RÉPUBLIQUE FRANÇAISE
Liberté
Égalité
Fraternité

INERIS
maîtriser le risque
pour un développement durable

ORIGIN OF CURRENT REGULATION ON HRS IN FRANCE AND CHALLENGES WITH ITS EVOLUTION

BRUNO DEBRAY, BENNO WEINBERGER
DEPUTY DIRECTOR OF STRATEGY AND SCIENTIFIC POLICY, HYDROGEN SAFETY SENIOR EXPERT

f
2
0
2
2

RÉPUBLIQUE FRANÇAISE
Liberté
Égalité
Fraternité

INERIS
maîtriser le risque
pour un développement durable

Current regulatory framework on HRS

Various permitting status under the hazardous installations regulation (Installations classées pour la protection de l'environnement) depending on the activity and amount of hydrogen present in the plant

HRS are submitted to **declaration** => before starting the opeartion the plant operator declares the refueling stations to authorities and must conform to a **generic regulation (arrêté de prescriptions générales** 22/10/2018**)** which imposes safety distances, safety measures and regular inspection by an independent body

Use (storage) of hydrogen is submitted to

- permitting if more than 1t of hydrogen is present in the plant. (above 5t application of the SEVESO directive)

- **declaration** between 100 kg and 1t.

Production is submitted to

- permitting (application of IED directive)

Process for elaboration of the regulation on HRS

The regulation must guarantee that the risk will be maintained below acceptable limits independently of the local context.

The regulation is elaborated by the ministry in charge of the environment with technical support by Ineris

Based on a generic safety study => definition of safety measures to avoid unacceptable risk

Discussed with industry to ensure the relevance of requirements (not to negociate the acceptable risk level)

Ineris involved in the safety studies either directly (in 2018 and 2023 for HRS) or as a third party reviewer (2024 for hydrogen storage)

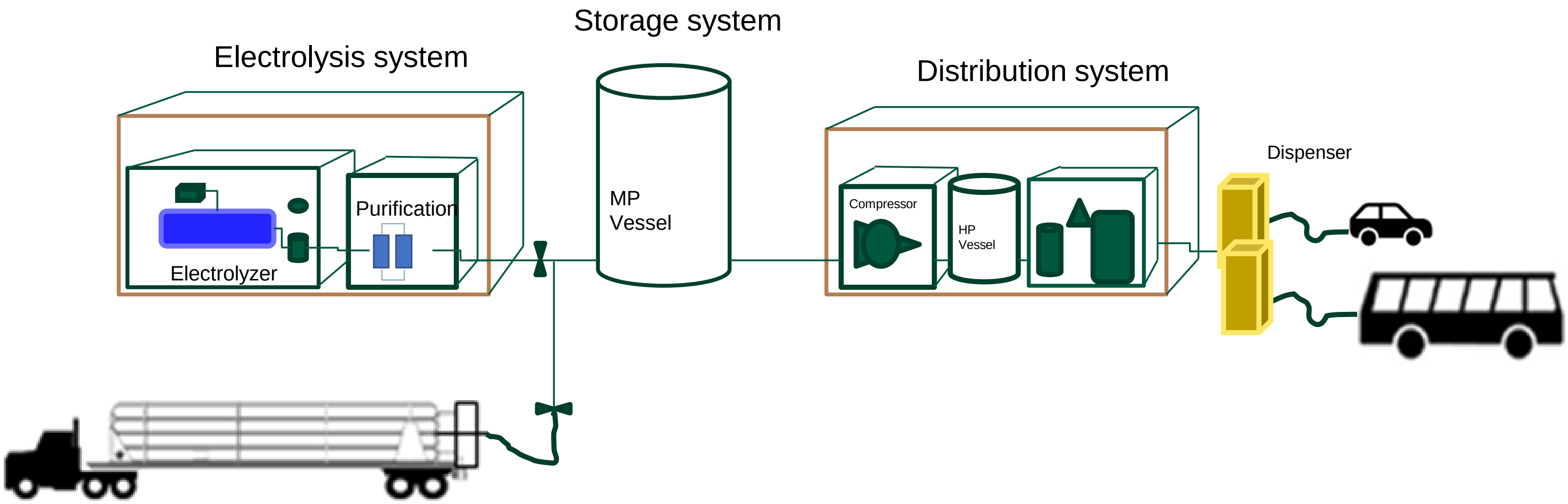
The regulation is currently being updated to take into account evolution of refuelling technologies

RÉPUBLIQUE FRANÇAISE
Liberté
Égalité
Fraternité

INERIS
maîtriser le risque
pour un développement durable

Safety study
Description of the studied facilities

Studied facilities



Introduction – Limits of the study

- This study consist in a risk assessment of the different components of a generic Gaseous Hydrogen Refuelling Station (GHRS)

- The methodology applied is inspired by the risk assessment to build safety report of Seveso facilities

- Limits of the study :
    - Liquid hydrogen (cryogenic) hasn't been studied, hydrogen is considered only gaseous on the GHRS
    - Multi-fuel stations haven't been studied
    - Only GHRS supplying road vehicles (heavy or light ones) have been in the scope (no refuelling of trains or ships)

Main hypothesis considered for the definition of the studied facilities

- Electrolysis
  - Electrolyser sheltered in a 20 feet maritime container
- Compression
  - Compressor sheltered in a 20 feet maritime container
  - Operating pressure ≤ 1000 bar
- Storage
  - For stationary storages (HP and LP) : aboveground and unsheltered
  - HP : volume max 80 L per storage at 950 bar
  - LP : volume max 45 m^3 per storage at 50 bar
  - LP storage can also be mobile in tube-trailer at 2090 L / 200 bar or 335 L / 500 bar
- Piping
  - LP ≤ 12.7 mm ID at 50 bar
  - HP ≤ 10 mm ID at 950 bar
- Dispenser
  - Max flow rate of 60 g/s at 700 bar and 120 g/s at 350 bar
  - Loading hose : 3 mm ID

RÉPUBLIQUE
FRANÇAISE
Liberté
Égalité
Fraternité

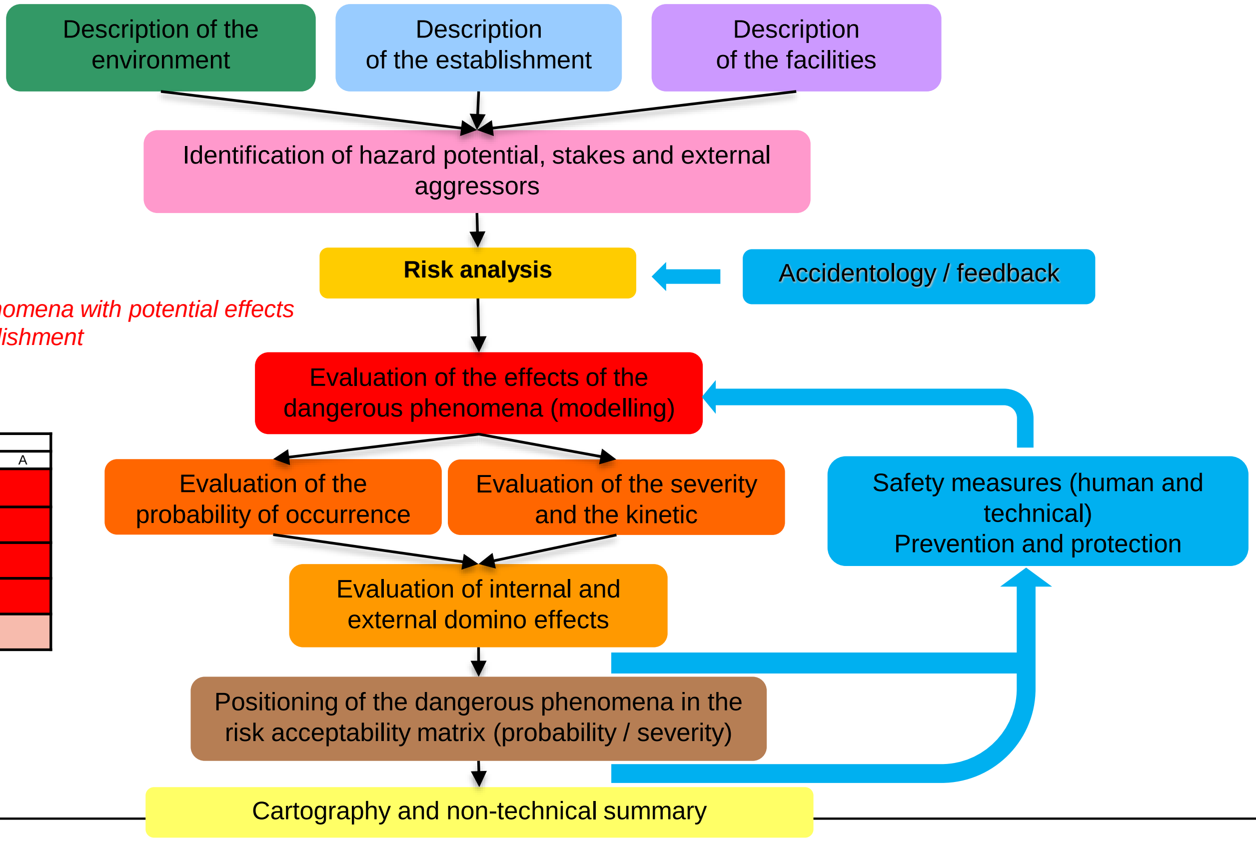
INERIS
maîtriser le risque
pour un développement durable

Methodology

RÉPUBLIQUE FRANÇAISE
Liberté
Égalité
Fraternité

INERIS
maîtriser le risque pour un développement durable

Methodology of a French safety report for Seveso establishment

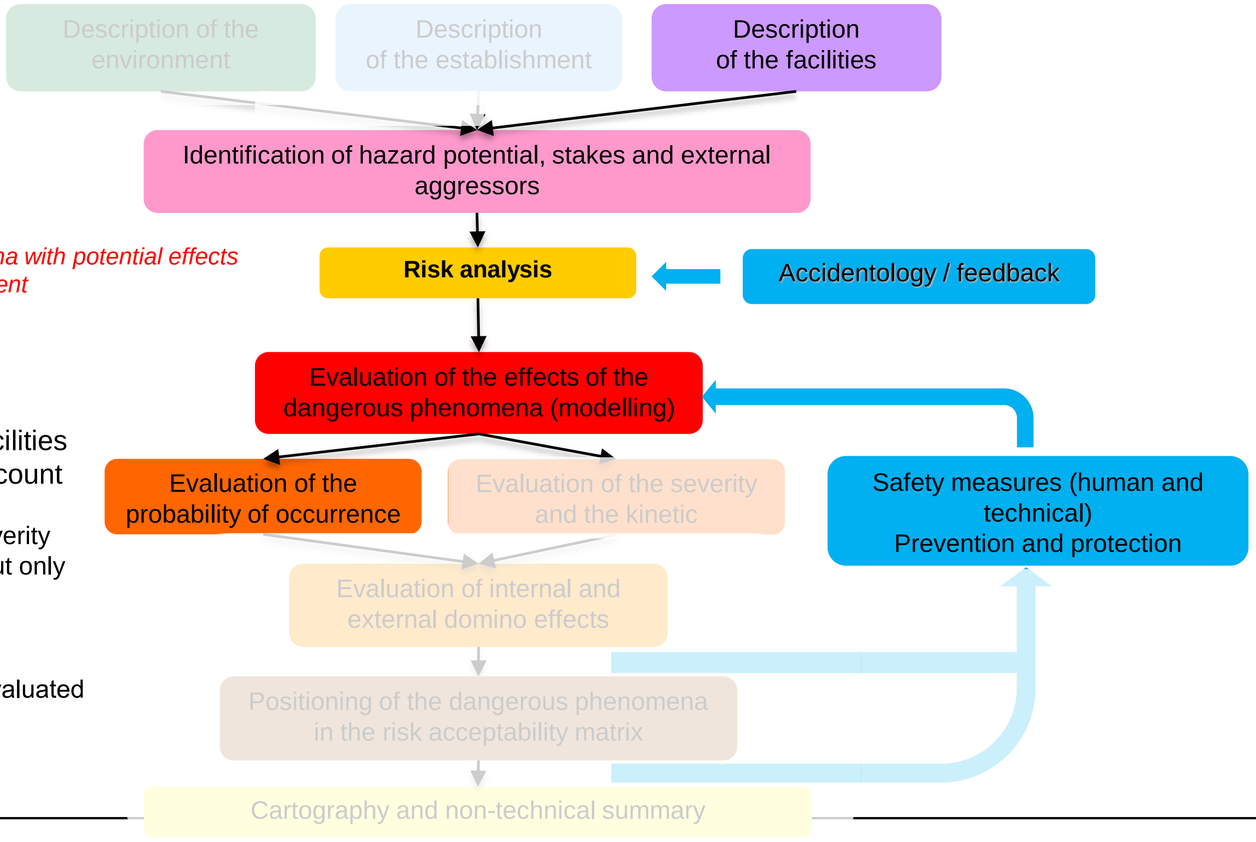


For dangerous phenomena with potential effects outside of the establishment

	Probability				
Severity	E	D	C	B	A
Disastrous					
Catastrophic					
Important					
Serious					
Moderate					

Methodology applied in this study

For dangerous phenomena with potential effects outside of the establishment



The study is applied to generic facilities
→ No environment to take into account

➔No evaluation of the total severity (i.e. evaluation of casualties) but only effect distances of hazardous phenomena

➔Risk acceptability can’t be evaluated

RÉPUBLIQUE FRANÇAISE
Liberté
Égalité
Fraternité

INERIS
maîtriser le risque
pour un développement durable

Accidentology

Accidentology

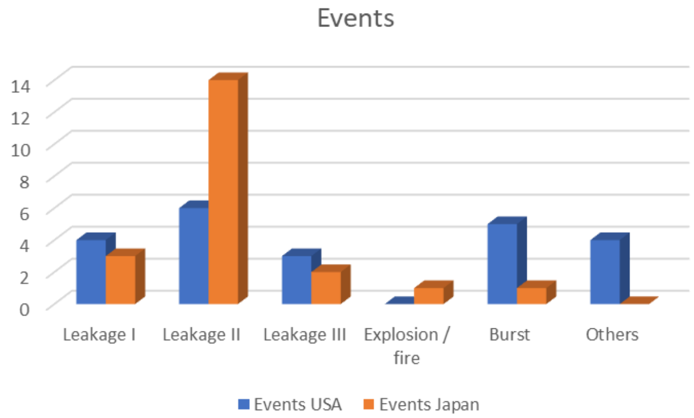
Literature study

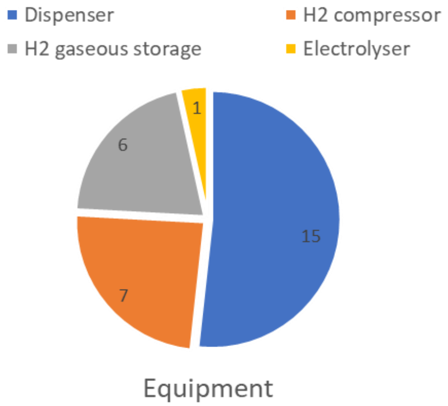
Events that have happened in Japan (between 2005 and 2014) and in the USA (between 2004 and 2014). 21 events have been identified in Japan and 22 In the USA.[1]

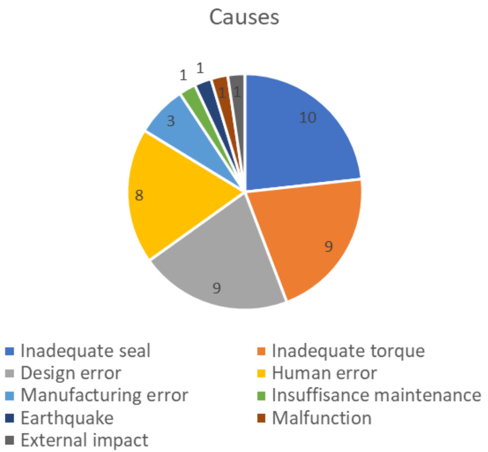
- Leakage I: leakages due to the damage and fracture of main bodies of apparatuses and pipes (including welded parts). It is mainly because of mechanical fatigue due to a design error;

- Leakage II: leakages from flanges, valves, and seals (including deteriorated nonmetallic seals). Thread connections are main causes;

- Leakage III: leakages due to other factors, e.g., human error and external impact. Human error is the main cause







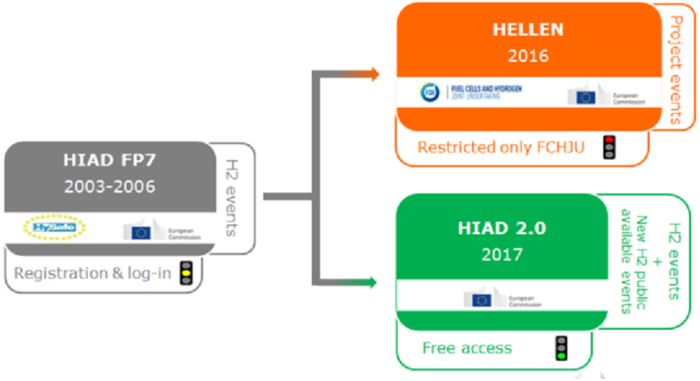
[1] J. Sakamoto, R. Sato, J. Nakayama, N. Kasai, T. Shibutani, A. Miyake, "Leakage-type-based analysis of accidents involving hydrogen fuelling stations in Japan and USA", Int. Journal of Hydrogen Energy, pp 21564-21570, 2016

Accidentology

HIAD & H2tools database

Ineris has consulted the EU databes HIAD and the American database h2tools.org. Releases of hydrogen has been identified on the different components of the GHFS, with various causes:

- H2 storage : leaking connection, inadvertent opening of a pressure relief device valve
- Compressor : crankshaft bearing failure, bad connection of the equipment, leak due to compressor vibrations that have caused the rubbing of a sensor on a hydrogen
- Dispenser: non-respect of a filling procedure, and there are some cases where the cause is not clearly identified



Risk analysis

Dangerous phenomena

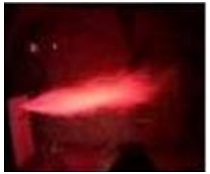
Hydrogen leakage

Dispersal and accumulation (in case of containment)

Inflammation

Immediate

Delayed



Torch Fire (flaming jet)

Thermal Effects

Explosion (uncontained: UVCE Confined: Burst of Capacity)

Overpressure effects
Thermal Effects
Shots

Heat Aggression

Internal overpressure

Impact

Tank bursting

Overpressure effects

Shots

Thermal Effects

Preliminary hazard analysis

Critical Events (CE)	Dangerous Phenomena (DP)
STORAGE	
Rise of temperature and/or pressure	Burst of storage
Loss of containment on the storage tank/bottle	Hydrogen leak; Jet fire, UVCE, flash fire
If delivered by truck: Loss of containment on the hose (at the delivery post)	
ELECTROLYSER	
Loss of containment on the electrolyser	Hydrogen leak; Jet fire, UVCE, flash fire
Formation of an explosive mixture in hydrogen and/or oxygen separators	Burst of the separator
PIPES	
Loss of containment on pipes (leak or full-bore rupture)	Hydrogen leak; Jet fire, UVCE, flash fire
Pressure safety valve opening	
COMPRESSOR	
Loss of containment on the compressor	Hydrogen leak; Jet fire, UVCE, flash fire
Formation of an explosive mixture in the compressor	Burst of the compressor
SHELTER (buildings, container) containing a part of the hydrogen facilities	
Formation of an explosive mixture	VCE in the shelter and burst of the shelter
DISPENSER	
Loss of containment on the filling hose	Hydrogen leak; Jet fire, UVCE, flash fire
Vehicle Fire	Burst of vehicle tank
Filling with “too hot” hydrogen	

RÉPUBLIQUE FRANÇAISE
Liberté
Égalité
Fraternité

INERIS
maîtriser le risque
pour un développement durable

Modelling of the effects of dangerous phenomena

Modelling of the effects of dangerous phenomena

Methodology

- French regulatory thresholds of effects

	Blast effects	Thermal effects	
	mbar	kW/m²	$(kW/m^2)^{4/3}.s$
Significant lethal effects threshold (SLET)	200	8	1800
First lethal effects threshold (FLET)	140	5	1000
Irreversible effects threshold (IET)	50	3	600
Indirect effect threshold (by broken window)	20	-	-

- Tools used for modelling
  - For the evaluation of the blast effects of a capacity burst, Ineris used its internal tools EFFEX and PROJEX;
  - For the evaluation of the effects of an UVCE or a flash fire of hydrogen, Ineris used an internal modelling tool called EXOJET;
  - For the evaluation of the effects of a jet fire of hydrogen, Ineris used the PHAST software .

Modelling of the effects of dangerous phenomena

Distances of effects

Scenario	Effects	Safety distance [m]		
		SLET	FLET	IET
STORAGE				
Burst of storage capacity:				
LP - 50 m³, 45 bar	Blast	58	75	170
HP - 80 L, 440 bar	Blast	9	12	27
HP - 80 L, 950 bar	Blast	12	15	35
Burst of tube-trailer:				
Trailer 1 - 2090 L, 200 bar	Blast	23	29	67
Trailer 2 - 335 L, 500 bar	Blast	15	20	45
Rupture of delivery hose:				
Hose 1 - ∅3 mm, 200 bar	Thermal	11	11	12
	Blast	NR	NR	7
Hose 2 - ∅3 mm, 500 bar	Thermal	17	17	19
	Blast	NR	6	15
ELECTROLYSER				
Burst of the separator:				
Separator (10 L)	Blast	4	5	12
Rupture of pipe:				
∅12,7 mm, 15 bar	Thermal	13	13	15
	Blast	NR	NR	11
SHELTER / CONTAINER				
Burst of capacity:				
Electrolyser container	Blast	6	8	18
Compressor container	Blast	12	16	36

Scenario	Effects	Safety distance [m]		
		SLET	FLET	IET
PIPES				
Rupture of pipe:				
Before compressor (∅10 mm, 200 bar)	Thermal	37	37	41
	Blast	23	26	39
Before compressor (∅10 mm, 450 bar)	Thermal	54	54	60
	Blast	36	41	64
After compressor (∅10 mm, 450 bar)	Thermal	54	54	60
	Blast	36	41	64
After compressor (∅10 mm, 1000 bar)	Thermal	77	77	84
	Blast	55	62	99
DISPENSER				
Rupture of filling hose:				
Hose 1 - ∅3 mm - 350 bar max flow = 120 g/s	Thermal	14	14	16
	Blast	NR	NR	12
Hose 2 - ∅3 mm - 700 bar max flow = 60 g/s	Thermal	10	10	11
	Blast	NR	NR	8
Burst of a tank in a vehicle in fire:				
80 L, 700 bar	Blast	9	12	28
87 L, 350 bar	Blast	8	10	23
Burst of a tank in a vehicle by overpressure:				
80 L, 700 bar	Blast	13	17	39
87 L, 350 bar	Blast	11	14	32

NR : Not Reached

→ Greatest distances : burst of storage, HP pipe rupture

Evaluation of the probability of occurrence of dangerous phenomena

Evaluation of the probability of occurrence of dangerous phenomena

Methodology

- Data used in this study
  - Generic databases : BEVI, OREDA

Critical event (CE)	Frequency	Database
STORAGE		
Instantaneous release of entire content	5×10^{-7} / year / capacity	BEVI
COMPRESSION		
Catastrophic failure of a compressor	1×10^{-4} / year / compressor	BEVI
Compression fault	2.3×10^{-5} / hour	OREDA
PIPES		
Rupture	1×10^{-6} / year if $\varnothing < 75$ mm	BEVI
Leak	5×10^{-6} / year if $\varnothing < 75$ mm	BEVI
HOSE		
Rupture	4×10^{-6} / hour	BEVI
Leak	4×10^{-5} / hour	BEVI
VEHICLE'S TANK		
Default of cooling or flow regulation during filling	2.3×10^{-5} / hour	OREDA

  - To consider domino effects, a 10^{-5} / year factor is added to the previous values (based on Ineris feedback)
  - Probability of ignition is conservatively considered equal to 1 (conservative value, if there is a release, we consider that it meets an ignition source)

RÉPUBLIQUE FRANÇAISE
Liberté
Égalité
Fraternité

INERIS
maîtriser le risque
pour un développement durable

Evaluation of the probability of occurrence of dangerous phenomena

Methodology

	Probability				
Severity	E	D	C	B	A
Disastrous					
Catastrophic					
Important					
Serious					
Moderate					

➢Classes of probability

Scale	E	D	C	B	A
Meaning	"Event not impossible but never encounter worldwide"	"Event very unlikely": similar event already encountered in the past but was tackled by means of corrective actions hence reducing significantly its likelihood	"Unlikely event": similar event already encountered in the past with the corrective actions not having a significant impact on the likelihood	"Likely event"	"Current event"
Quantitative (/ year)	10^{-5} 10^{-4} 10^{-3} 10^{-2}				

Evaluation of the probability of occurrence of dangerous phenomena

RÉPUBLIQUE FRANÇAISE
Liberté
Égalité
Fraternité

INERIS
maîtriser le risque
pour un développement durable

Evaluation of probability classes

Critical event	Evaluation of the probability of occurrence		Probability Class
STORAGE			
Burst of a capacity	5×10^{-7} / year / capacity		E
Rupture of delivery hose	≈ 10 h of working/year (1 truck/week and filling time ≈ 10 min)	F_1 = hose rupture frequency = $10 \times 4 \times 10^{-6} = 10 \times 4 \times 10^{-5}$ / year F_2 = dominoes effect frequency = 10^{-5} / year $F = F_1 + F_2 =$ **5×10^{-5} / year**	D
SHELTER / CONTAINER			
Explosion of the electrolyser container **(Leaks are not considered)**	Pipe ∅ 12,7 mm, L = 10 m	F_1 = Pipe rupture frequency = $10 \times 10^{-6} = 10^{-5}$ / year F_2 = dominoes effect frequency = 10^{-5} / year $F = F_1 + F_2 =$ **2×10^{-5} / year**	D (Leaks not considered)
DISPENSER			
Burst of tank in a vehicle in fire	F = dominoes effect frequency = **10^{-5} / year**		D
Burst of vehicle tank due to « too hot » hydrogen or to overpressure	≈ 300 h of working/year (5 vehicles/day and filling time ≈ 10 min)	F_1 = Cooling default frequency = $300 \times 2.3 \times 10^{-5} = 7 \times 10^{-3}$ / year F_2 = Flow regulation default frequency = $300 \times 2.3 \times 10^{-5} = 7 \times 10^{-3}$ / year F_3 = Compression default frequency = $300 \times 10^{-5} = 3 \times 10^{-3}$ / year F_4 = dominoes effect frequency = 10^{-5} / year $F = F_1 + F_2 + F_3 + F_4 =$ **1.7×10^{-2} / year**	A
Rupture of filling hose	<u>If flow rate is limited to 60 g/s</u>: ≈ 300 h of working/year (5 vehicles/day and filling time ≈ 10 min)	F_1 = Hose rupture frequency = $300 \times 4 \times 10^{-6} = 1.2 \times 10^{-3}$ / year F_2 = dominoes effect frequency = 10^{-5} / year $F = F_1 + F_2 =$ **1.2×10^{-3} / year**	B
	<u>If flow rate is limited to 120 g/s</u>: ≈ 200 h of working a year (5 vehicles/day and filling time ≈ 7 min)	F_1 = Hose rupture frequency = $200 \times 4 \times 10^{-6} = 8 \times 10^{-4}$ / year F_2 = dominoes effect frequency = 10^{-5} / year $F = F_1 + F_2 =$ **8.1×10^{-4} / year**	C

Identification and evaluation of safety measures

Identification and evaluation of safety measures

Methodology

- Safety measures can be:
  - Technological or organisational
  - Acting in prevention or protection / mitigation

- A safety measure can be valued in a risk assessment only if:
  - It is independent from the event that will then lead to its solicitation
  - It is efficient to fulfill the safety function it was chosen for
  - Its response time is appropriate given the kinetic of the dangerous phenomenon it must control

- If the 3 criteria are met, a trust (confidence) level (TL) can be attributed to the measure:
  - TL1 means reduction by 10^1 of the probability,
  - TL2 reduction by 10^2
  - TLn by 10^n

Identification and evaluation of safety measures

Example of safety measures for the dispenser

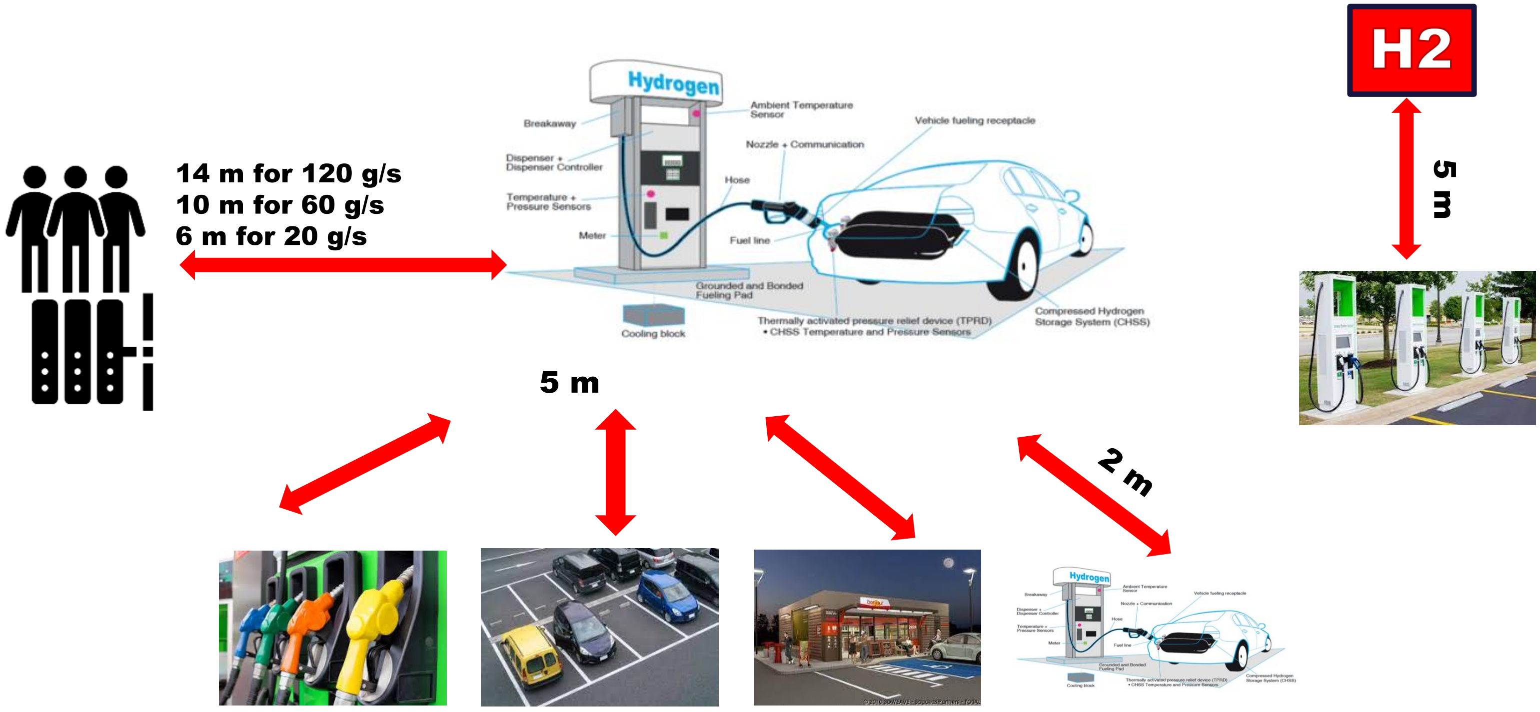
Critical event	Initial probability class	Proposed safety measures	Final probability class
Rupture of the filling hose	If flow rate limited to 60 g/s: **B**	- Flow limiter (safety measure already considered for evaluation of intensity) - Hydrogen detecting system in the dispensing area action an automatic shutdown of the hydrogen feed (**TL1 only if the dispenser is in a semi-confined area, TL0 otherwise**) - Presence of safe breakaway device (SBD) at the base of every filing hose with automatic filling shutdown (**TL1**) - Leak test of the filling hose before every filling (**TL1 for leak only**) - Pressure switch low (PSL) at the dispenser with facility shutdown (**TL1**) - If a main pipe split to feed several dispensers, to put an isolation valve on each branch. Regulation and flow valves must be independent; the second one is used for the normal filling stop and the safety one (**TL0**) - Check valve on the dispenser to avoid a return of hydrogen from the vehicle when the filling is stopped (**TL0**) - To put at least one manual emergency stop button (ESB) at the dispenser and a second (recommended) to stop the filling remotely. Actions: to stop the filling immediately (shut valves) and start depressurization of the hoses (shut the compressors) (**TL0)** - To put an isolation valve before the dispenser	**D** if presence of 2 measures (SBD+PSL)
Rupture of the filling hose	If flow rate limited to 120 g/s: **C**		**E** if presence of 2 measures (SBD+PSL)
Leak on the filling hose	If flow rate limited to 60 g/s: **A**		**B** if leak test (PSL is judged ineffective for leaks)
Leak on the filling hose	If flow rate limited to 120 g/s: **B**		**C** if leak test (PSL is judged ineffective for leaks)

Identification and evaluation of safety measures

Good practices

- In addition to safety measures, good practice rules can (must) be applied to reduce risks

- For instance, for the dispenser:
  - To plan the change of filling hose on a periodic manner
  - To design the dispenser so that the hydrogen quantity released when disconnecting the hose is not bigger than the amount contained in the hose and the dispenser intern pipes at ATP
  - To design the dispensing nozzle so that it can’t be untied from the vehicle before being depressurized through a ventline
  - To install the HRS in a non confined area (no garage, not tunnel or underground station)
  - To position the filling hose so that it doesn’t touch the ground when not used
  - To protect dispensers against vehicles impact
  - To install only the terminal and the filling hose in the dispensing area
  - …


14 m for 120 g/s
10 m for 60 g/s
6 m for 20 g/s
Hydrogen
Breakaway
Dispenser + Dispenser Controller
Temperature + Pressure Sensors
Meter
Ambient Temperature Sensor
Nozzle + Communication
Hose
Fuel line
Vehicle fueling receptacle
Grounded and Bonded Fueling Pad
Cooling block
Thermally activated pressure relief device (TPRD)
• CHSS Temperature and Pressure Sensors
Compressed Hydrogen Storage System (CHSS)
H2
5 m
5 m
2 m

RÉPUBLIQUE FRANÇAISE
Liberté
Égalité
Fraternité

INERIS
maîtriser le risque
pour un développement durable

Challenges with evolution of the regulation

Examples of evolutions

New requests from the industry, evolutions of the technology or of safety knowledge are currently being studied and a new regulation is in preparation

- Higher flowrate up to 300 g/s => bigger safety distances (as they are based on hose break hypothesis)
- Evolution of refuelling protocols (300 g/s covered by the new SAE J2601-5)
  - Issues with the verification (certification) of the proper application of a valid refuelling protocol
- Mobile refuelling stations
- Slow fuelling without human supervision (e.g. fur busses)
- Generalized use of tube trailers as storage units
  - Need for safe safety barriers (automatic shut-off valves) on trailer's side in relation with the potential rupture of the flexible hose
  - Issues with the protection of tube trailers equipped with Type III or Type IV tanks against fire scenarios (some are not equipped with TPRD, not required in ADR)

    If tanks are not protected against burst, burst is taken as the reference scenario for safety distances
- Issues with the ventilation requirements of containers : what release scenario to consider for the design of ventilation (normal and emergency)
- Multifuel service stations

RÉPUBLIQUE FRANÇAISE
Liberté
Égalité
Fraternité

INERIS
maîtriser le risque
pour un développement durable

Thanks for your attention