzers) in both the civil and industrial sector.**

- The implementation of **such investments requires the need for accurate design and verification of hydrogen systems, with particular attention on fire safety**. Due to its chemical-physical characteristics, hydrogen is highly flammable and is often stored at very high-pressure levels.

- **ISO 22734 and NFPA 2 are the main international standards which are currently available for the design of hydrogen generators and systems**, both of which include fire safety requirements.

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Paper submitted introduction

- **The paper submitted analyses the main existing Regulations, Codes and Standards (RCS)** for hydrogen generators with the purpose of evaluating and comparing fire safety measures, **with focus on both active protection** (detection systems, extinguishing systems) **and passive protection** (safety distances, separation walls).

- **The scope of the paper is to identify safety measures which can be considered generally applicable and provide a reference for further fire safety regulations.**

- The analysis carried out identifies potential gaps in RCS and suggests areas for potential future research.

Hydrogen generators: main hazards

- **Electrolyzers are devices that produce hydrogen through electrolysis, a chemical process that uses electricity to separate water molecules into hydrogen and oxygen atoms.** The produced hydrogen can be stored as **GH2** or **LH2** and can be used in different appliances within industrial or automotive appliances (fuel cells can power transport vehicles).

- Hydrogen, as well as any other flammable gas, needs an oxidizer and a source of ignition to cause a fire or an explosion. Considering that hydrogen/oxidizer mixtures need a very low energy level to ignite and that air is a largely available oxidizer for standard applications,

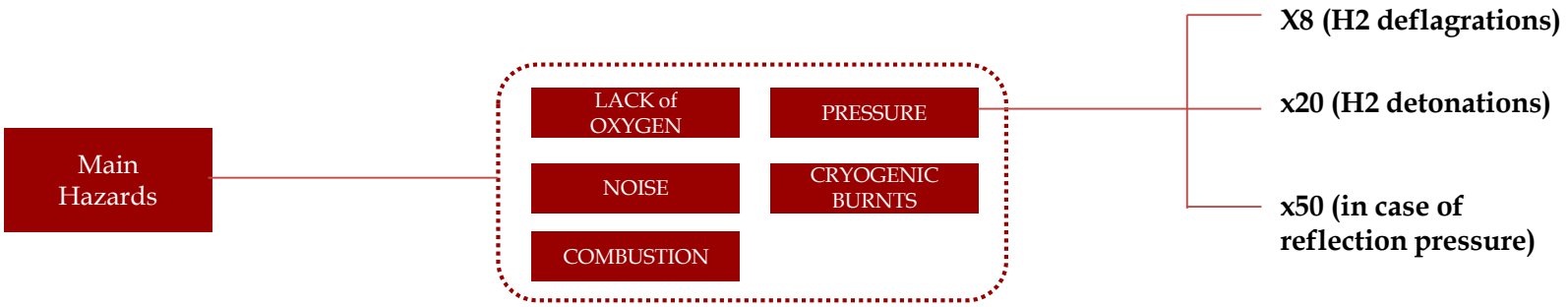
  => prevention is the most reliable method for hazard reduction.

Separation of hydrogen from the oxidizers is the primary explosion protection measure.

Hydrogen generators: main hazards

- **In addition, hydrogen production systems have further specific risks related to the possibility of directly producing hydrogen-oxidizer mixtures in case of failure** (with mechanical and chemical related risks). This can lead to an uncontrolled combustion of hydrogen and high-energy releases that can develop as a fire (non-premixed combustion) or an explosion (deflagration and detonation).

- **For hydrogen-air mixtures, deflagrations can produce pressures up to 8 times the initial pressure, detonations up to 20 times the initial pressure (but for shorter durations) and with reflection pressures can reach up to 50 times the initial pressure.**



Regulations, Codes and Standards (RCS) for H2 generators

- **There are several hydrogen production technologies, mostly developed since 20th century, and technical standards for systems and components dealing with hydrogen** that have been issued for decades, both by internationally recognized standardization bodies and by private entities.

- The fast development of hydrogen production technology and research has led to the development of innovative systems that in many cases are not covered by existing RCS. As a result, **manufacturers and installers of hydrogen systems often need to design their systems by analogies or conduct in-depth analyses in order to place them on the market**.

- **In the paper, among many existing RCS, it has been chosen to focus on the most widely used ones in industrial and fuel cells applications which contain safety recommendations**; this doesn't exclude the possibility that further useful guidance can be found in other existing RCS.

- **Safety measures have been compared to assess whether and how the analyzed RCS differ.**

Regulations, Codes and Standards (RCS) for H2 generators

RCS that have been analyzed in this paper are:

- **ISO 22734 "Hydrogen generators using water electrolysis - Industrial, commercial, and residential applications"**; it establishes criteria for the construction, safety and performance of hydrogen generators by electrolysis, and it mainly covers electrolyzers and auxiliary equipment (fans, pumps, heat exchangers, compressors, etc.) but it doesn't include other plant elements such as storages and dispensing or LH2 equipment;
- **NFPA 2 "Hydrogen Technologies Code"**; specifies safety measures for the generation, installation, storage, and distribution of GH2 and LH2, including dispensing;
- **Health and Safety Executive "Installation permitting guidance for hydrogen and fuel cell stationary applications"** (hereafter referred to as **HSE IPG**); it provides best practices for the installation of hydrogen systems, including fuel cells, giving guidance on the main preventive and protective measures to be provided;
- **CAN/BNQ 1784-000/2022 "Canadian Hydrogen Installation Code"**: it provides guidance on the installation of hydrogen generators, dispensing, storage and piping, and it applies to both GH2 and LH2;
- **FM Global Property Loss Prevention Data Sheet 7-91 "Hydrogen" (hereafter referred to as FM GLOBAL DS 7-91**); it includes measures for both GH2 and LH2 storage and dispensing systems, but it doesn't include electrolyzers.

The analysis has been limited to common and directly comparable aspects.

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Active protection measures comparison

Active Protection Measures

	ISO 22734	NFPA 2	HSE IPG	CAN/BNQ 1784-000	FM GLOBAL DS 7-91
Hydrogen detectors	According to manufacturer's risk assessment	For hydrogen generator	Yes	In indoor areas	In indoor areas (if hydrogen cylinders are not installed in gas cabinets)
Fire Detectors	–	For hydrogen generator	For hydrogen generator	For indoor storage	–
Fire Alarm	–	Manual	For hydrogen generator	Yes	–
Emergency Stop Device (ESD)	Start at: 50% LEL, ventilation malfunction	Start at: 25% LEL, fire alarm, ventilation malfunction, ESD activation	Start at: 10% LEL, ventilation malfunction	Start at 40% LEL	Start at 25% LEL, release in dispensing areas
Automatic extinguishing systems	–	Sprinkler for hazardous occupancies	Water spray for storage, grouped piping and pumps	Water spray	Sprinkler for dispensing areas and HEE
Fire Hydrants	–	–	–	–	Yes

Common Aspects

- All cases include **Hydrogen detection sensors** and an emergency stop device: however, the "inputs" for activating the Emergency Stop Device (ESD) are different and differ from case to case
- In most cases **a fire extinguishing system** is provided with the main purpose of ensuring cooling of the system elements

Main Differences

- **Flame and smoke detection systems are not always provided**
- **Only the FM GLOBAL document requires a hydrant network**

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Passive protection measures comparison

Passive Protection Measures

	ISO 22734	NFPA 2	HSE IPG	CAN/BNQ 1784-000	FM GLOBAL DS 7-91
Fire Reaction	Enclosure and insulating materials with proper flammability classification	Hydrogen Equipment Enclosures of non-combustible materials	Vessel supports of non-combustible material	Hydrogen rooms of non-combustible material	Hydrogen Equipment Enclosures and storage support in non-combustible building
Fire Resistance	–	From 30 to 120 minutes	30 minutes for Hydrogen Equipment Enclosures	120 minutes for indoor storage	120 minutes for Hydrogen Equipment Enclosures and storage supports
Separation Distances	–	From 0 to 68 m	T.B.D. case-by-case	From 0 to 5 m	From 4,6 to 30 m
Fire Barriers	–	From 30 to 120 minutes to reduce separation distances	Bast walls	120 minutes to reduce separation distances	–

Common Aspects

- **All cases provide "adequate" Fire Reaction measures** without providing further references
- **Fire Resistance measures are provided mainly** with reference to the characteristics provided for the **separation barriers** assumed to reduce safety distances

Main Differences

- **Safety Distances have wide ranges of values**
- **The range of values provided for Fire Resistance measurements is wide**

Preventive measures comparison

Preventive measures comparison					
	ISO 22734 [1]	NFPA 2 [2]	HSE IPG [3]	CAN/BNQ 1784-000 [4]	FM GLOBAL DS 7-91 [5]
Area classification	According to IEC 60079-10-1	According to NFPA 69	According to IEC 60079-10-1	According to IEC 60079-10-1	According to Data Sheet 5-1
Ventilation	Natural or mechanical	Mechanical for HEE	Natural or mechanical	Natural or mechanical	Mechanical
Materials	Suitable for hydrogen (ref. ISO/TR 15916 ISO 11114-4)	According to ASME B31.12	Suitable for hydrogen	According to ASME B31.12 and ISO/TR 15916	-

- Given the ease of ignition of hydrogen/oxidizing mixtures, it is essential to rely on preventive measures to avoid accidents. **The most effective preventive measure is to avoid and reduce the formation of explosive atmospheres (ATEX),** where international standards and directives apply. An explosive atmospheres risk assessment is a fundamental requirement in these kinds of installations

- **Among other preventive measures which may be effective in preventing the formation of explosive atmospheres, the main one is natural or mechanical ventilation**, to ensure that hydrogen concentrations above LFL are not reached in closed areas.

- **Materials subjected to high stresses and temperatures and exposed to contact with hydrogen are subject to hydrogen embrittlement, which is an increased susceptibility to corrosion, and which causes a decrease in the strength and ductility of metals.** Embrittlement can manifest in various ways, such as blistering, cracking, hydride formation, and reduced ductility. This phenomenon is well known and typical of hydrogen applications and must be taken into account in materials choice for piping and vessel.

Conclusions

In this paper, **hydrogen production systems and facilities RCS have been analyzed and compared in order to highlight their common active and passive protection systems and their main differences.**

Comparing the analyzed RCS, **some measures are always provided and can therefore be considered standard for these types of plants, regardless of the electrolyzer technology and the characteristics of the specific project (hydrogen quantities, pressures, process, etc.). These common measures are:**

–hydrogen detection

–Emergency Shutdown System

–sprinklers to protect hydrogen-containing vessels

–materials fire reaction properties

–fire resistance of HEE

–vessel supports, separation distances from storages

–hazardous area classification

–ventilation.

There are further measures that are provided only by some RCS that can be evaluated by designers. These measures are: smoke and flame detectors, fire hydrant network, fire barriers.

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Thank you for your attention