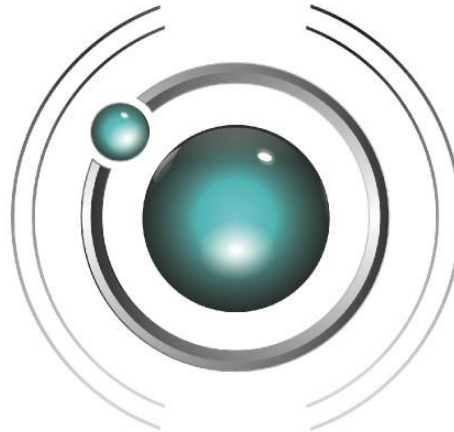


3rd Pilot Training Session, 06 -10 June 2016,
ENSOSP, Aix-en-Provence, France



HyResponse

Strategies and Intervention tactics -
H₂ refuelling station and storage installations

Franck Verbecke, AREVA Energy Storage



Agenda

- Hydrogen behavior and properties
- Storage and piping systems
- Hydrogen refuelling station

Hydrogen behaviour and properties



HyResponse

Hydrogen properties

- Low density: a safety attribute

Combustibles	Density	Stagnation
Hydrogen	0.07	No
Methane	0.65	No
Propane	1.88	Yes
Gasoline (vapors)	4.4	Yes

Outdoor, no stagnation

Indoor, risk of accumulation

- Low activation energy - **at high concentration**

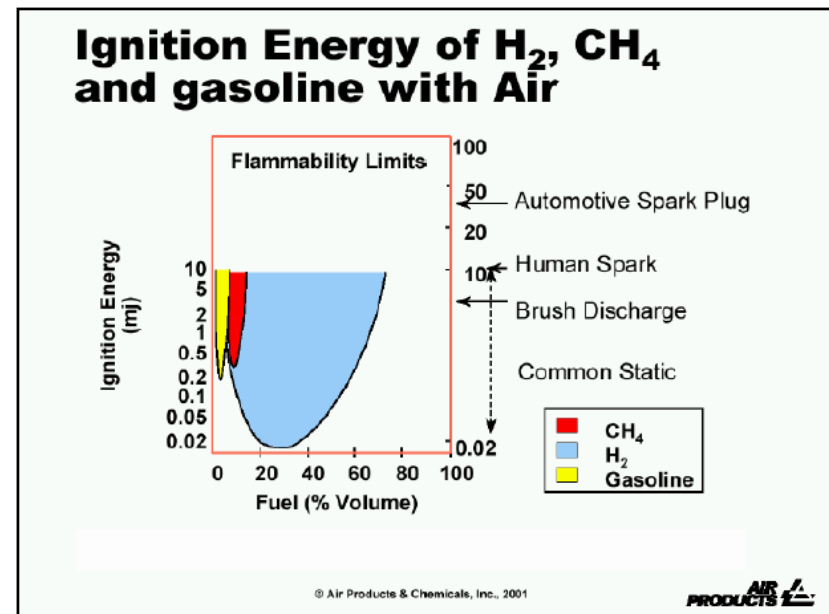
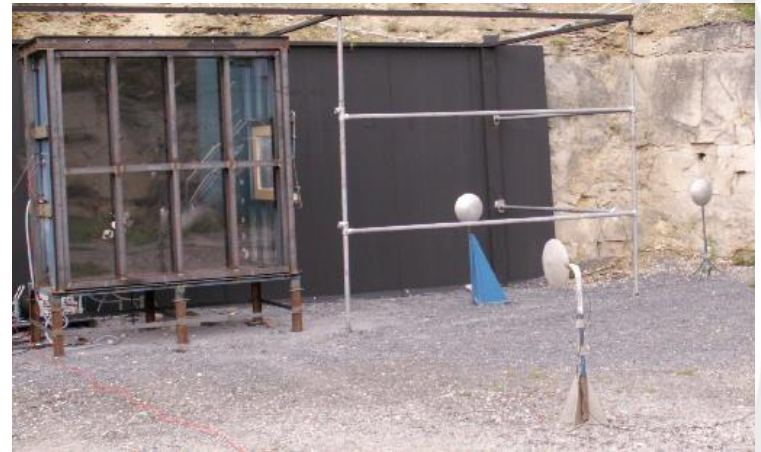


Figure 1: Flammability Limits vs. Ignition Energy of H₂, CH₄, and Gasoline in Air

Combustion characteristics in confined geometry

● A large flammability range

Combustibles	LFL % vol in air	UFL % vol in air
Hydrogen	4.0	75.0
Methane	5.3	17.0
Propane	1.7	10.9
Gasoline (vapors)	1.0	6.0



● Deflagration of homogeneous mixture:

7,3 % H₂



16,5 % H₂



10,5 % H₂

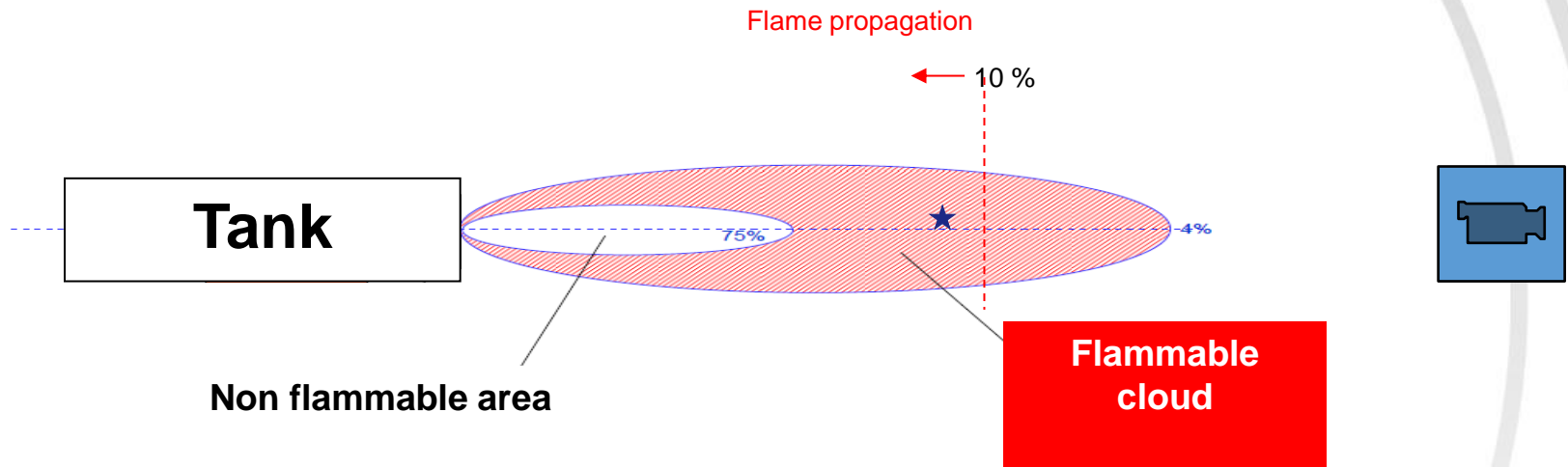


28.7 % H₂



Insignificant pressure effects for combustion of lean H₂-air mixtures (<10 % H₂ in air)

Ignition of hydrogen jets



Ignition of a hydrogen jet may produce pressure effects in surroundings

More experiments required to adjust classical blast model to better estimate overpressure effects

Storage and piping systems

Gaseous hydrogen storage in racks or cylinders

- Well established technology with no specific concerns
- In Europe, most of transportable cylinders have only a valve as safety barrier
- In USA, for instance there is TRD on transportable combustible cylinders
- More and more controversial prescription due to leaks



Bundle



Basket for transportation

Example of outdoor storage installation on MYRTE platform

- Safety manual valves as close as possible to the storage tank
- Tank equipped by a pressure relief device (PRD) connected to a vent
- In case of power outage or emergency stop, each storage tank is isolated by the electro-valves located close to each reservoir
- Check valves may also be used in piping and storage systems
- Flow excess valves may also be used to stop massive leaks



Hydrogen trailers



6 200 Nm3 of H2 trailer



3 000 Nm3 of H2 trailer



Typical storage system

Tank type and composition	Tank capacity	Storage pressure (bar)	Volume in water (L)	Volume of hydrogen contained	Mass of hydrogen (kg)
Type I (Steel)	B20	200	20	3.3	0.3
	B50	200	50	8.4	0.75
	Rack V9 B50	200	450	75.2	6.76
	Rack V18 B50	200	900	150.4	13.5
Trailer (2 m³)	Trailer	200	2 000	350	29
Type I (Steel)	Tank (7 m ³)	35	7 000	236	19.7
Type I (Steel)	Tank (14 m ³)	35	14 000	473	39.4
Type I (Steel)	Tank (28 m ³)	35	28 000	946	78.8
Composite type III	Bottles 74 L	595	74	20	1.8
Type IV	Rack H4 B142	525	568	207.5	18.7
	Bottle 80	700	80	35.8	3.2
	Rack H4 B142	700	568	254.1	22.8
	B142	700	142	63.5	5.7

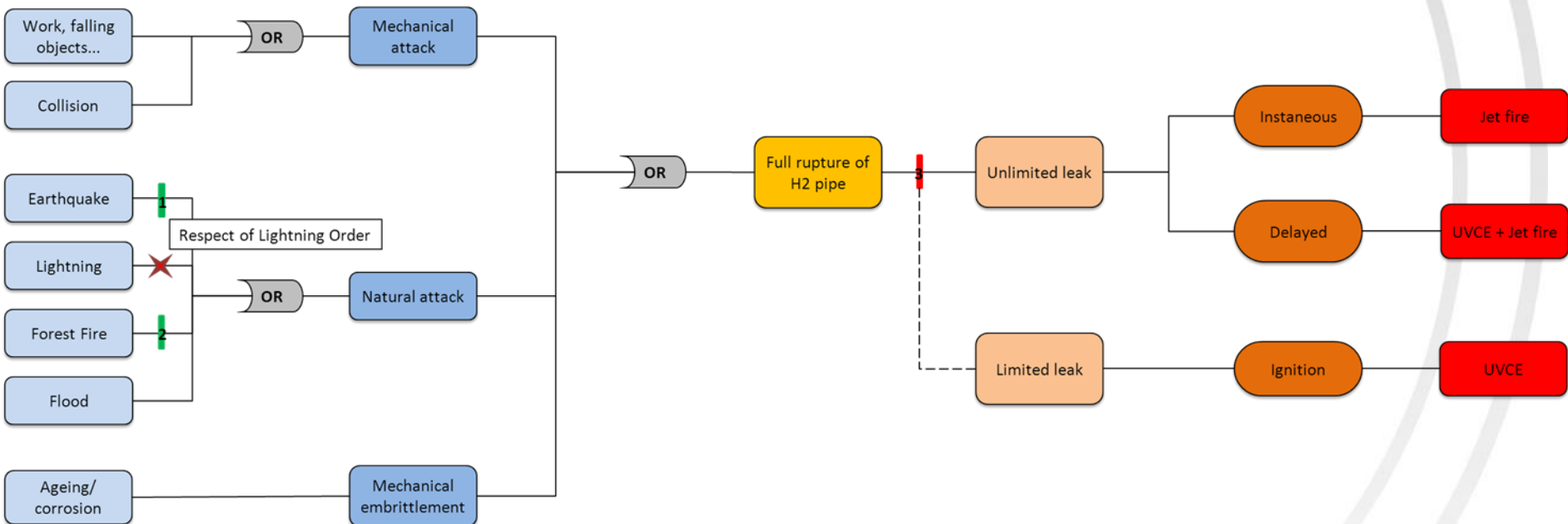


Hazard identification for stationary storages and piping systems

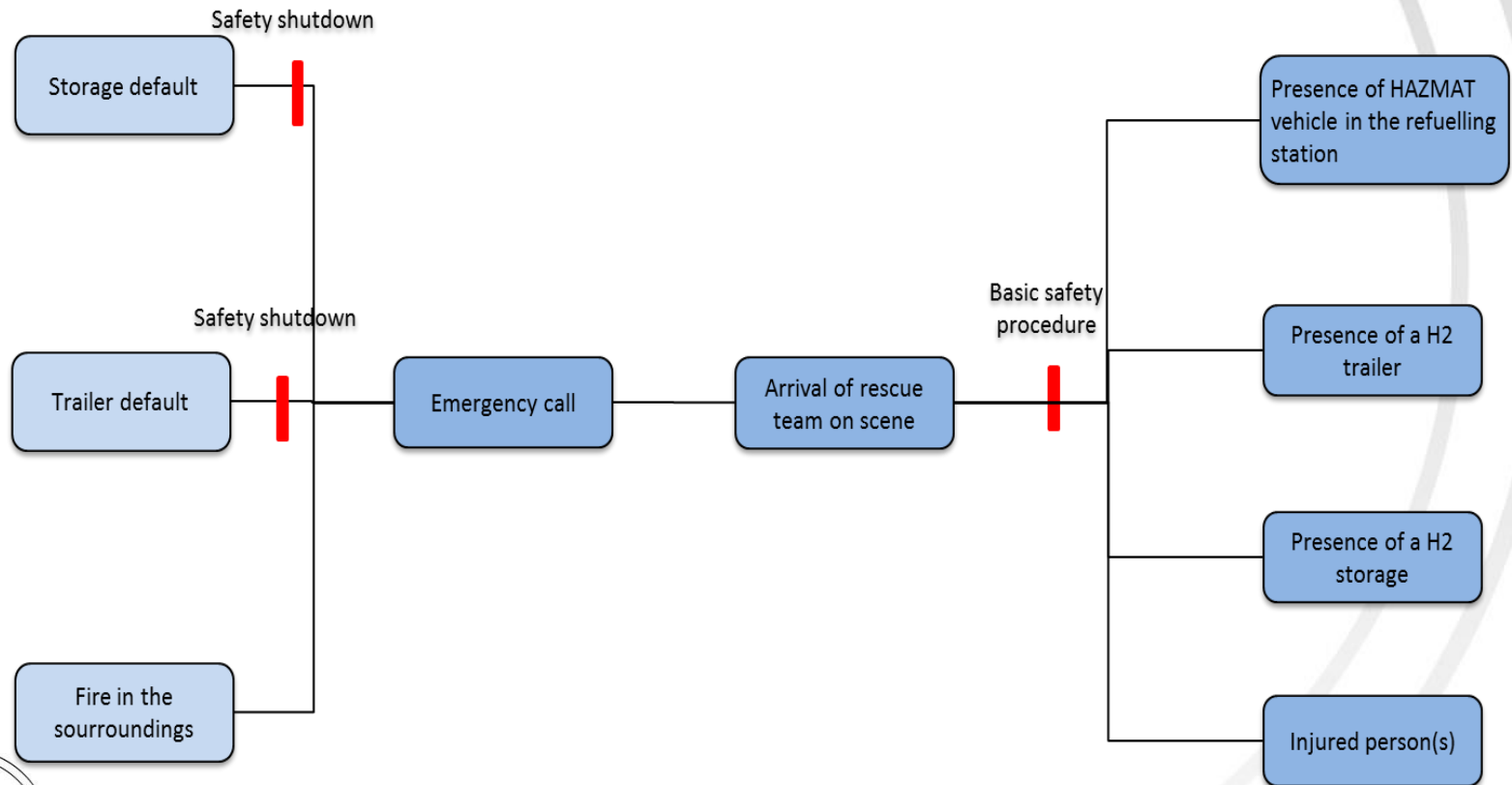
Products	Equipment of hazards	Potential hazard
Hydrogen	Tanks	Burst
Hydrogen	Pipes	UVCE Jet Fire



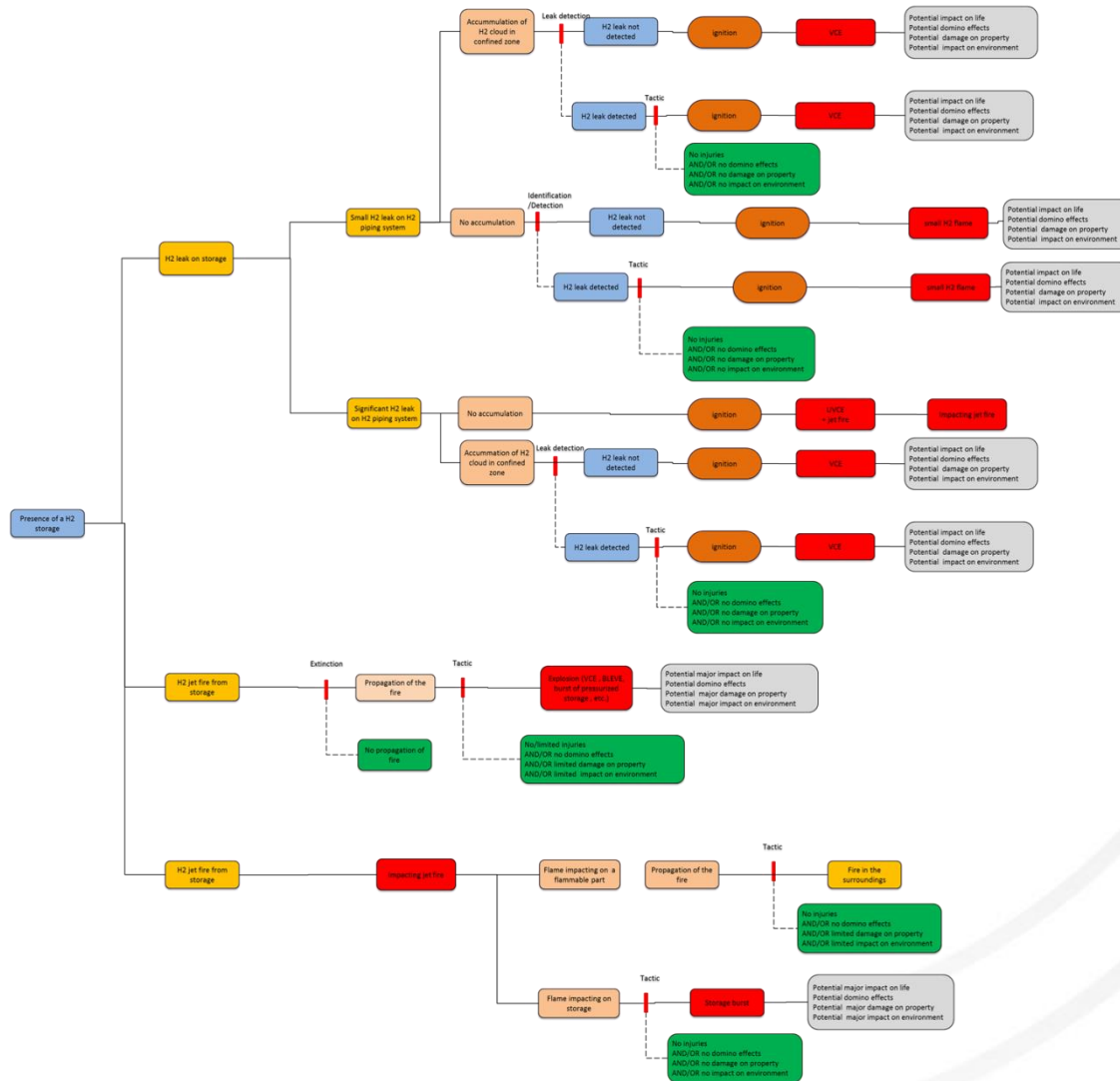
Example of Fault/Event tree analysis for piping system



Example of scenario sequence for a storage and distribution platform



Example of possible scenario for a storage and distribution platform



Blowdown time as a function of tank type, pressure and leak size

Type of tank	Storage pressure (bar)	Blowdown time						
		0.1 mm	0.25 mm	1 mm	2.3 mm	4 mm	5.3 mm	9.1 mm
B20 (20 l)	200	128 min	21 min	-	-	5 s	-	-
B50 (50 l)	200	320 min	52 min	-	-	12 s	-	-
Rack V9 B50	200	48 h	461 min	-	-	2 min	-	-
Rack V18 B50	200	96 h	921 min	-	-	4 min	-	-
Trailer (2 m ³)	200	213 h	34.08 h	-	-	8 min	-	-
Tank (7 m ³)	35	-	-	-	-	-	-	6 min
Tank (14 m ³)	35	-	-	-	-	-	-	13 min
Tank (28 m ³)	35	-	-	-	-	-	-	25 min
Bottles 74 L	595	10 h	2 h	6 min	-	23 s	-	-
Buffer 1 m3	450	144 h	23 h	-	-	-	3 min	1min
Buffer 2 m3	450	288 h	46 h	-	-	-	6 min	2 min
Rack H4 B142	525	86 h	14 h	52 min	10 min	-	-	-
Bottle 80	700	13 h	127 min	8 min	1.5 min	-	-	-
Rack H4 B142	700	93 h	15 h	56 min	11 min	-	-	-



Distances of thermal and overpressure effects due to a pipe rupture/leak in the open environment

Type of tanks	Piping leak diameter, mm	Pressure of the tank (bar)	Direct ignition (JET FIRE)					Delayed ignition (UVCE)			
			Thermal effects (m)			Flame length (m)		Overpressure effects (m)			
			3 kW/m ²	5 kW/m ²	8 kW/m ²	L	r	20 mbar	50 mbar	140 mbar	200 mbar
Tank (7 m ³)	0.1	35	0.06	0.06	0.06	0.06	0.01	-	-	-	-
Tank (14 m ³),	1	35	0.8	0.8	0.7	0.7	0.1	-	-	-	-
Tank (28 m ³),	5	35			3.9	3.9	0.7	-	-	-	-
Tank (56 m ³),	10	35	14	12	10	8	1.3	40	20	8.5	6.1
Trailer, Tank V9 B50, Tank V18 B50	0.1	200	0.2	0.2	0.2	0.2	0.03	0.5	-	-	-
	0.2	200	0.5	0.4	0.4	0.4	0.06	1	0.5	-	-
	4	200	11	9	8	7	1.2	20	10	6	5
	Full rupture of flexible of trailer	200	7.2	7.2	7.2			13.1	8.2		
Buffer 1 m ³ .	0.1	450	0.2	0.2	0.2			0.8	0.4		
Buffer 2 m ³	4	450	16	14	12	11	1.8	30	15	9	7
Tank H4 B142	0.1	525	0.4	0.3	0.3	0.4	0.06	1	0.5	-	-
	0.21	525	0.7	0.6	0.6	0.8	0.13	2	1	-	-
	2.3	525	9	7.9	7	7	1.2	18	9	6	5
	4	525	17	15	13	12	2	32	16	9	8
	5.2	525	22	19	17	15	2.5	42	21	12	10
Tank H4 B142	0.1	700	0.2	0.2	0.2	0.5	0.08	1	0.5	-	-
	0.2	700	0.8	0.4	0.4	0.8	0.13	2	1	-	-
	2.3	700	10	9	8	8	1.3	22	11	6	5
	4	700	19	17	15	14	2.3	38	19	11	9

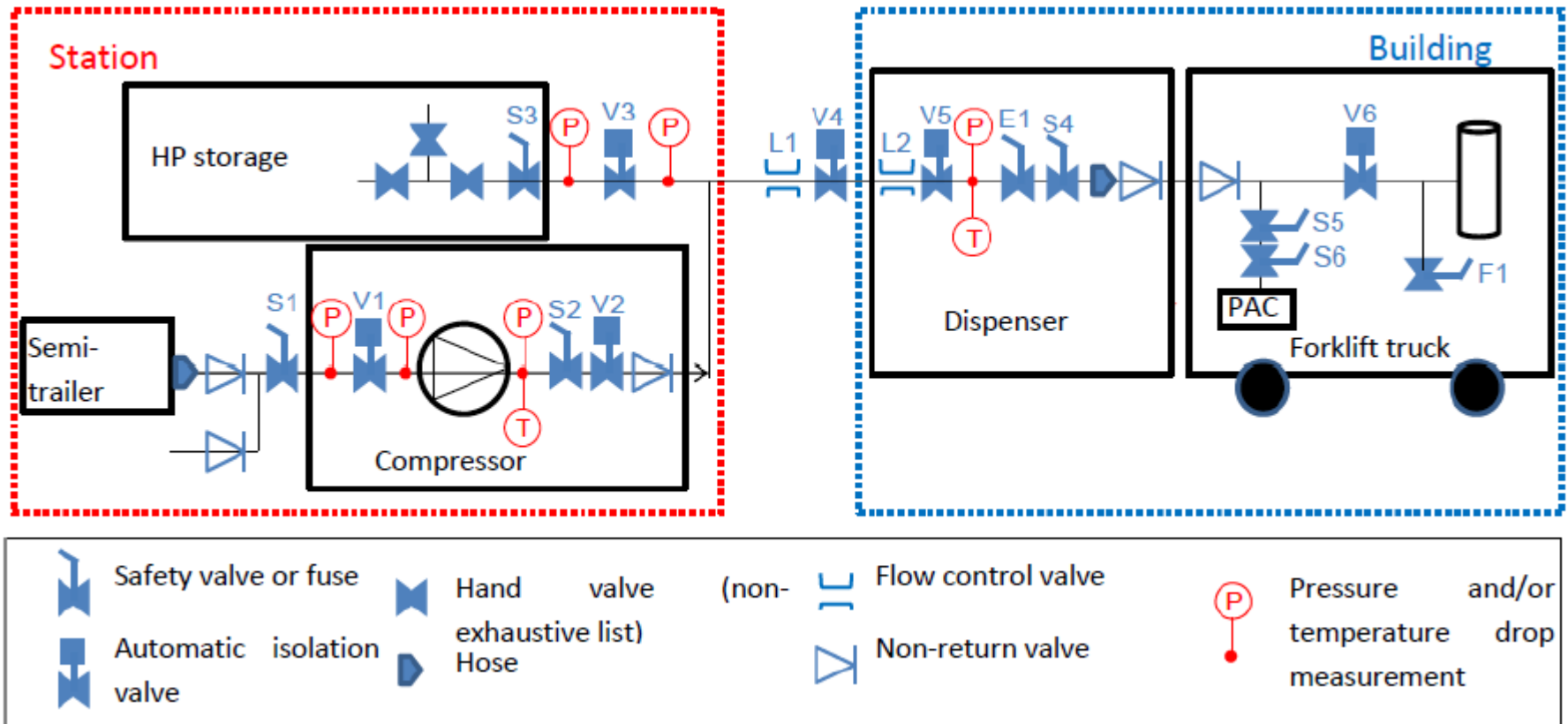
Distances of the overpressure effects due to tank burst

Type of storage	Tank capacity	Storage pressure (bar)	Overpressure burst (bar)	Significant lethal effects – Domino effects 200 mbar (m)	Lethal effects 140 mbar (m)	Irreversible effects 50 mbar (m)	Indirect effects : broken glass 20 mbar (m)
Type I	B20 (20 l)	200	380	5	6	16	32
Type I	B50 (50 l), Rack V9 B50, Rack V18 B50	200	380	7	9	22	44
Type I	Tank (7 m ³)	35	53	18	22	55	110
Type I	Tank (14 m ³)	35	53	22	28	69	139
Type I	Tank (28 m ³)	35	53	28	35	87	175
Type I	Tank (56 m ³)	35	53	35	44	110	220
Type I	Trailer (2 m ³)	200	430	22	29	67	134
Type I	Buffer (cigar) 1 m ³	450	675	23	29	72	145
Type I	Buffer 2 m ³	450	675	26	36	85	170
Type IV	Rack H4 B142	525	578	9	13	31	62
Type IV	Bottle 80	700	770	9	12	28	56
Type IV	Rack H4 B142	700	770	13	16	40	79
Type I	Buffer (cigar) 1 m ³	1000	2000	34	40	105	211
Type I	Buffer 2 m ³	1000	2000	42	50	133	266

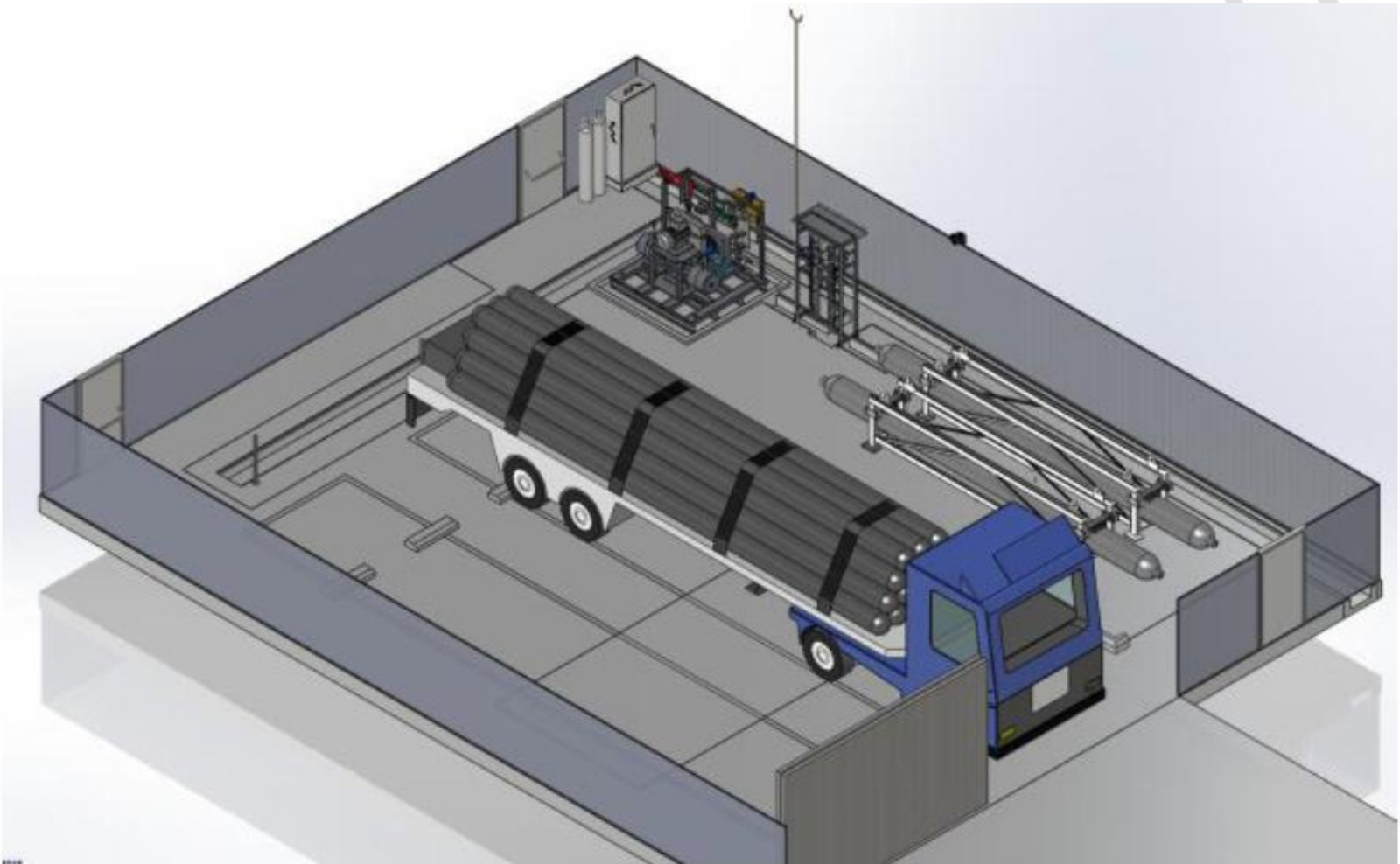


Hydrogen refuelling station

Overall process



Typical layout of an outdoor area



Compressor

- A compressor comprises:
 - a diaphragm or hydraulic compressor for the hydrogen,
 - a compressor cooling system,
 - miscellaneous equipment (valves, relief valves, etc.).



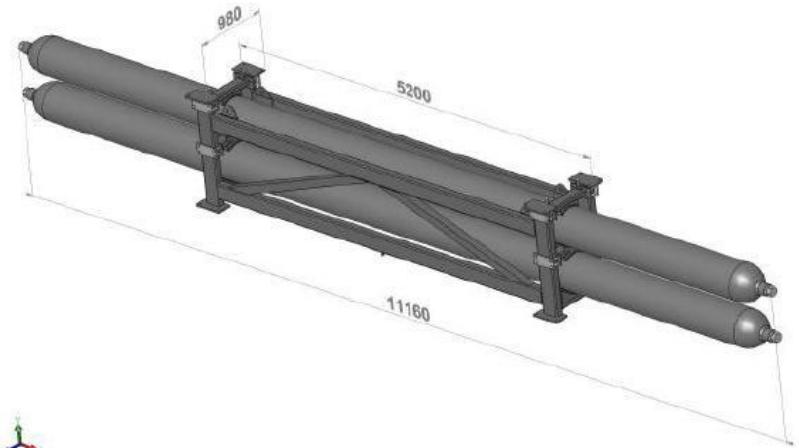
Compressor in a container



Compressor in protected by a shed

HP Storage (or "buffer")

- Compliant with the Pressurised Equipment Directive (DESP)
- Volume : between 1,000 and 3,000 L in water
- HP storage is:
 - 450 bar for forklift truck
 - 1000 bar for car
- Storage is protected by a relief valve
- Relief valve is evacuated through the same vent stack as that the compressor



Connecting piping work

- Connects HP storage to the dispenser
- Length can vary between several tens and several hundreds of meters
- Outdoor routing preferable to avoid the risk of a leak indoors
- Parts crossing access roads are contained in a channel or supported on a gantry or buried
- Exposed parts are protected (possibly physical protection on vertical sections, passing through walls or on a roof)
- Pipework enters the building at the last possible moment for connection to the dispenser
- The characteristics of the pipework are:
 - Material: compatible with the use of hydrogen (example: 316L stainless steel).
 - Outside diameter: less than 1" depending on the length of the pipework.



The dispenser

- The dispenser may be installed in one of three different places:
 - in a storage cell
 - in a dedicated room,
 - outside
- A naked flame detector (UV/IR sensor appropriate to the radiation characteristics of a hydrogen flame) could be positioned above the dispenser
- Hydrogen detection is installed in the dispenser at the top of the mast (25% of the LEL)
- During the filling stages, if the flame or H₂ detector triggers, then all isolation close and vent valve opens.
- Other than during the filling phase, the isolation valves are closed and the vent valve is open.

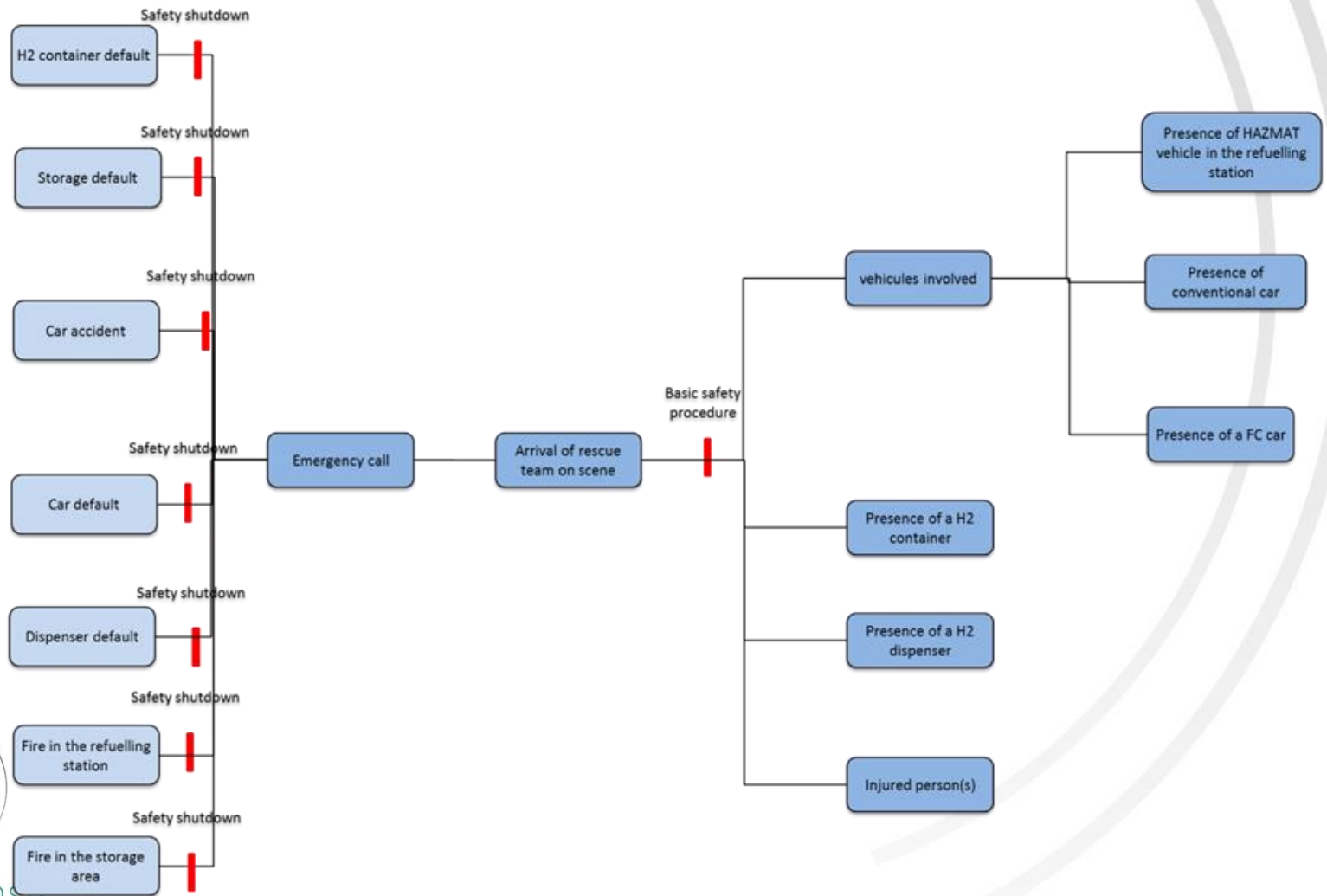


Hazard identification

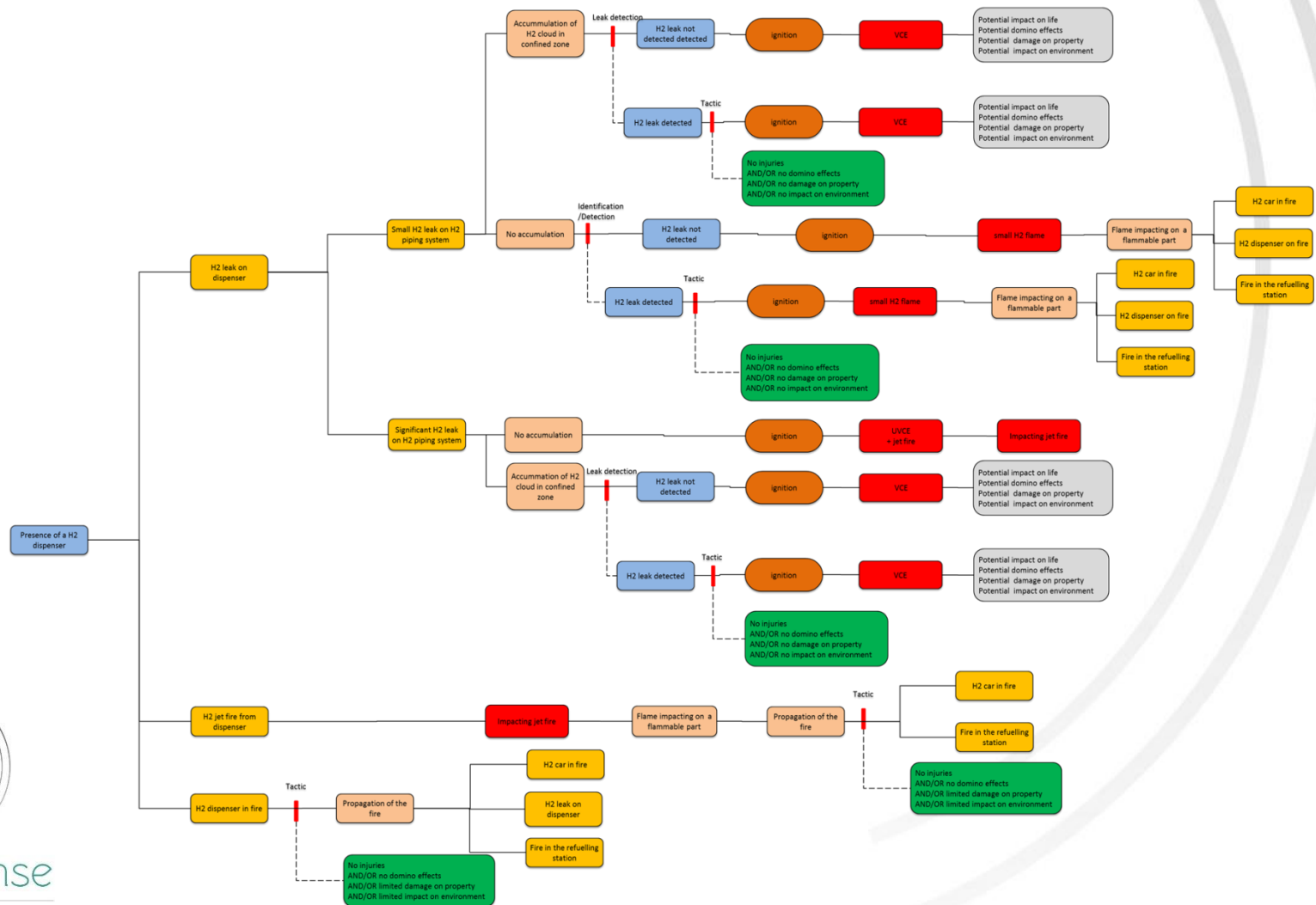
Products	Equipment of hazards	Potential hazard
Flammable materials	vehicles, batteries, containers, tyres, engine, etc.	Fire, toxic smoke
Hydrogen	Tanks	Burst
Hydrogen	Pressure relief valve	UVCE Jet Fire
Hydrogen	Pipes and other components	UVCE Jet Fire
Electricity	Cable/cabinets	Electrocution



Example of scenarii at a refuelling station



Example of scenarii at a refuelling station



Hydrogen jet fires from piping system

Piping leak diameter, mm	Pressure of the tank (bar)	Direct ignition (JET FIRE)					Delayed ignition (UVCE)			
		Thermal effects (m)			Flame length (m)		Overpressure effects (m)			
		3 kW/m ²	5 kW/m ²	8 kW/m ²	L	r	20 mbar	50 mbar	140 mbar	200 mbar
1	200	3.1	2.9	2.7	1.3	0.22	-	-	-	-
2.3	200	5.6	5.4	5.2	3	0.5	17	8.5	3.8	2.7
4	200	11	10.5	10	5.5	0.9	30	15	6.5	4.8
1	350	3.2	3	2.8	1.6	0.3	9.5	4.8	2	1.5
2.3	350	7	6.5	6	3.8	0.6	22	11	4.7	3.4
1	700	3.5	3.3	3	1.9	0.3	12	6	2.6	1.9
2.3	700	10	9	8	4.7	0.8	29	14.5	6.1	4.5
1	1000	4.3	4.1	3.9	2.1	0.4	13.8	6.9	2.9	2.3
2.3	1000	10	9	8	5	0.85	32	16	6.7	4.9



Hydrogen accumulation followed by an explosion in a containerized compressor

Hazardous phenomena	Volume, m ³	Free volume 70%	Significant lethal effects – Domino effects 200 mbar (m)	Lethal effects 140 mbar (m)	Irreversible effects 50 mbar (m)	Indirect effects : broken glass 20 mbar (m)
Explosion of container 10 feet L x l x H (m): 3 x 2.4 x 2.4	17	12	14	17	40	80
Explosion container 20 feet L x l x H (m): 6 x 2.4 x 2.4	34	24	17	21	51	102



Thank you for your attention

<http://www.hyresponse.eu/>

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