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Zone Negligible Extent: Example of specific detailed risk assessment for low pressure equipment in a Hydrogen Refuelling Station

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Safety and Permitting for Hydrogen at Multifuel Retail

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"(…) lack of guidelines and instructions for local authorities can cause **delays**, **extra costs** and **divergent interpretations** from case-to-case, further complicating the obligations of HRS operators."
2018, https://www.hylaw.eu/

Definition of **commonly applicable, effective, and evidence-based guidelines** to facilitate the construction of HRS in multi-fuel refuelling stations through

- Identification of relevant gaps in the current legal and administrative framework;
- Acquisition of experimental data from engineering research;
- Active engagement with a community of stakeholders in the overall process.

Hydrogen Europe
Air Liquide creative oxygen
BESPOKE RESEARCH AND CONSULTANCY FROM HSE
INERIS maîtriser le risque pour un développement durable
ENGIE Lab CRIGEN
ITM POWER Energy Storage | Clean Fuel
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snam
Shell Hydrogen
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MultHyFuel Project

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WP6 – Project management

WP1 - Detailed investigation of current status

- T1.1 Definition of scope for regulatory analysis (Cross-country research framework)
- T1.2 Research into permitting requirements and public guidance on required risk assessments
- T1.3 Comparative assessment and gap analysis

WP2 - Practical research to address gaps in current understanding

- T2.1 Leakage characterisation of H2 dispensers
  - Task 2.1.1 Leakage characteristics
  - Task 2.1.2 Dispersion characteristics
  - Task 2.1.3 Ignition probabilities
  - Task 2.1.4 Efficiency of safety barrier
- T2.2 Fire and explosion hazards
  - Task 2.2.1: Defining a zoning threshold
  - Task 2.2.2 Domino effect arising from faults on hydrogen dispensers
  - Task 2.2.3 Vulnerability of hydrogen dispensers to incidents involving other fuel dispensers

WP3 - Generate best practice guidance

- T3.1 State of the art of technology
- T3.2 State of the art on risk assessment methodologies
- T3.3 Preliminary risk analysis
- T3.4 Detailed risk assessment
- T3.5 Identification of critical scenarios
- T3.6 Risk assessment review of critical scenarios & hazardous areas
- T3.7 Best practice guidelines redaction

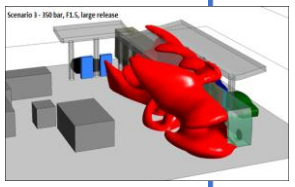
WP4 – Engagement

- T4.1 Establishment of the Network
- T4.2 Inception phase
- T4.3 Workshop on state of the art and case study models
- T4.4 Workshop on refined case study models and WP2 methodology
- T4.5 Workshop on results of WP2 and WP3
- T4.6 Workshop on development of best practice guidance
- T4.7 Meeting on adoption of best practice guidance (WP3)

WP5 - Dissemination, Communication and exploitation

Paper ID219

Paper ID252



Paper ID263

This paper

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Objectives – Hazardous Area Classification

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Main objective (WP3): To develop best practice guidelines that can be used as a common approach to risk assessment, addressing the safe design for hydrogen refueling stations in a MultiFuel context:

- Hazardous area classification area around H_2 dispenser

Propose harmonized guidance, including experimental measurement and aiming to address knowledge gaps or differences in approaches taken within Europe

The aim of this work is to consider whether it is appropriate to classify low pressure releases* in enclosures within a Hydrogen Refuelling Station as Zones of Negligible Extent (NE).

IEC 60079-10-1:2020 defines a Zone NE as follows:

Such a zone implies that an explosion, if it takes place, will have negligible consequences. The zone NE concept can be applied irrespective of any other adjustments for risk assessment to determine EPL.

The criteria for a zone NE classification should be based on the following factors:

i) Ignition would not result in sufficient pressure to cause harm either due to the pressure wave or due to damage that could cause flying objects or particles e.g. broken glass from windows.

ii) Ignition would not result in sufficient heat to cause harm or a fire from surrounding materials.

iii) For gas distributed at pressures above 1 000 kPag (10 barg) consideration shall be given to a specific risk assessment

iv) A zone NE shall not be applied to gas distributed at pressures above 2 000 kPag (20 barg) unless a specific detailed risk assessment can document otherwise.

*Low pressure in comparison to the dispensing pressures (700 barg or 350 barg)

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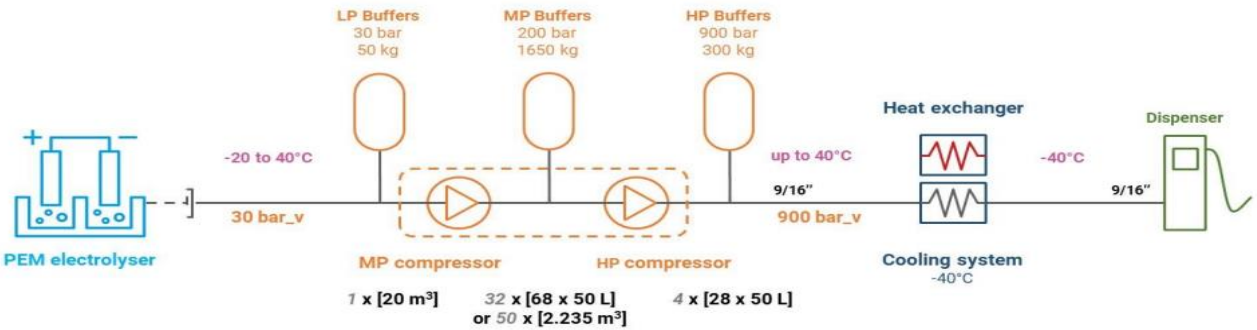
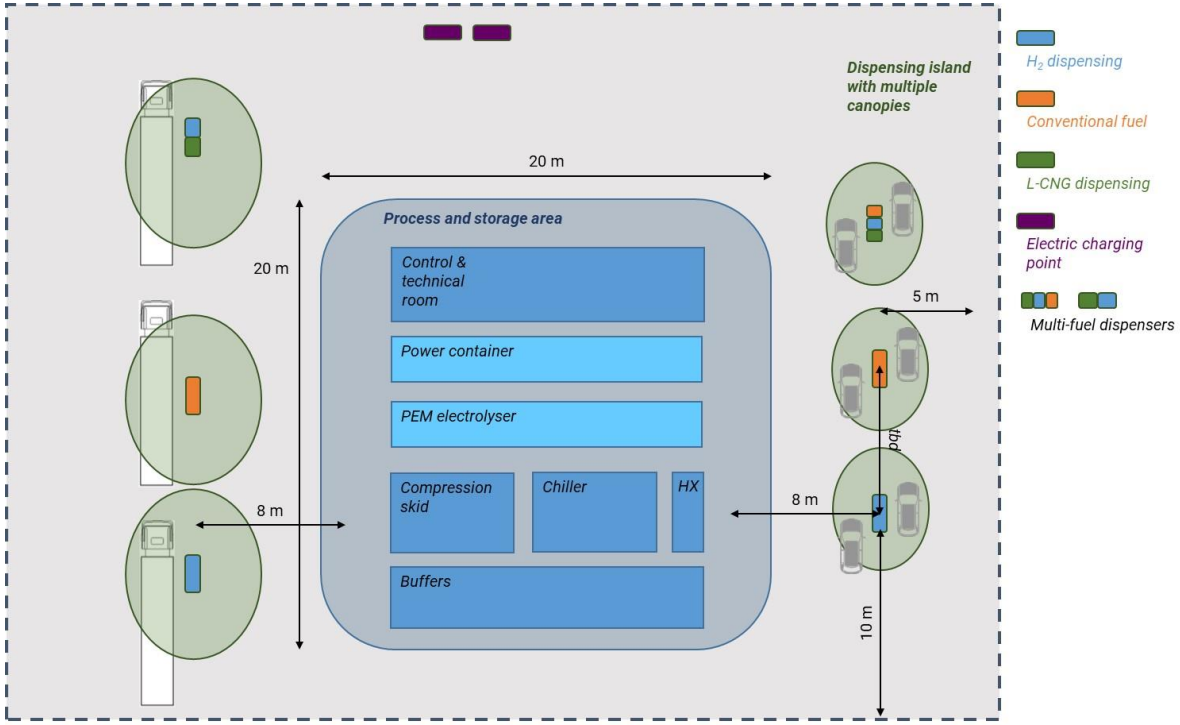
Configuration 2

Three configurations/case studies have been analyzed in the project. Only the configuration “on-site” production is detailed in this presentation

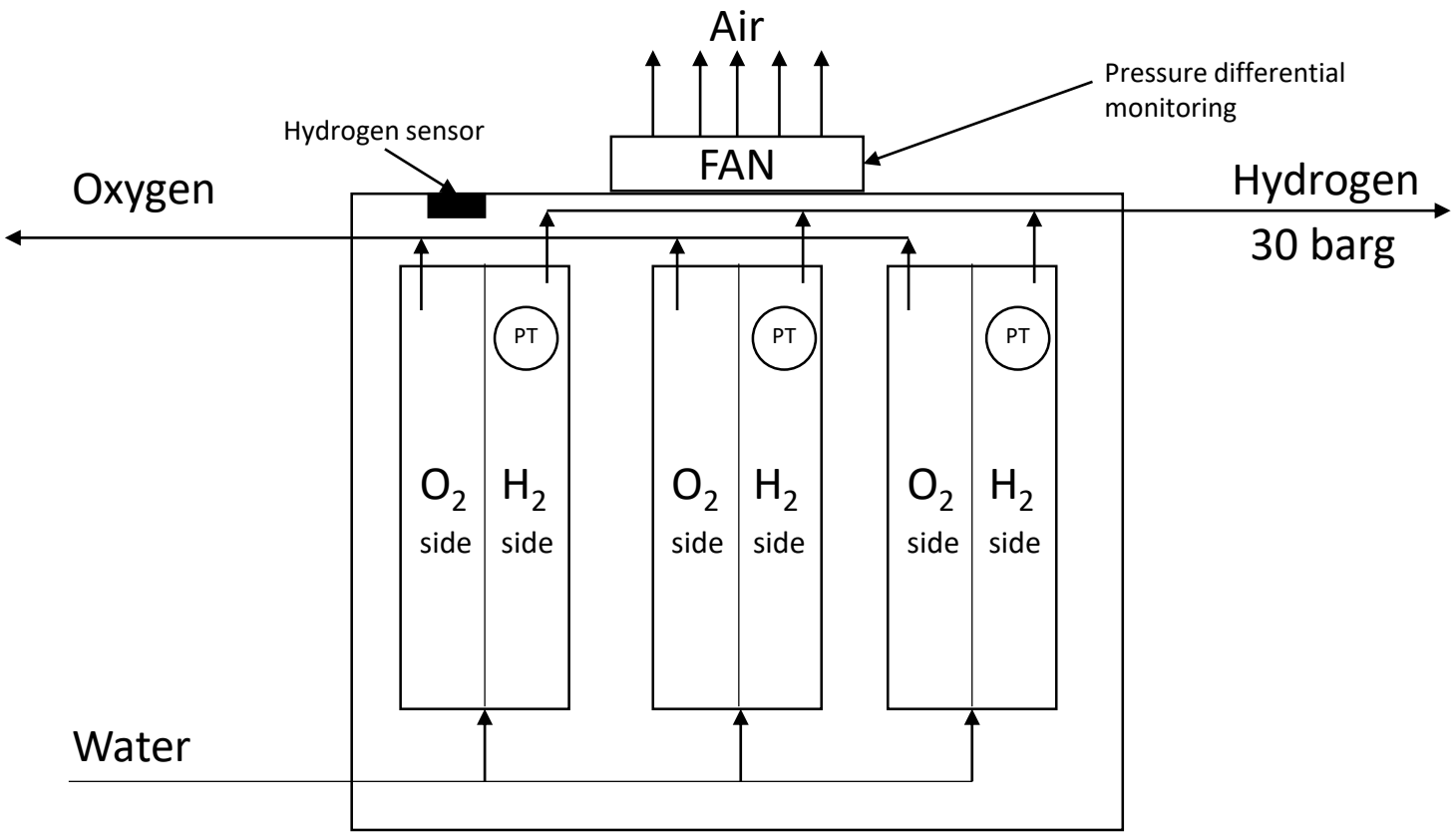


An example of a “on-site” production hydrogen refuelling station was proposed for the risk assessment. The example does not represent a suggested configuration of a HRS.

- **H_2 sourcing**
  - On-site gaseous H_2 production
    - PEM Electrolysis (30 barg)
- **H_2 storage – inventory 2 t-H_2**
  - Compression from 30 bar to 200 bar or more
  - Stationary H_2 high pressure storage
- **H_2 dispensing**
  - "Classic" dual & Multi-fuel dispenser for cars - **Multiple canopies** on the forecourt to protect islands
    - For car – pressure: 700 bar, maximum flow rate: 60 $g.s^{-1}$
    - For buses and heavy duty vehicles – pressure 350 bar, maximum flow rate: 120 $g.s^{-1}$



Example – Enclosure in an Electrolyser

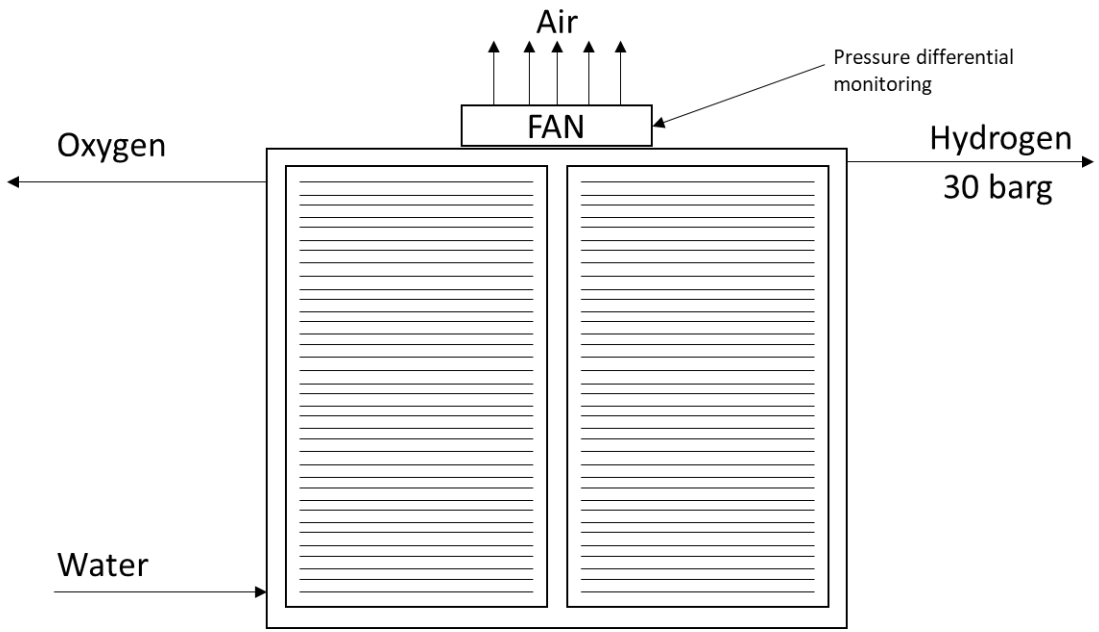


Generator description (Example)

- Hydrogen (@30 barg) is produced in the generator by water electrolysis. The stacks are placed in a room with a free volume of 10 m^3.
- The room has artificial ventilation (extraction fan) on the roof. It is assumed that the minimum flow rate in the vertical direction is 1.5 m^3/s and the predominant direction of flow is from to bottom to top*. The area perpendicular to the floor is 3.4 m^2 (assuming 3 meters height).
- Walls of the room have sufficient air inlets to allow sufficient air flow.
- Operators cannot access the room when the system is pressurized.

* This is a simplification for the analysis, however, a detailed analysis (measurements, CFD, etc) should be considered to determine the flow pattern inside the enclosure, considering the area and position of the openings, together with obstructions in the room. In addition, dead volumes should be estimated and considered within the analysis.

Example – Enclosure in an Electrolyser



- The enclosure have two doors on one of the walls. It is estimated that the doors cover approximately 80% of the area of that side.
- The entire surface of the doors have louvres to promote the ventilation. (50% of the area would be open).
- All hydrogen piping is facing the louvres. No fittings are placed in front of the solid wall, roof or corners.

Generator description (Example)

- Gas sensor warning at 10 % LFL and alarm/shutdown at 25% LFL. Shutdown initiates depressurization of the system and removal of energy to the stacks.
- Fan flow monitored by pressure differential – if pressure differential correlates to a flow below 1.5 m^3/s, shutdown is performed.
- Interlock to the doors of the room generates shutdown* of the system.
- Pressure monitoring in the hydrogen system, generating alarm/shutdown in case of Low-Low pressure.
- Automatic pressure drop test performed to the system in order to detect leaks in the system.

Hole selection

- Hole size justification for the electrolyser enclosure example:
  - Pressure assemblies tested (pressure and leak test). After installation on site, pressurised hydrogen system will not be moved.
  - No moving parts in this enclosure: actuated valves for operation/shutdown outside the enclosure. No vibratory equipment
  - In operation, automatic pressure drop test just after pressurisation and after a period of time if continuous operation.
  - Small bore fittings (12 to 25 mm OD).
  - Operational pressure well below rated pressure of fittings and pipework: rated pressures ranging between 160 and 400 barg.
  - Hydrogen sensor (part of the Safety Instrumented System), generating shutdown if 25% LFL is measured by the instrument

Control systems according to a Functional Safety standard may reduce the potential for a source of release and/or the quantity of a release (e.g. batch sequence controls, inerting systems). Such controls may therefore be considered where relevant to the hazardous area classification.

Type of item	Item	Leak Considerations		
		Typical values for the conditions at which the release opening will not expand	Typical values for the conditions at which the release opening may expand, e.g. erosion	Typical values for the conditions at which the release opening may expand up to a severe failure, e.g. blow out
		S (mm²)	S (mm²)	S (mm²)
Sealing elements on fixed parts	Flanges with compressed fibre gasket or similar	≥ 0,025 up to 0,25	> 0,25 up to 2,5	(sector between two bolts) x (gasket thickness) usually ≥ 1 mm
	Flanges with spiral wound gasket or similar	0,025	0,25	(sector between two bolts) x (gasket thickness) usually ≥ 0,5 mm
	Ring type joint connections	0,1	0,25	0,5
	Small bore connections up to 50 mm[a]	≥ 0,025 up to 0,1	> 0,1 up to 0,25	1,0
Sealing elements on moving parts at low speed	Valve stem packings	0,25	2,5	To be defined according to Equipment Manufacturer's Data but not less than 2,5 mm² [d]
	Pressure relief valves[b]	0,1 x (orifice section)	NA	NA
Sealing elements on moving parts at high speed	Pumps and compressors[c]	NA	≥ 1 up to 5	To be defined according to Equipment Manufacturer's Data and/or Process Unit Configuration but not less than 5 mm² [d and e]

[a] Hole cross sections suggested for ring joints, threaded connections, compression joints (e.g. metallic compression fittings) and rapid joints on small bore piping.

[b] This item does not refer to full opening of the valve but to various leaks due to malfunction of the valve components. Specific applications could require a hole cross section bigger than suggested.

[c] Reciprocating Compressors – The frame of compressor and the cylinders are usually not items that leak but the piston rod packings and various pipe connections in the process system.

[d] Equipment Manufacturer's Data – Cooperation with equipment's manufacturer is required to assess the effects in case of an expected failure (e.g. the availability of a drawing with details relevant to sealing devices).

[e] Process Unit Configuration – In certain circumstances (e.g. a preliminary study), an operational analysis to define the maximum accepted release rate of flammable substance may compensate lack of equipment manufacturer's data.

NOTE Other typical values or guidance on erosion and failure conditions may also be found in national or industry codes relevant to specific applications.

Area Classification – IEC 60079-10-1:2020

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Determination of mass release rate from hole size at T, P of the gas

$$W_g = C_d\, S\, p \sqrt{\gamma \frac{M}{Z\,R\,T}\left(\frac{2}{\gamma+1}\right)^{(\gamma+1)/(\gamma-1)}} \quad \text{(kg/s)}$$

Determination of gas density and characteristic volumetric gas release (Q_c)

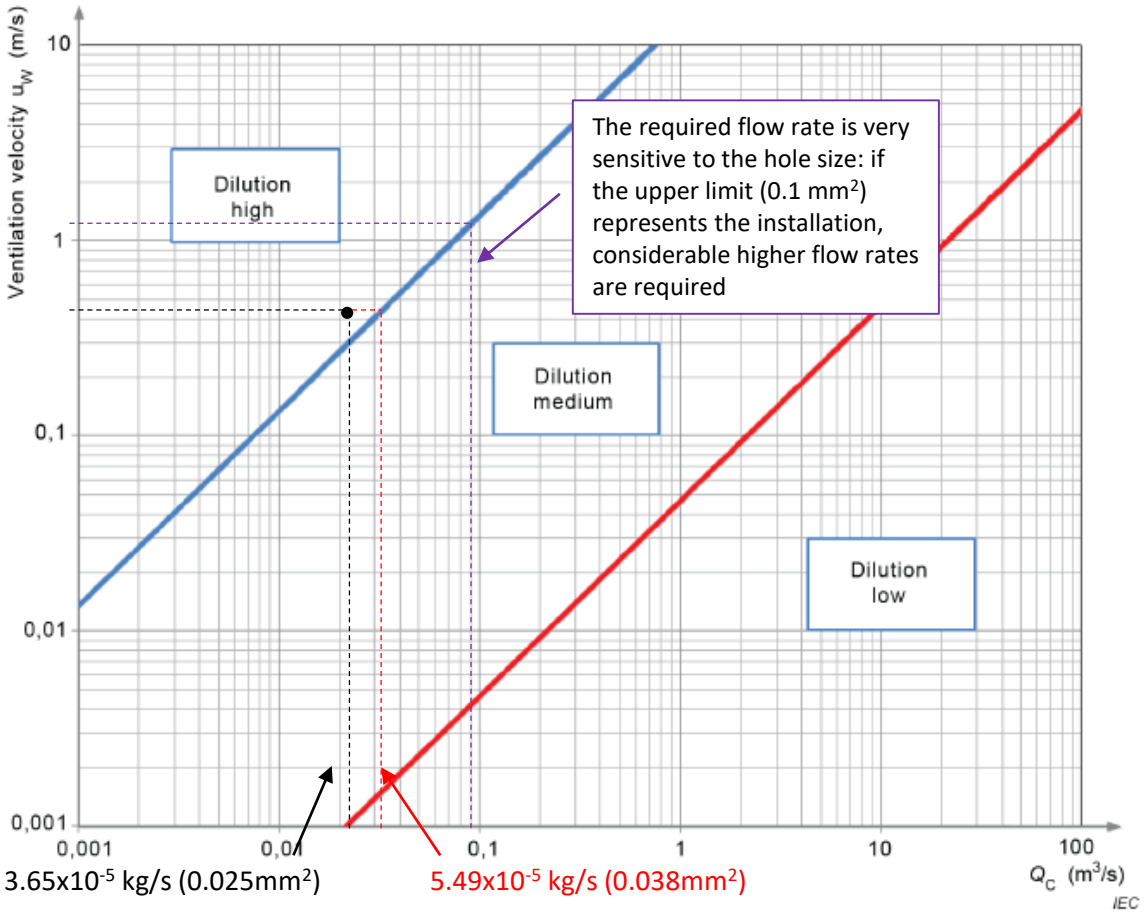
$$Q_C = \frac{W_g}{\rho_g \times LFL}$$

$$\rho_g = \frac{p_a\, M}{R\; T_a}$$

Determination of ventilation velocity (U_w) from ventilation flow rate and enclosure dimensions

$$u_w = \frac{1.5\ m^3/s}{3.4\ m^2} = 0.44\ m/s$$

Determination of degree of dilution from u_w and Q_c



Blue line: Represents a flammable volume of 0.1 m^3, so any intersection to the left represents an even smaller cloud volume.

Red line: Represents a flammable volume of 100 m^3, so any intersection to the right represents an even smaller cloud volume.

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Neglibible Extent – Specific Requirements IEC 60079-10-1:2020

Such a zone implies that an explosion, if it takes place, will have negligible consequences. The zone NE concept can be applied irrespective of any other adjustments for risk assessment to determine EPL*

The criteria for a zone NE classification should be based on the following factors:

i) Ignition would not result in sufficient pressure to cause harm either due to the pressure wave or due to damage that could cause flying objects or particles e.g. broken glass from windows.

ii) Ignition would not result in sufficient heat to cause harm or a fire from surrounding materials.

iii) For gas distributed at pressures above 1 000 kPag (10 barg) consideration shall be given to a specific risk assessment

iv) A zone NE shall not be applied to gas distributed at pressures above 2 000 kPag (20 barg) unless a specific detailed risk assessment can document otherwise.

Table D.1 – Zones for grade of release and effectiveness of ventilation

Grade of release	Effectiveness of Ventilation						
	High Dilution			Medium Dilution			Low Dilution
	Availability of ventilation						
	Good	Fair	Poor	Good	Fair	Poor	Good, fair or poor
Continuous	Non-hazardous (Zone 0 NE)[a]	Zone 2 (Zone 0 NE)[a]	Zone 1 (Zone 0 NE)[a]	Zone 0	Zone 0 + Zone 2[c]	Zone 0 + Zone 1	Zone 0
Primary	Non-hazardous (Zone 1 NE)[a]	Zone 2 (Zone 1 NE)[a]	Zone 2 (Zone 1 NE)[a]	Zone 1	Zone 1 + Zone 2	Zone 1 + Zone 2	Zone 1 or zone 0[d]
Secondary[b]	Non-hazardous (Zone 2 NE)[a]	Non-hazardous (Zone 2 NE)[a]	Zone 2	Zone 2	Zone 2	Zone 2	Zone 1 and even Zone 0[d]

[a] Zone 0 NE, 1 NE or 2 NE indicates a theoretical zone which would be of negligible extent under normal conditions.

[b] The Zone 2 area created by a secondary grade of release may exceed that attributable to a primary or continuous grade of release; in this case, the greater distance should be taken.

[c] Zone 1 is not needed here. I.e. small Zone 0 is in the area where the release is not controlled by the ventilation and larger Zone 2 for when ventilation fails.

[d] Will be Zone 0 if the ventilation is so weak and the release is such that in practice an explosive gas atmosphere exists virtually continuously (i.e. approaching a 'no ventilation' condition).

'+' signifies 'surrounded by'.

Availability of ventilation in naturally ventilated enclosed spaces is commonly not considered as good.

<u>Additional low dilution criteria</u> (X_b<25% LFL = 0.01):

$$X_b = \frac{f \times Q_g}{Q_2}$$

$X_b = 3.06 \times 10^{-4}$ for f = 1

$X_b = 1.53 \times 10^{-3}$ for f = 5

* Equipment Protection Level

Neglibible Extent – Specific Requirements

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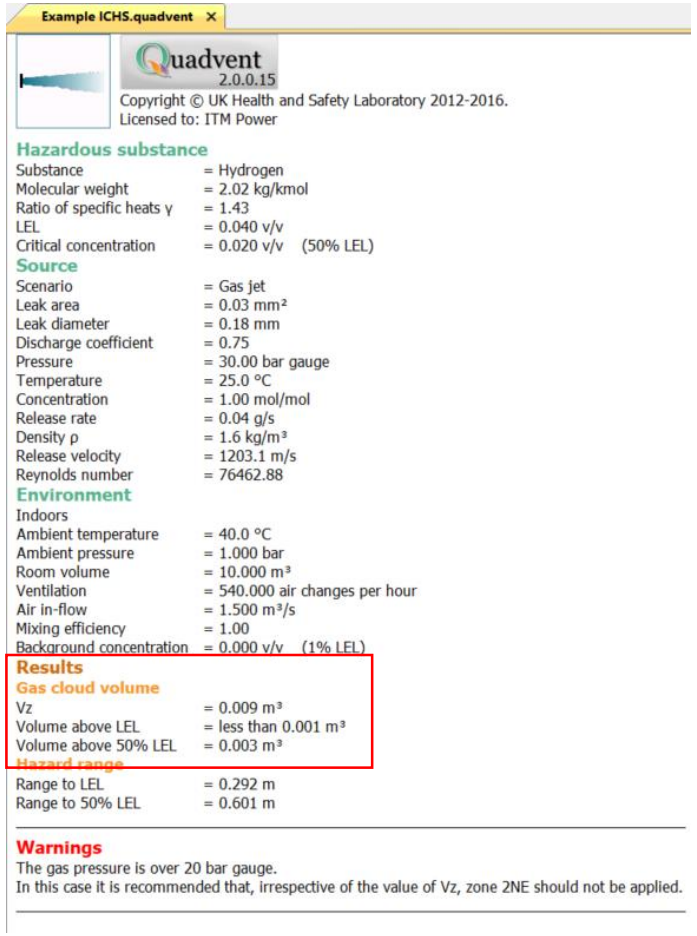
If availability of ventilation is at least fair, the area can be classified as Zone 2 NE extent for secondary releases with the characteristics analyzed in the previous slides (assuming only one leak point is present). However, section 4.4.2 of BS EN IEC 60079-10-1:2021 presents specific conditions for Negligible Extent application:

> An example of zone NE is a natural gas cloud with an average concentration that is 50 % by volume of the LFL and that is less than 0.1 m^3 or 1.0 % of the enclosed space concerned (whichever is smaller). For other gases a zone NE may be considered based on the ratio of the heat of combustion, maximum explosion pressure and the maximum rate of pressure rise of the gas to methane multiplied by the parameters used for methane.

Material Proprerty	Hydrogen	Methane	Ratio CH_4/H_2
Heat of Combustion (MJ/kg)	141.8	55.5	0.39
Max. Explosion Pressure (bar g) [22]	8.3	8.4	1.01
Max. Rate of Pressure Rise (bar·m/s)	550	55	**0.10**

From the table, the requirement for hydrogen used in this work would be "hydrogen cloud with an average concentration that is 50% by volume of the LFL and that is less than 0.01 m^3 or 0.1% of the enclosed space."
This means that Vz should be less than 0.01 m^3.



Example ICHS.quadvent

Quadvent 2.0.0.15

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Hazardous substance

Substance	= Hydrogen
Molecular weight	= 2.02 kg/kmol
Ratio of specific heats γ	= 1.43
LEL	= 0.040 v/v
Critical concentration	= 0.020 v/v (50% LEL)

Source

Scenario	= Gas jet
Leak area	= 0.03 mm²
Leak diameter	= 0.18 mm
Discharge coefficient	= 0.75
Pressure	= 30.00 bar gauge
Temperature	= 25.0 °C
Concentration	= 1.00 mol/mol
Release rate	= 0.04 g/s
Density ρ	= 1.6 kg/m³
Release velocity	= 1203.1 m/s
Reynolds number	= 76462.88

Environment

Indoors

Ambient temperature	= 40.0 °C
Ambient pressure	= 1.000 bar
Room volume	= 10.000 m³
Ventilation	= 540.000 air changes per hour
Air in-flow	= 1.500 m³/s
Mixing efficiency	= 1.00
Background concentration	= 0.000 v/v (1% LEL)

Results

Gas cloud volume

Vz	= 0.009 m³
Volume above LEL	= less than 0.001 m³
Volume above 50% LEL	= 0.003 m³

Hazard range

Range to LEL	= 0.292 m
Range to 50% LEL	= 0.601 m

Warnings

The gas pressure is over 20 bar gauge.
In this case it is recommended that, irrespective of the value of Vz, zone 2NE should not be applied.

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Consequences Approach – Delayed ignition

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If the overpressure obtained by the ignition of the localized cloud for an average concentration equal to LEL is below the minimum harm criteria, it would be true for the average of 50% LEL

- Assuming a localized cloud explosion that is confined in the enclosure, the Equivalent Stoichiometric Volume* approach can be used assuming a volume of fuel of 0.01 m^3 and a concentration of H_2 of 4% v./v. in air

$$V_{ESV} = V_{fuel}\left(\frac{C}{\phi}\right)$$

$$P = P_{max}\left(\frac{V_{ESV}}{V}\right)$$

Vfuel	Volume of the cloud
Pmax	Maximum Pressure stoichiometric
C	Concentration
ϕ	Stoichiometric concentration
V	Volume of the room

$$V_{ESV} = 0.01\ m^3 * \left(\frac{4\%}{29.5\%}\right) = 0.0014\ m^3$$

$$P = 8.3\ barg * \left(\frac{0.0014\ m^3}{10\ m^3}\right) = 1.13\ mbarg$$

Overpressure is well below the minimum harm criteria for damage of weak elements and fragments generation: 13.5 mbarg ("No harm" limit based in temporary loss hearing threshold [HyResponder, 2021])

*HSE Report RR630 - Area classification of secondary releases from low pressures - Section 4.2

Consequences Approach – Immediate ignition

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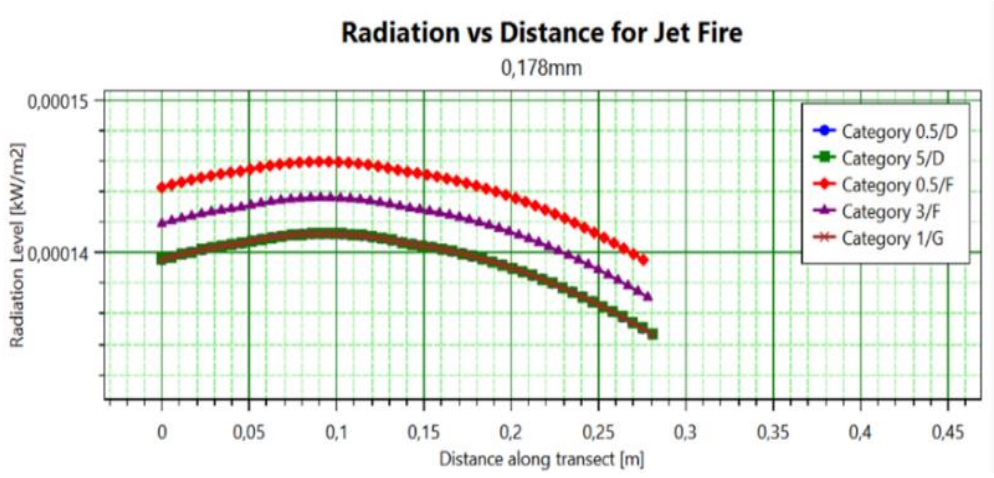
Jet Fire calculations

Name	Symbol	Value	Unit
H2 pressure in reservoir	p_1	30	bar
H2 temperature in reservoir	T_1	293	K
Orifice diameter	d_3	0.18	mm
Ambient pressure	p_4	1.01325e+5	Pa
Ambient temperature	T_{atm}	333	K
Flame length	L_F	0.172631	m
No harm (70°C) separation distance	X_{70}	0.604209	m
Pain limit (5 mins, 115°C) separation distance	X_{115}	0.517894	m
Third degree burns (20 sec, 309°C) separation distance	X_{309}	0.345262	m



- Temperature thresholds taken as reference due to micro-flame structure.
- If a continuous jet fire is present, third degree burns would potentially happen at distances below 0.34 m and pain limits at 0.5 m.
- No harm – 0.6 m around the flame.

Significant damage to equipment – 37.5 kW/m^2 (EIGA 75 – 2021) – Phast simulation shows that the Thermal Intensity is well below this threshold

Considerations in risk assessment

- No access to the enclosure when pressurised, therefore not direct impact to the operators expected.
- Shutdown in case of detection of leak, stopping jet fire
- High air velocity affecting the micro-flame

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Qualitative Risk Assessment (Group Exercise)

Central Feared Event (CFE)	Causes	Existing Prevention barriers	Dangerous phenomena (DPh)	Existing protection Barriers	Observations
Loss of H_2 containment - small leak equivalent to Negligible Extent cloud (0.025 mm^2 - ~0.18 mm) on H_2 piping (fittings/seals)	a) Equipment failure (Erosion, corrosion, metal embrittlement due to hydrogen, Weld failure, cycle fatigue, vibrations)	a) Compliance with PED regulations and specific standards in the choice of materials and welding (where applicable) a) maintenance and inspection of H_2 piping/accessories a) Procedure of controls: ISO 22734:2019 [14] -Type and routine tests	No Ignition: No Consequence	-Automatic pressure drop test (details in Table 1) - Forced ventilation (section 3) with pressure differential on the fan to initiate shutdown in case of loss of ventilation - H2 detection initiating shutdown (details in Table 1) Calibration and inspection to follow the manufacturers operating procedures. Exiting protection barriers to avoid ignition: - Equipment required to act in case of leak is rated for hazardous areas for a scenario without artificial ventilation. - Prohibition of smoking , mobile	Asphyxiation not credible for the leak size and ventilation degree. In addition, no personnel in the room when the system is pressurized
	b) malicious act (very unlikely due to containerized configuration with locked access)	b) locked container and restricted access to the process area authorized persons b)interlock in the doors to initiate shutdown in case of opening during generation.	Delayed ignition: Confined explosion (ignition of localized cloud)		With the incorporation of the barriers (active pressure drop detection, forced ventilation, etc), the explosion severity is estimated to be below the required pressure to generate failure of the weakest part of the system (see section 4.1)
	c) Human error during maintenance (check not done, part missing, inadequate sealing following maintenance)	c) Training / maintenance procedures before starting (pre-checks, four eyes controlling of the installation before re-start) c) management of changes (For example: see references [18, 19])	Immediate ignition: Jet fire		Estimations of jet fire suggest limited radiative heat and temperatures (see section 4.2) affecting the materials inside the room (material are unlikely to promote a fire). No access to the room when pressurised, and shutdown would stop jet fire.

Conclusions

An example of a specific detailed risk assessment applied to an enclosure for an electrolyser:

- A methodology from IEC 60079-10-1:2020 has been implemented for the hazardous area classification for internal releases.
- Various criteria for Negligible Extent zones have been applied to releases of hydrogen in an enclosure
- In order to fulfil the requirements of clause 4.4.2 of IEC 60079-10-1:2020, the step below were implemented:
  - **Localized cloud explosion:** An overpressure of 1.13 mbarg has been estimated for a cloud of Negligible Extent (NE) with an overall concentration of 4% v./v. H_2, well below the "No harm" criteria of 13.5 mbarg.
  - **Jet fire:** Estimation of the distance from the release point to obtain a temperature of 70°C (No harm) suggest that a minimum of 0.60 m is required. However, shutdown in case of opening of the doors and prohibited access to the enclosure when pressurized reduce the likelihood of harming an operator.
  - **Qualitative risk assessment:** A Qualitative risk assessment was performed for the specific scenario of a small leak within the enclosure with the characteristics used for the hazardous area classification. Scenarios are considered negligible considering the safeguards and consequences estimated in the work.

The simplified example is based on assumptions regarding the ventilation and installation characteristics, which would require a detailed assessment when put into practice.

Thank you for your attention!

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