



TotalEnergies

Powder to kill explosion (VEMIS system)

EPSC Technical Meeting

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Didier Batherosse

Current position: **TotalEnergies**, Headquarters | HSE Major Risks Division
Process Safety Expertise & Integrity Management

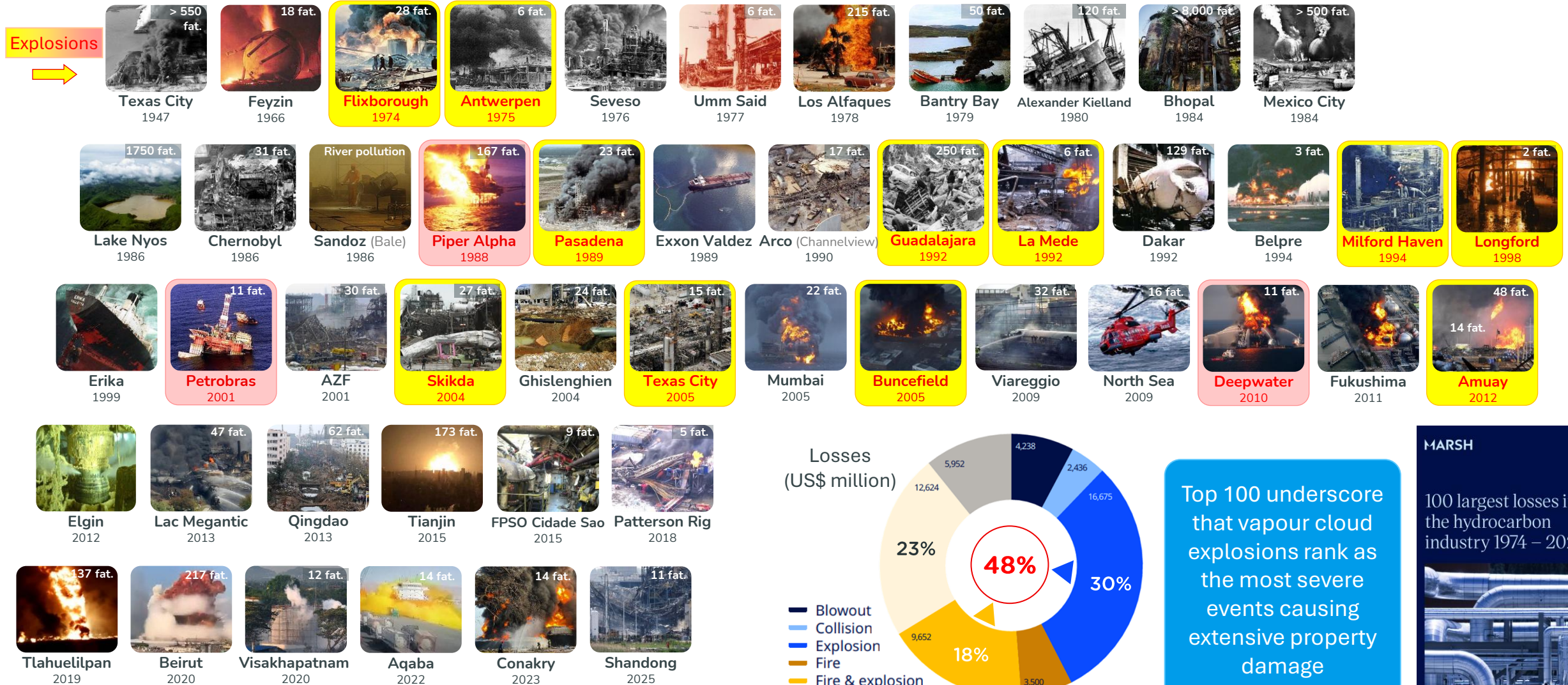
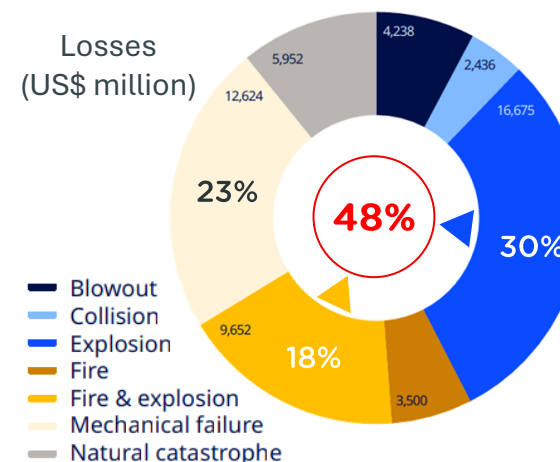
Experience: 28 years in process safety and risk management for Oil & Gas (upstream, downstream, hydrocarbon depots, LNG terminal), chemicals, pipelines, and mining industries.

Academic career:

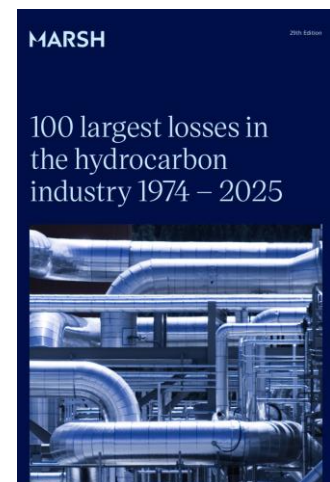
- Functional Safety Engineer, Quali-SIL certification, INERIS.
- Field Processing and Surface Production Facilities (Upstream), IFP school.
- Master of Science Degree in Risk Management and Environment (IMT Mining school Alès, 1996).
- **Large-scale atmospheric dispersion tests of ammonia** with local fire brigade (Alès, 1995-1996):
 - Concentration monitoring with/without water curtains generated with a peacock tail.
 - Development of an easy digital tool for fireman to estimate quickly safety distances.
 - These experiments were conducted before large scale experiments organized by INERIS (1999).



Explosion one of the most feared accident in industry



Top 100 underscore that vapour cloud explosions rank as the most severe events causing extensive property damage



Vapour cloud explosion frequencies

Unit	Event	Per 10.000 year
Ethylene Oxide	Vapour Cloud Explosion	58
Steam cracker	Vapour Cloud Explosion	43
FCCU	Vapour Cloud Explosion	13
Vacuum distillation	Large fire	10.6
Polyethylene (HD)	Vapour Cloud Explosion	5.99
Polyethylene (LD)	Vapour Cloud Explosion	5.13
Atmospheric Distillation	Vapour Cloud Explosion	4.9
HDS (refinery)	Major Fire	4.16
Polypropylene	Vapour Cloud Explosion	4.1
Hydrotreater	Vapour Cloud Explosion	2.8
Polystyrene	Vapour Cloud Explosion	< 1.1
HDS (refinery)	Vapour Cloud Explosion	0.52

Average frequency of VCE

$\sim 5.10^{-4}$ / year

Number of process units in large oil company

~ 200

Probability of major VCE in large oil company

Once every 10 years !



La Mède, 1992



Buncefield, 2005

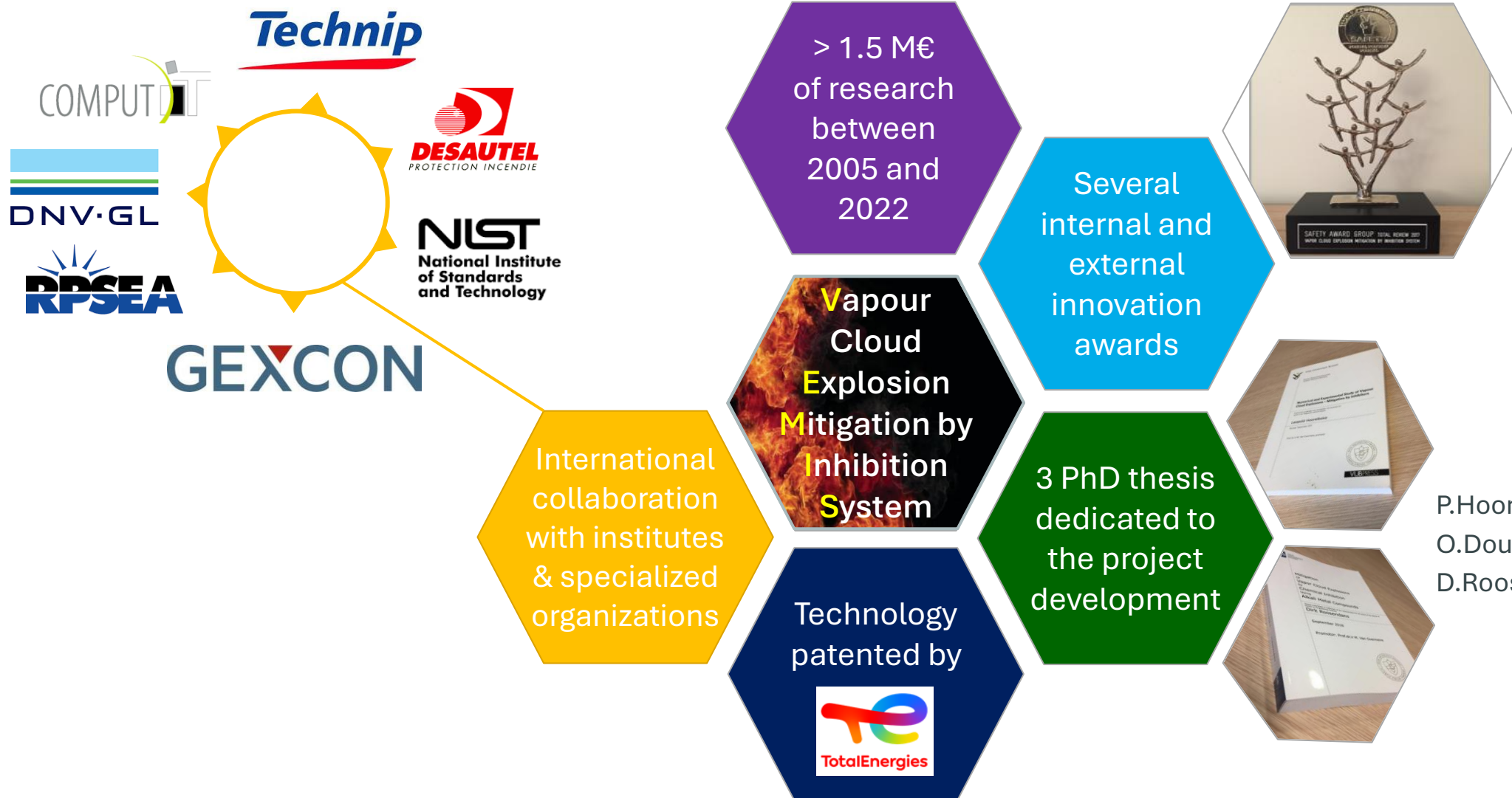


Texas City, 2005



Macondo, 2010

VEMIS project characteristics



P.Hoorelbeke (2011)
O.Dounia (2017)
D.Roosendans (2018)

Vapour Cloud Explosions (experiment)

6 kg of natural gas



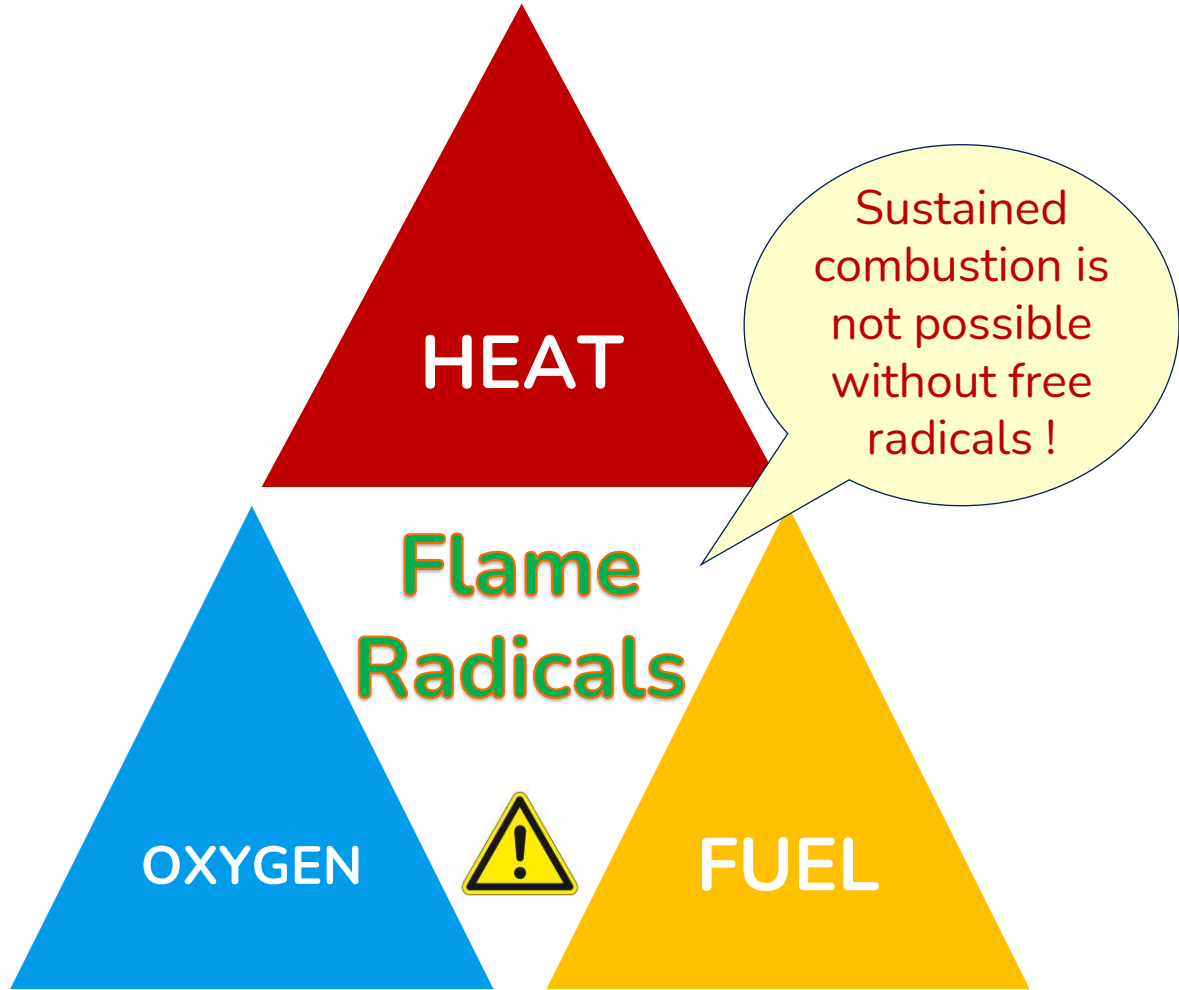
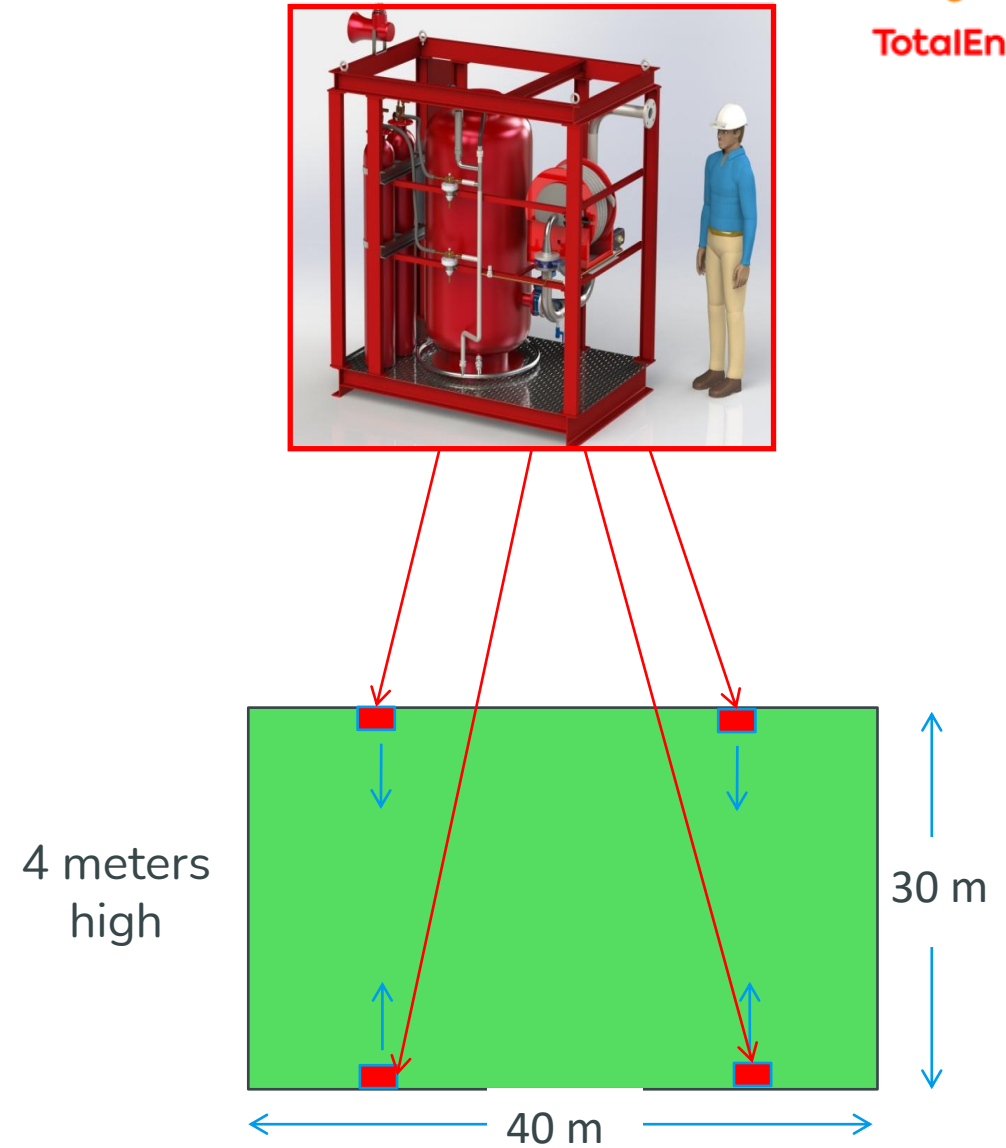
Vapour Cloud Explosions



Facilities with potential large gas cloud > 1000 kg within very dense/congested areas



VEMIS technology



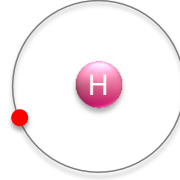
Radicals and combustion reactions

The **combustion mechanism** is not simply a direct reaction between fuel and oxygen. It proceeds through a complex series of chain reactions involving free radicals

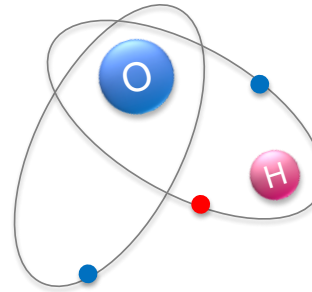
What are free radicals in combustion mechanism?

Free radicals are highly reactive chemical species that contain one or more unpaired electrons. Because they are unstable, they react rapidly with other molecules and play a crucial role in sustaining a flame.

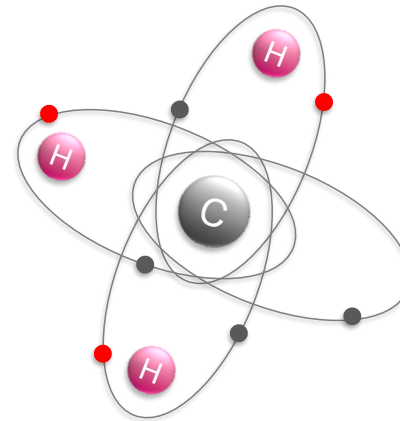
1) **Initiation**: creation of radicals



2) **Chain propagation**: multiplication of radicals



3) **Termination**: elimination of radicals

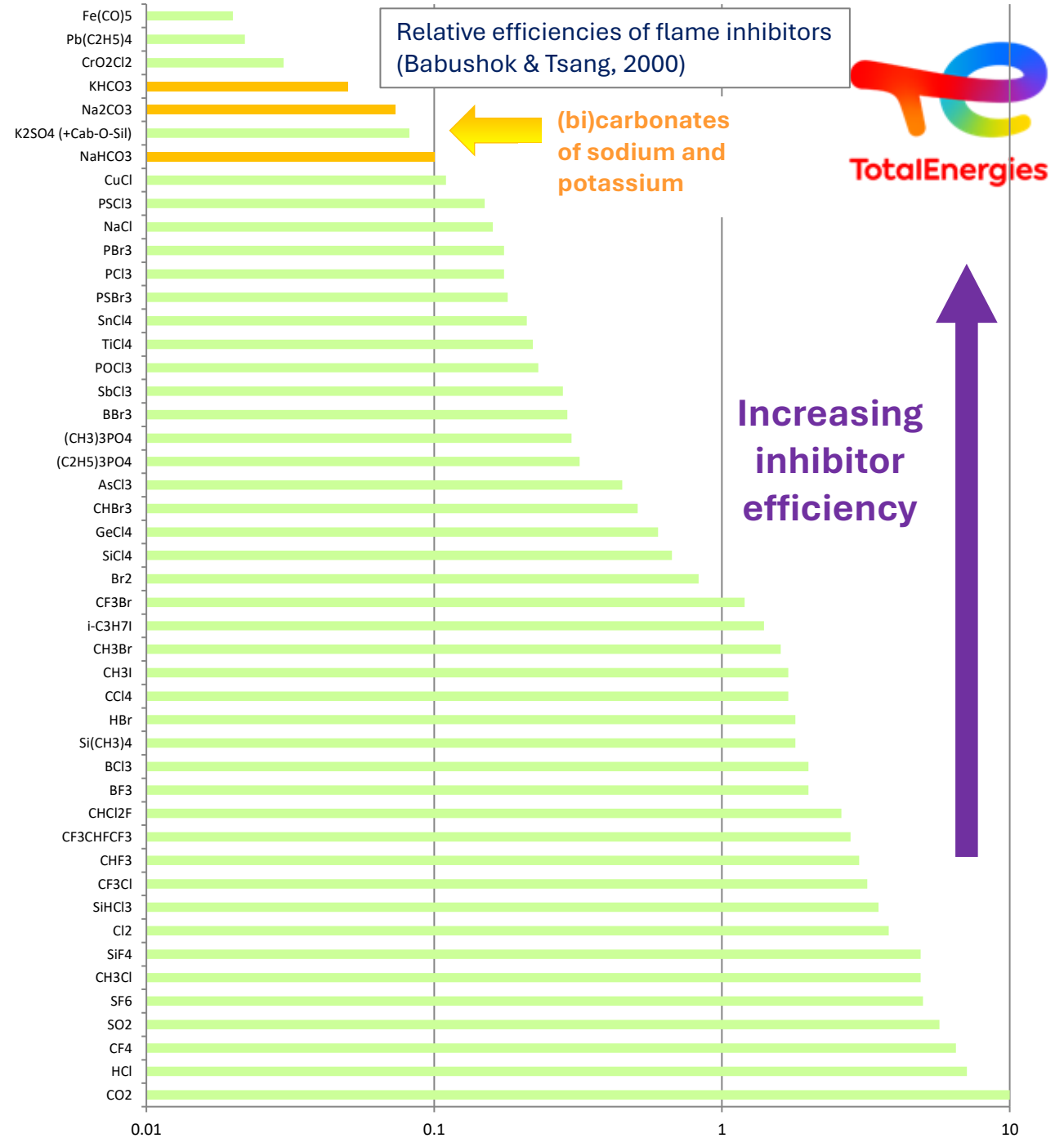


Let us try to disturb
the chemical chain
reaction!

Inhibitor efficiencies

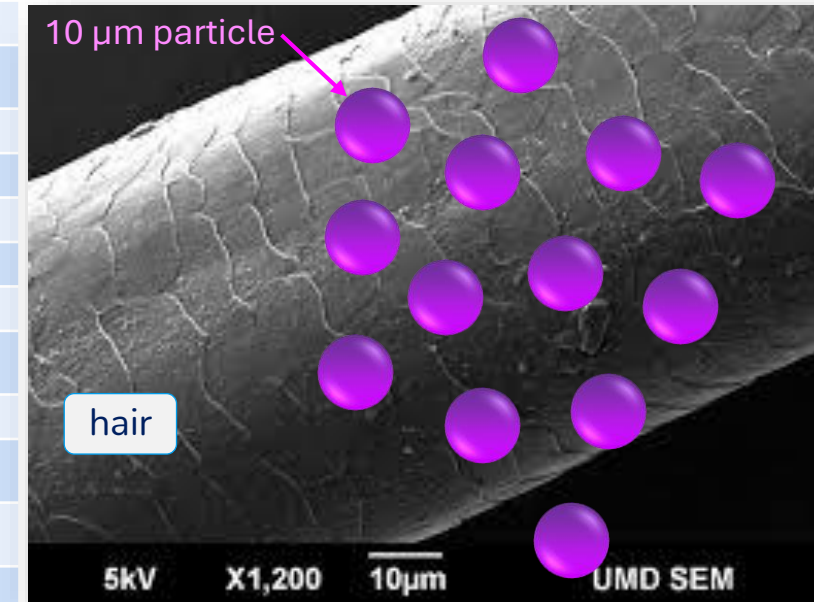
Experiments in literature show that carbonates, and bicarbonates of sodium and potassium are **very effective** flame inhibitors !

These inhibitors are also **compatible** with the use in an industrial environment (toxicity, stability, corrosive properties, cost, availability,...)



Influence of particle size

Particle material	Flame Type	Optimum particle diameter (µm)	Reference
Water	Laminar stoichiometric premixed methane/air flame	10	Yang and Kee (2002) Fuss et al (2002) Fleming et al (2002)
	Laminar non premixed counter flow methane/air flame	15 - 20	Seshadri (1978)
	Laminar non-premixed counter flow propane/air flames	14	Chin and Lefebvre (1983) Fleming et al (2002)
	Turbulent flames	10	Van Wingerden (2000)
	Turbulent flames	30	Acton et al (1990)
	Turbulent flames	18	Sapko et al (1977)
	Counter diffusion methane flame	~ 20	Lentati and Chelliah (1998)
NaHCO ₃ , KHCO ₃	Laminar propane/air counter flow non-premixed flame	< 38	Fleming et al (1998)
NaHCO ₃	Heptane pool fire	< 16	Ewing et al (1984) Ewing et al (1989)
	Laminar non-premixed counter flow methane/air-flame	0 – 10	Chelliah et al (2002)
	Counter flow diffusion methane flame	< 20	Lintaris et al (2001) Wanigarathne et al (2000)
	Counter flow diffusion flame, liquid heptane	0 – 10	Hamins et al (1994) Trees et al (1997)
	Simulation of hydrogen/air flame at $\phi = 0.5$ (burning velocity of 50 cm/s) and $\phi = 1.4$ (burning velocity of 300 cm/s)	< 17 µm < 3 µm	Mitani (1983)
	Premixed methane/air flame ($\phi=1.2$)	12 - 28 µm	Iya et al. (1975)
NaHCO ₃ + ...	Turbulent flame inhibited by NaHCO ₃ , KHCO ₃ , Na ₂ CO ₃ , K ₂ CO ₃	< 20	Hoorelbeke (2011)
NaOH solution	Laminar non-premixed methane/air flame	10 – 20	Lazzarini et al. (2000)
	Laminar premixed and non-premixed opposed flow flames	10 – 20	Wanigarathne et al. (2001) Chelliah et al. (2002)
	Counter diffusion methane flame (modeling)	15	Lentati and Chelliah (1998)



To be effective,
inhibitors must be applied
as **very fine powders**

VEMIS technology

Without inhibitor



Notice the
difference in flame
acceleration and
blast overpressure!

With inhibitor

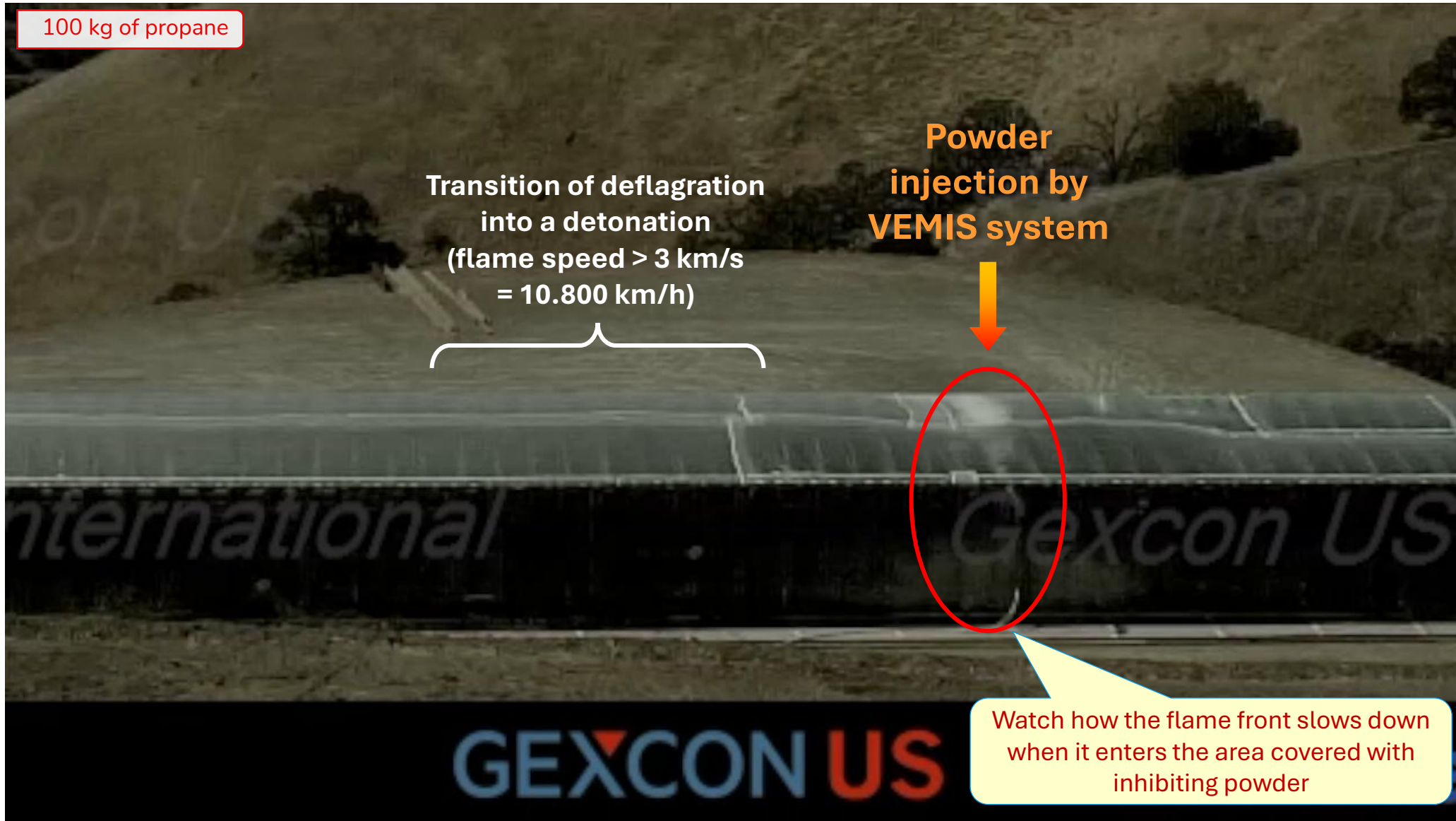


Large scale testing (Livermore, US, 2016)

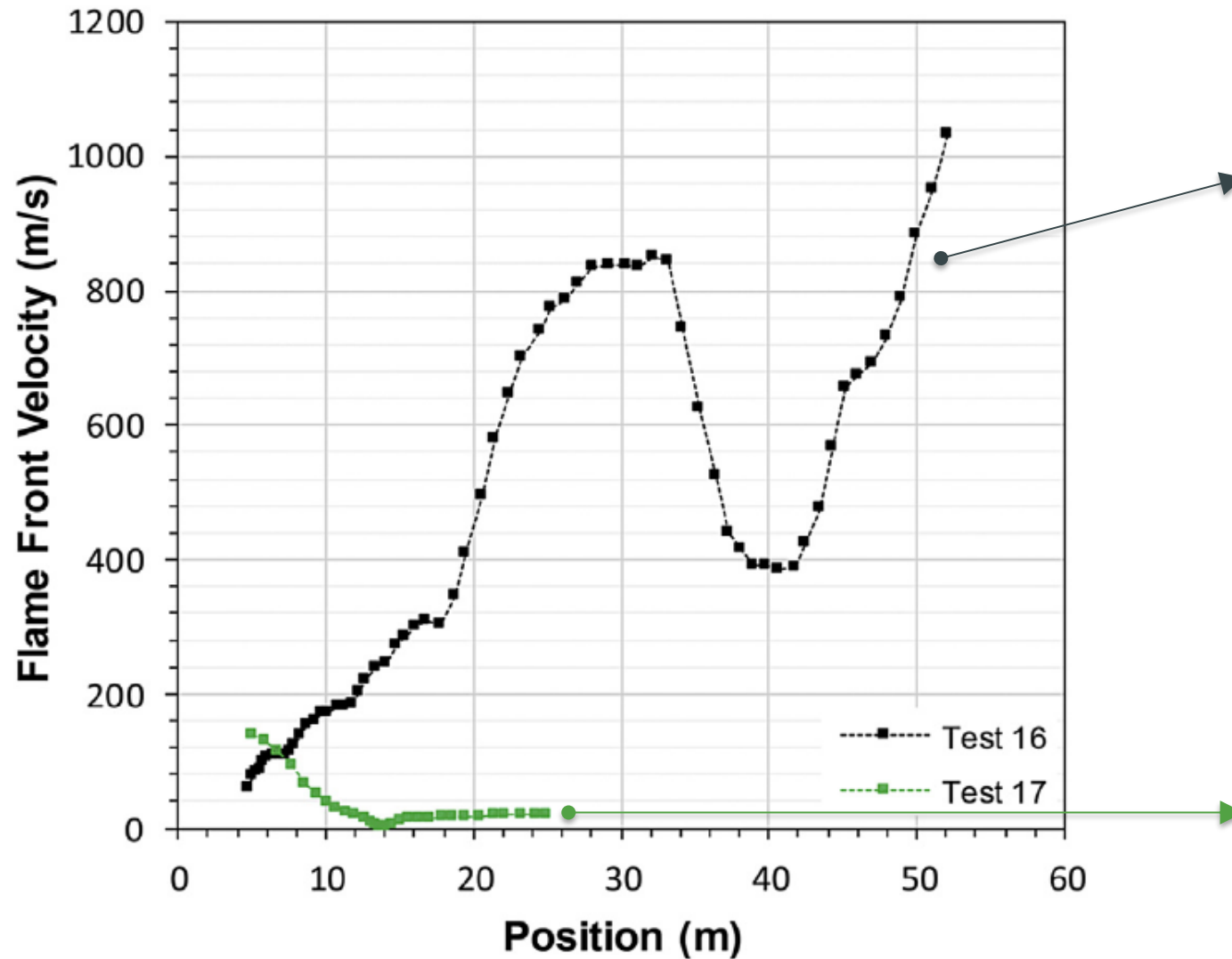


Man walking : to give an idea
of the test rig size

Large scale testing (Livermore, US, 2016)



Large scale testing (Livermore, US, 2016)

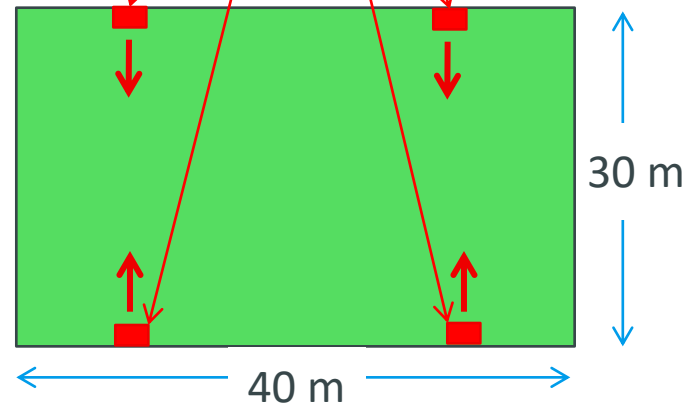
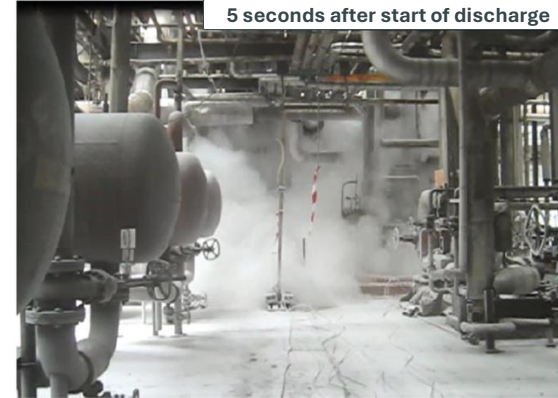


Inhibitor powder dispersion testing



4 skids are needed to protect a process unit volume of about **5.000 m³** (40 m long and 30 m wide)

4 meters high



5 seconds after start of discharge



10 seconds after start of discharge



15 seconds after start of discharge

Visibility in inhibitor powder cloud

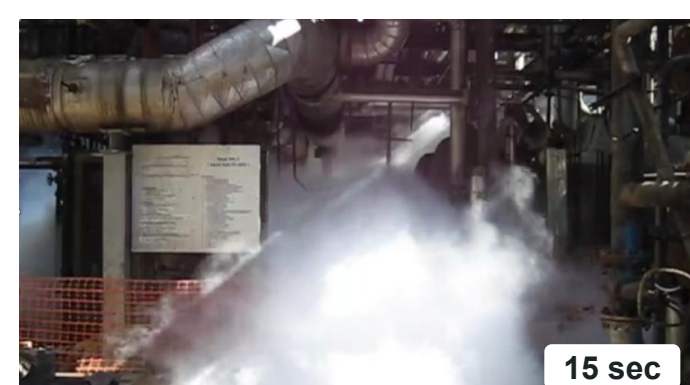
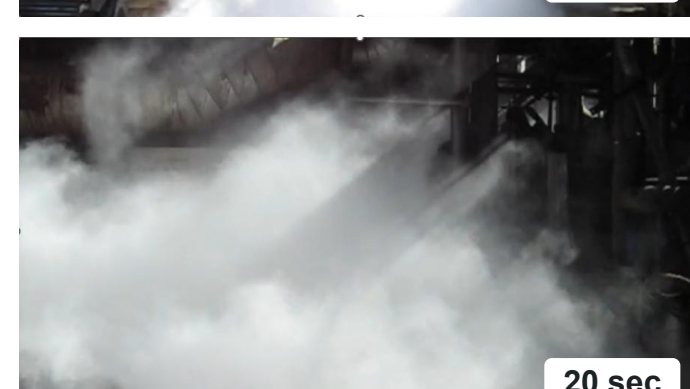
Industrial application of the technology



- **1 skid** = 600 kg capacity of powder
- Duration of release = 5 min at a flowrate of 2 kg/s



Inhibitor dispersion testing (Carling, France)



Detection and activation systems

Pre-ignition strategy

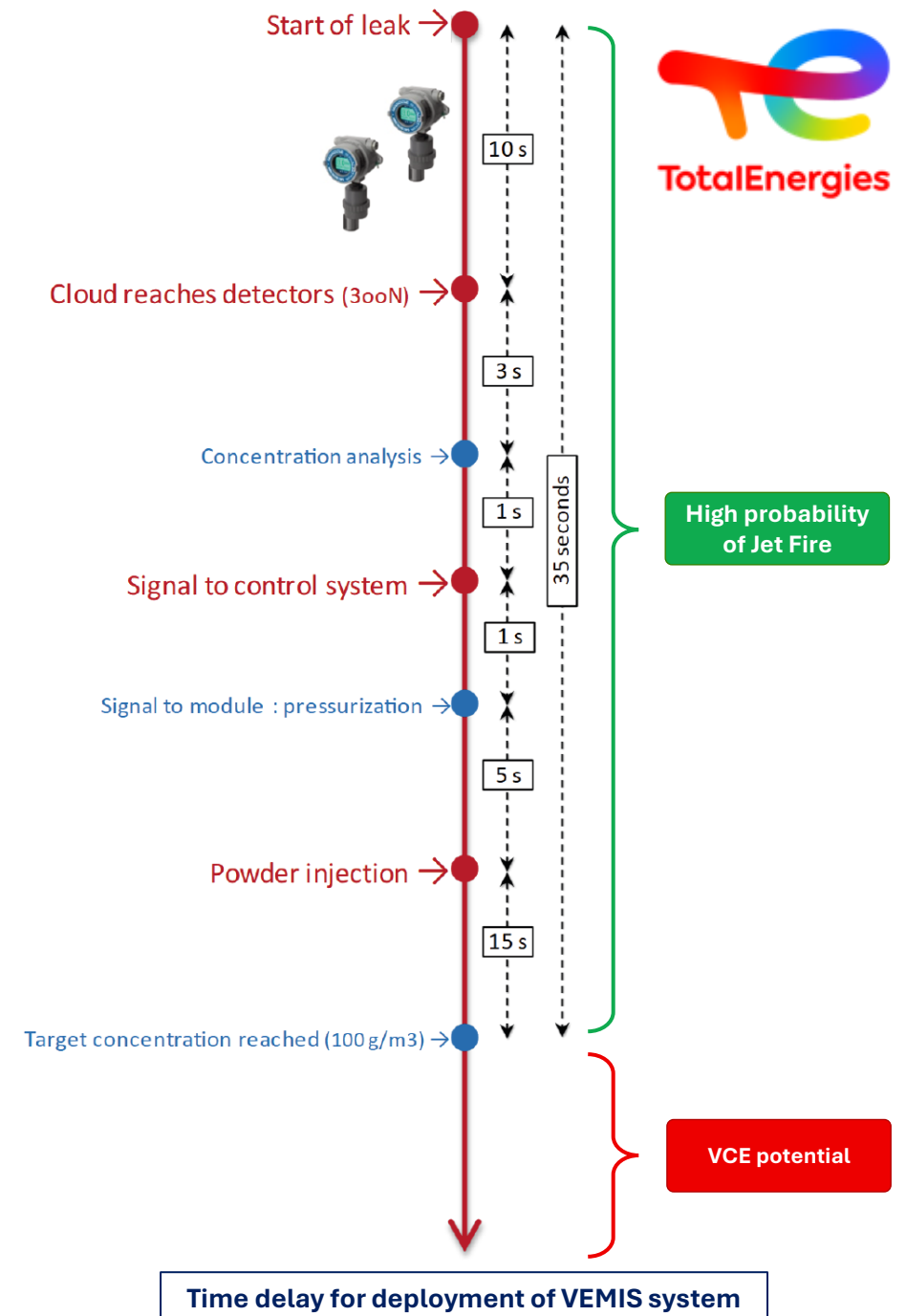
Activation of the inhibitor system is based on gas detection with 2 possibilities :

- **Manual** activation: the activation sequence is started directly by an operator in control room
- **Automatic** activation: the activation sequence is started automatically upon confirmed gas detection

➔ The inhibitor powder can be **spread in 35 seconds !!!**

➔ **Reliability** of VEMIS system:

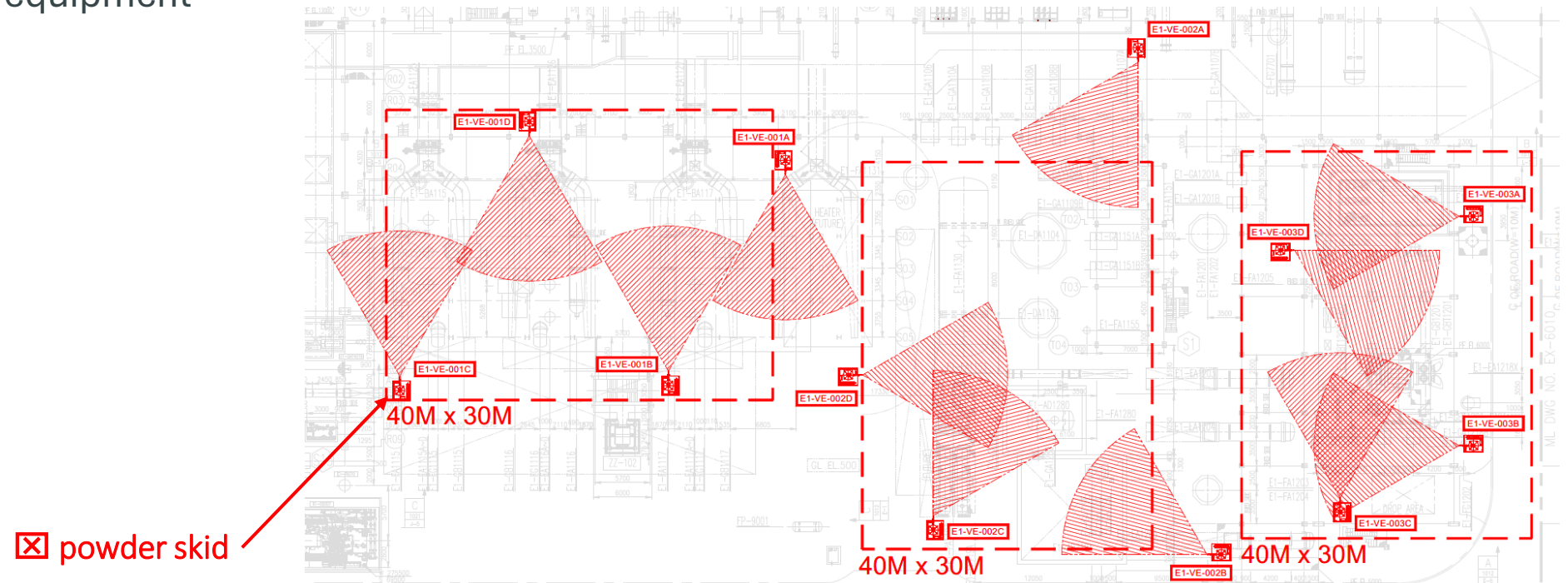
- If redundancy and **efficient gas detection coverage**, then **reliability is SIL2** (PFD = $4E-03$).
- In case of impaired gas detection system, or bad coverage then reliability is SIL1 (PFD = $2E-02$)



Impact after spurious activation

Spurious activation of VEMIS system in 2021 :

- Where? South-Korea, Steam Cracking Unit
- Spurious activation during shutdown (contractor pushing a local pushbutton for activation of the system)
- 10 among 12 VEMIS modules were activated
- No impact on equipment due to very fine powder particle size (cables, instrumentation, ...) or when restarting rotating equipment



Existing and future implementations



Year	Company	Location	Unit
2019	Hanwha TotalEnergies Petrochemical	Daesan (South Korea)	Side Cracker
2020	Hanwha TotalEnergies Petrochemical	Daesan (South Korea)	PE unit ^[1]
2025	ExxonMobil	Rotterdam (Netherlands)	Refinery ^{[2] [3]}
2026	ExxonMobil	Baytown (US)	Refinery ^{[2] [3]}
2026	ExxonMobil	Fawley (UK)	Refinery ^{[2] [4]}

[1] Copy of TotalEnergies technology

[2] Installation of VEMIS as part of facility siting layout issue (no possibility to relocate occupied buildings near units with VCE potential)

[3] Deployment of VEMIS skids in progress.

[4] Evaluation ongoing

Cost of VEMIS implementation
< 1000 €/m² of unit to be protected



VEMIS vs. Reinforcement of occupied buildings

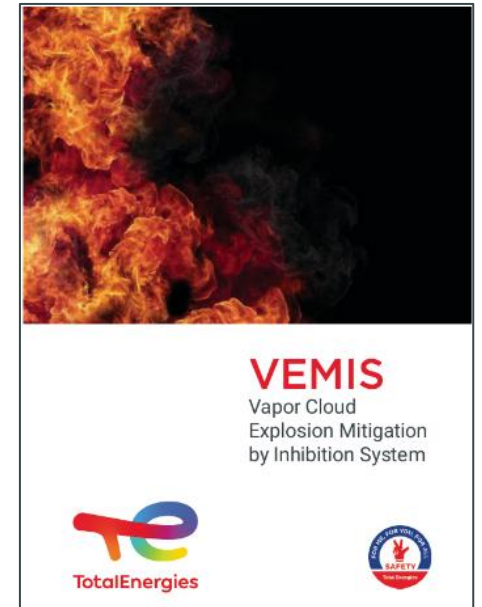


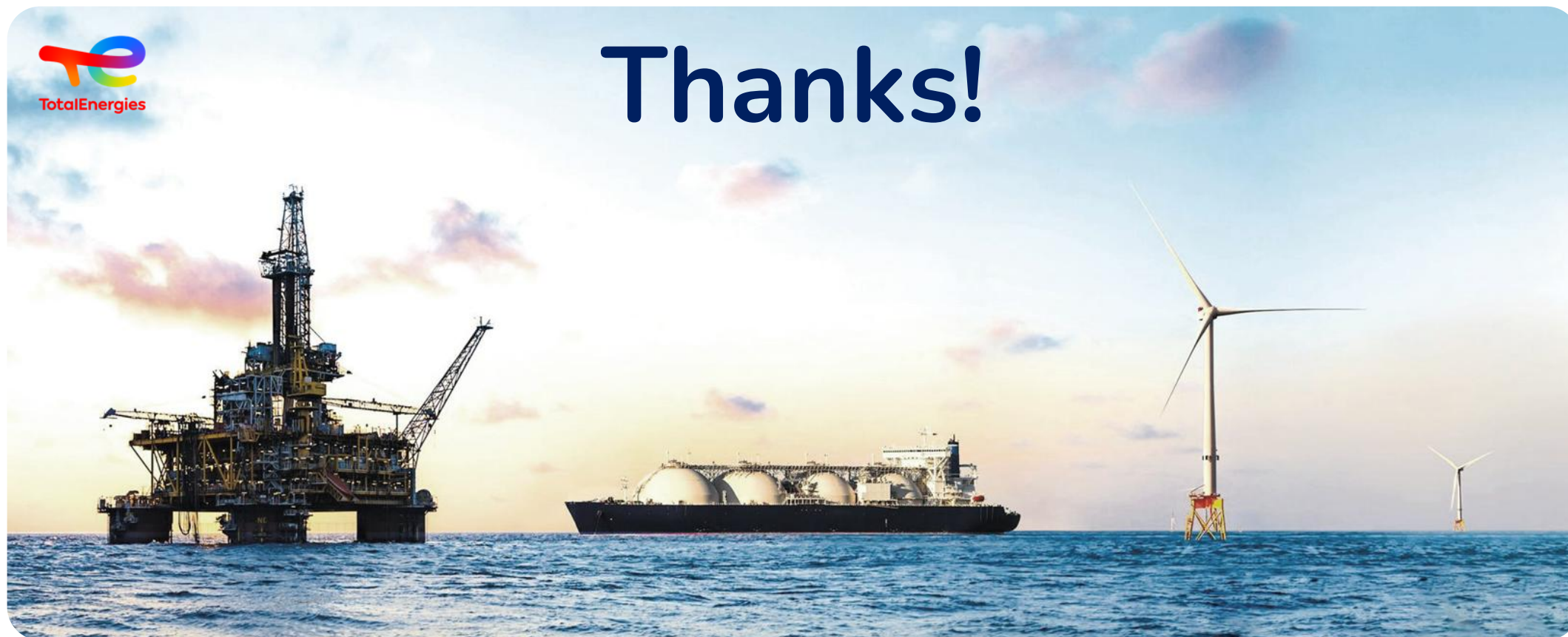
Benefit	Disadvantage	
	Treatment of occupied building	VEMIS system
Cost impact	<ul style="list-style-type: none"> Non-reinforced building $\approx 1.5 \text{ k€}/\text{m}^2$ Reinforced building $\approx 2.5 - 4.0 \text{ k€}/\text{m}^2$ 	<ul style="list-style-type: none"> Median size of congested process unit with VCE potential: $3.000 \text{ to } 4.000 \text{ m}^2$ VEMIS installation cost : 2.7 to 3.3 M€ for an average refinery unit
Protection of people in occupied buildings	Yes	Yes
Protection of assets against explosion and fire	No	Yes
Mitigation of potential domino effects related to vapour Cloud Explosions	No	Yes
Availability / Reliability	Passive protection	Active system SIL2 reliability if redundancy and efficient gas detection coverage

Summary



- VEMIS (Vapour Cloud Explosion Mitigation by Inhibition System) is a proprietary TotalEnergies technology developed to **mitigate the consequences of large Vapour Cloud Explosions** in congested industrial environments (the patent has been abandoned).
- Intent of the VEMIS system (injection of inhibition powder) is **not to replace existing mitigation barriers** (shutdown system, water deluge systems, water curtains,...) but rather to complement existing safety barriers by **rapidly reducing flame acceleration** and blast overpressure following large flammable gas releases.
- VEMIS is a **cost-effective** alternative solution for reinforcement or relocation of building in refineries. It also **mitigates potential escalation effects** against surrounding equipments, and units.





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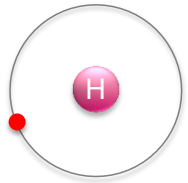
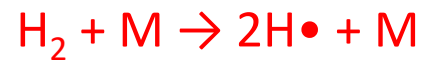
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Backup Slides

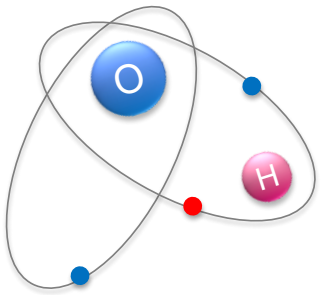
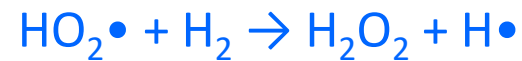
Radicals and Combustion Reactions

Consider the combustion of hydrogen (H_2) in oxygen (O_2): $2\text{H}_2 + \text{O}_2 \rightarrow 2\text{H}_2\text{O}$

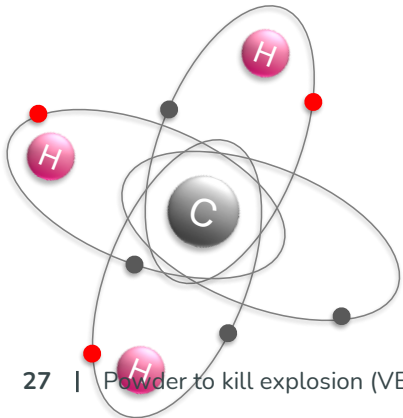
The **combustion mechanism is much more complicated** than suggested by the simple reaction equation and involves dozens of elementary radical reactions



Initiation reactions
(= **creation of radicals**)



Propagation/branching reactions
(= **multiplication of radicals**)



Termination reactions
(= **elimination of radicals**)

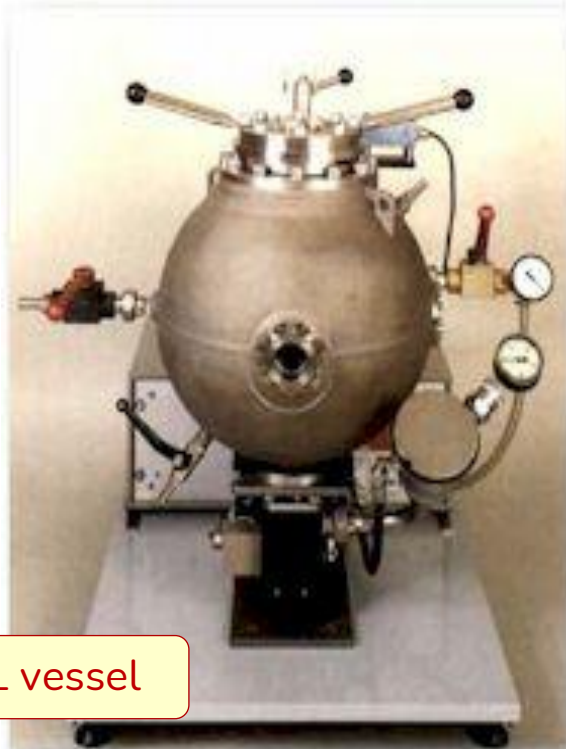
Let us try to disturb
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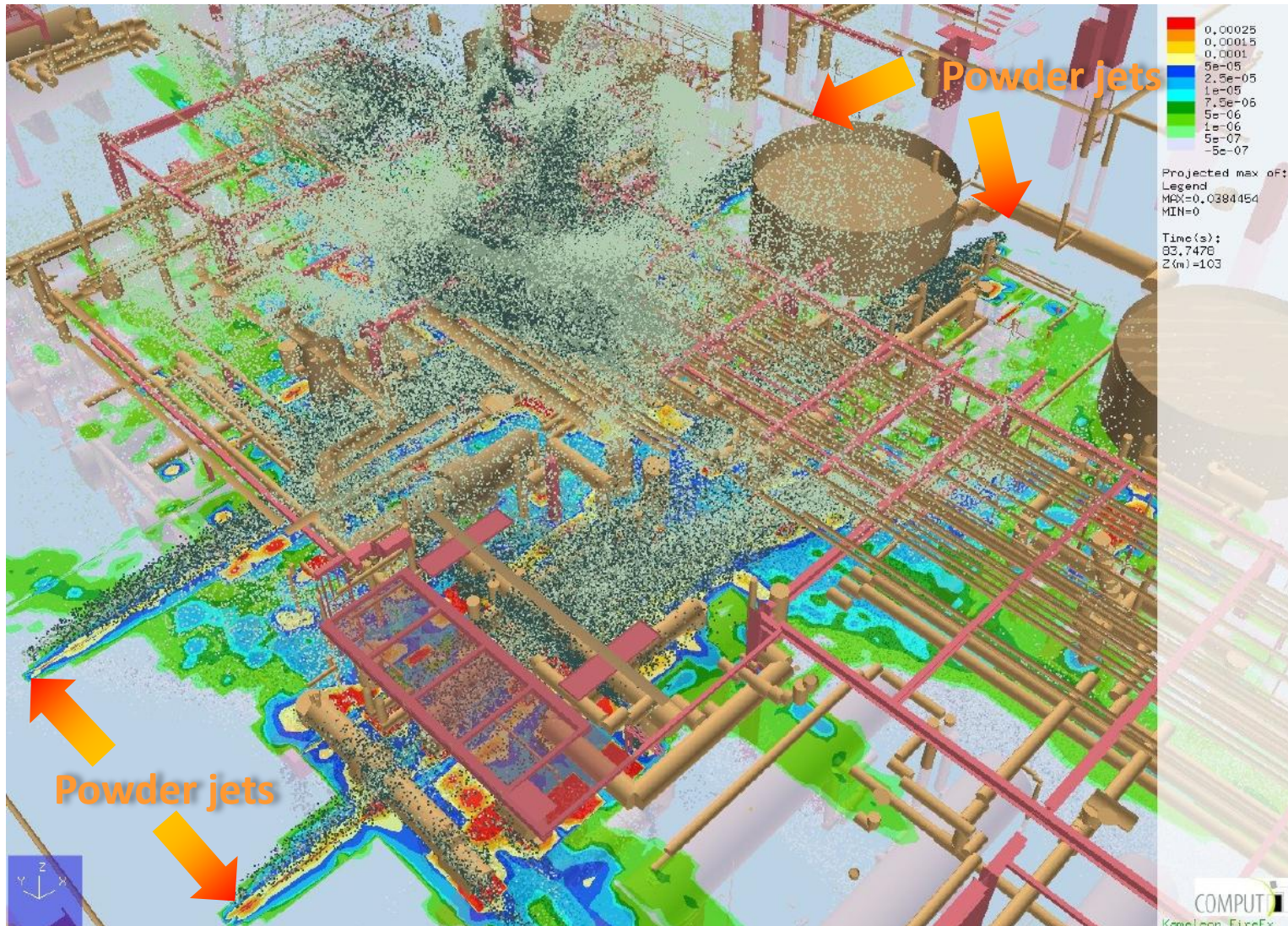
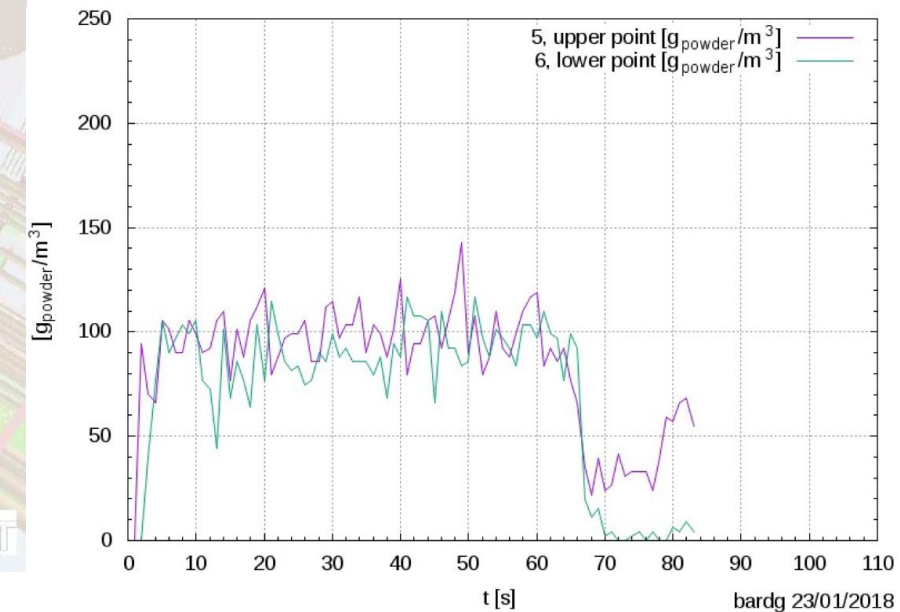
Experimental program 2008 – 2010

Purpose of experiments:

- To determine the relationship between inhibitor characteristics (concentration, type, etc.) and flame combustion velocity of a fuel-air mixture. 316 tests in a 20L vessel
- To verify the effectiveness of inhibitors in medium scale conditions. 103 tests in a 50 m³ rig.



CFD simulations to verify dispersion effectiveness



Industrial application of the technology



Is the VEMIS system replacing other safety barriers?

- The intent of the VEMIS system is not to replace existing barriers (ESD system, water deluge systems, water curtains,...) but to complement existing barriers by providing a quick acting mitigating barrier to reduce the overpressure effects of Vapour Cloud Explosions following a large release of a flammable gas in a congested environment.

What is the impact of the inhibitor powder on nearby personnel (toxicity, visibility in the cloud)?

- The inhibitor powder are alkali salts (carbonates and bicarbonates of potassium). These substances are used as food additives.
- The high LD50 and LC50 values reported in literature to characterize the acute toxicity of sodium bicarbonate and potassium bicarbonate suggest that the risk of short term (< 1 minute) exposure of people to high concentrations of dusts of sodium bicarbonate or potassium bicarbonate is limited.
- No serious adverse effects on human health are expected upon short term exposure of humans to sodium bicarbonate or potassium bicarbonate dusts upon activation of the inhibitor injection system.
- The alkali salts are not harmful for the environment
- The visibility inside a powder cloud is limited. Before activation of the VEMIS skids and discharge of the powder, a visible and audible alert is given at the location of every skid. After 30 seconds, the power is released. This delay gives nearby operators time to escape from the location.
- The powder discharge is at height (4 meters from ground level) to avoid direct impact of people by the powder jet.

How to clean the equipment after a discharge of inhibitor powder?

- A cleaning protocol needs to be developed for removal of the powder after activation of the VEMIS system. This protocol includes mechanical removal of the solid powder using e.g. vacuum equipment. The remaining powder can be removed by flushing with large amounts of water (the alkali salts are very soluble in water).
- A spurious activation of a VEMIS system occurred in a petrochemical facility in South-Korea (event on 11 March 2021) because of erroneous operation by a contractor pushing a local VEMIS activation pushbutton in the field during shutdown activities at the site, resulting in the activation of all 12 installed VEMIS skids. It took 6 days to clean the facilities (including 15 people). There were no problems reported with contamination of equipment exposed to the powder after the cleaning. The restart of the unit was normal without issues related to exposure of equipment to the inhibiting powder.

How is the system activated?

- The system is activated automatically by confirmed gas detection.
- Manual activation by operators after detection of a large leak is not recommended since the time between a large release of a flammable gas and the occurrence of a VCE is usually not more than a few minutes.

How to avoid a spurious activation of the system?

- To avoid a spurious activation of the system, the activation logic should be based on a voting system (MooN detectors). The number of detectors needed to activate the system is to be decided based on the applied protection philosophy (and a trade-off between safety and reliability).

How is the system tested?

- A yearly test is foreseen for the VEMIS skids. The full sequence (from gas detection trigger to activation of the valves in the skid) is included in the test protocol, but to avoid that inhibitor powder is released during a test, a discharge valve in the outlet of the skid is kept closed during the test.

What is the reliability of the system?

- The system is modular (separate modules) and every module is independent of each other
- The VEMIS skids do not need external utilities (nitrogen, power) to function. Every module is operated by the pressure in nitrogen bottles available in every skid.
- The reliability of every VEMIS skid is equivalent to a SIL2 system
- The overall reliability of the system is governed by the reliability of the gas detection system
- A safety margin of a factor of 5 was included in the design of the system (meaning that the loss of one particular VEMIS skid is compensated by the action of other skids)