# A BRIEF HISTORY OF PROCESS SAFETY MANAGEMENT

**Hudson, R[1], Boss, M.J[2], Cook, G.T[3],Weeda, T.[4]**
**[1] Environmental, AECOM, Quayside Newcastle-upon-Tyne, NE1 2HF, United Kingdom, bob.hudson@aecom.com**
**[2] Risk Management, AECOM, Shamrock Plaza, Omaha, 68154, United States, martha.boss@aecom.com**
**[3] Renewables and Energy Transition, AECOM, Portwall Lane, Bristol, BS1 6NA, United Kingdom, graeme.cook@aecom.com**
**[4] Environmental, AECOM, Shamrock Plaza, Omaha, 68154, United States.**

**ABSTRACT**

Common root causes are often to be found in many, if not most, process safety incidents. Whilst large-scale events are relatively rare, such events can have devastating consequences. The subsequent investigations often uncover that the risks are rarely visible, the direct causes are often hidden, and that a ‘normalization of deviation’ is a common human characteristic.

Process Safety Management (PSM) builds on the valuable lessons learned from past incidents to help prevent future recurrences. An understanding of how PSM originated and has evolved as a discipline over the past 200 years can be instructive when considering the safety implications of emerging technologies. An example is hydrogen production where risks must be effectively identified, mitigated, and addressed to provide safe production, transportation, storage and use .

*“Those who don’t know history are destined to repeat it” Edmund Burke*

## 1.0 A LOOK BACK AT PROCESS SAFETY MANAGEMENT

### 1.1 Why concern ourselves with Process Safety Management’s history?

Studying the history of PSM is useful because large-scale events while relatively rare can have devastating consequences. When we investigate incidents of this type; we find that the risks are rarely visible, that direct causes are often hidden, and that a “normalization of deviation” is a very common human trait.

Understanding how PSM originated and has evolved as a discipline can be instructive when considering the safety implications of emerging technologies such as, for example, hydrogen. As we will see, common root causes are at the heart of many if not most process safety incidents. Let us look back at how process safety management became a discipline, and how that disciplines have evolved over the past 200 years.

### 1.2 Origins of PSM Practice

The most famous origin story, at least in the U.S., involves the E.I. DuPont Company and its Brandywine (Gun) Powder Works [1] founded in 1802 near Wilmington, Delaware, USA on the Brandywine River.

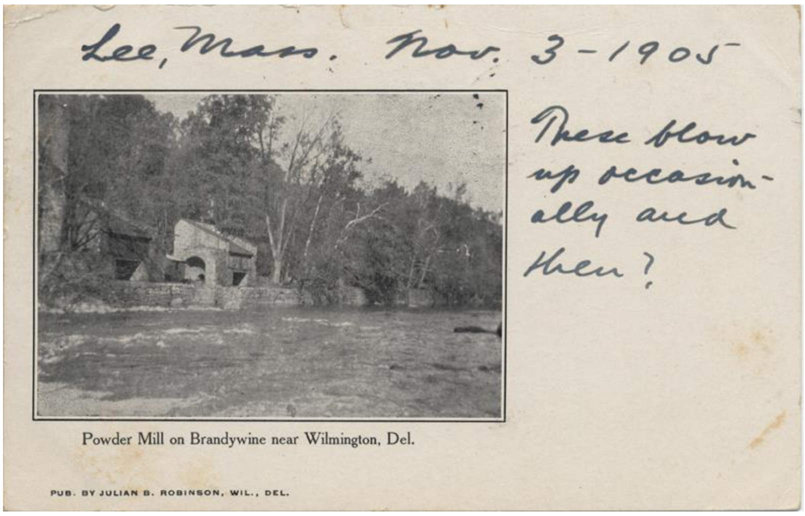


Figure 1. du Pont Gunpower Mill (1905)

Process safety considerations guided the layout of the Works, the design of building and equipment, and even worker clothing. Separation of buildings at "prudent distance" was carried out. Certain buildings were set apart from other buildings as the stamping process had mechanical operations that directly involved gunpowder and the graining mill contained the largest quantities of finished powder. In addition to physical isolation, building design features were used to minimize injury in the event of an explosion. Three sides of these buildings were constructed of high and thick granite walls while the fourth side was left open, facing the river, and the roof was constructed of light gauge material. Exits were located to allow workers to leave the buildings quickly and redundant safety valves were installed. The pegs or hobnails in workers' boots were made of wood and their clothing did not include pockets or trouser cuffs that could accumulate combustible material. Members of the du Pont family and supervisors were accountable for the Work's safe operation and corporate policy required that management be present whenever new equipment or processes were started up. In fact, a sign was posted over the doorway to the mills stating that "No employee may enter a new or rebuilt mill until a member of top management has personally operated it." Despite these, and many other precautions, 288 explosions occurred between the Works' founding in 1802 and 1921.

In the 1860s, construction of the first transcontinental railroad across North America prompted the implementation of another key process safety consideration: the minimizing the transport of hazardous materials.[2] The western mountain ranges required extensive blasting using Nitro-glycerine for tunnelling. After several "in transit" incidents, the transportation of Nitro-glycerine was banned. Black powder was used exclusively until the Summit Tunnel in the Sierra Nevada required the use of something more powerful. The Central Pacific Railroad then hired a chemist, James Howden, to manufacture Nitro-glycerine at Donner Pass, near the point of use. A few years later Alfred Nobel developed and licensed the manufacture of dynamite in the U.S.

### 1.3 Formalizing PSM Practices

Moving to more recent times, the post-World War II period saw several incidents involving ammonia and air separation plants that lead to the first conference on process safety, led by the American Institute of Chemical Engineers (AIChE) in the 1950s. This conference resulted in the formation of the AIChE's Health and Safety Division in 1979. The AIChE's Center for Chemical Process Safety was established in 1985.

### 1.4 Formative Incidents

With the advent of the formal discipline of process safety, a greater and more widespread industrial activity, improvements in incident reporting practices, and increased public interest in the environmental effects of industry; the legislative attention was drawn to large-scale incidents like never before. Some of the PSM incidents that led directly to legislation or other organized reactions included:

Seveso, Italy - 1976 — An incident released 6 tons of dioxin, resulting in the contamination of an area of 18 $km^2$ and the deaths of 3,000 animals. Many persons developed chloracne and primary neuropathy. This incident resulted in the establishment of the Seveso Directive and the UK's COMAH regulations covering industrial manufacture or use of hazardous substances.

Bhopal, India – 1984 – The release of methyl isocyanate, a pesticide intermediate, resulted in at least 3,787 deaths, an equal number of disabling injuries and affected over 500,000 people in all. This incident led to the U.S. establishing the OSHA PSM and EPA RMP regulations.

Macondo Prospect, United States– 2010 – A blowout on an offshore deepwater drilling unit resulted in an explosion, fire, and oil release to the Gulf of Mexico. Eleven workers died, the rig was lost, with at least 4 million barrels of oil released to the sea. This incident led to establishment of the Bureau of Safety and Environmental Enforcement within the U.S. Dept. of Interior, the Well Control Rule and Safety and Environmental Management Systems (SEMS) regulations for offshore operators.

Figure 2. Macondo Prospect Field (2010)

*Other Sources of Lessons*

Other notable incidents occurring over the past 80 years from which lessons can be learnt include:

- Cleveland, Ohio, USA – 1944 - Liquified natural gas release, explosion and fires killed 130 people and destroyed one square mile of the city.
- Cumbria, UK – 1957 - Windscale nuclear power reactor fire resulted in an estimated 100 – 200 excess cancer deaths
- Flixborough, UK – 1974 – Chemical plant explosion killed 28 people.

- Harrisburg, Pennsylvania, USA – 1979 – Partial meltdown of a nuclear reactor at the Three Mile Island Nuclear Generating Station caused major damage and disrupted the U.S. nuclear power sector for decades.
- Chernobyl, USSR – 1986 – Nuclear powerplant core meltdown predicted to cause at least 9,000 premature deaths. The event occurred during a test of the emergency cooling system.
- Piper Oilfield, UK – 1988 – Offshore petroleum production platform explosion killed 167 people.
- Houston, USA – 1989 – Release and subsequent explosion of 39 tons of flammable gases killed 23 workers. Reversal of compressed air connections to actuation valves was the direct cause of the initiating event.
- Buncefield, UK – 2005 – Fire and explosion at petroleum terminal resulting from the overfilling of a gasoline tank. The tank's level sensor did not show the tank as full and the automatic feed shutoff failed to operate.
- Texas City, USA – 2005 – Over filling of a tower resulted in the formation and subsequent explosion of a vapor cloud. 15 workers were killed. Numerous technical and operational failings were identified by the U.S. Chemical Safety Board (CSB).

Figure 3. Texas City (2005)

- Fukushima, Japan – 2011- a tsunami hitting nuclear plant resulted in core meltdowns and radiation release.
- Cyprus - 2019 - Evangelos Florakis Naval Base munitions explosion said to be the largest artificial non-nuclear explosion of the 21st century prior to the 2020 Beirut explosion.
- Texas City, USA – 1947; West, Texas, USA – 2013; Tianjin, China – 2015; Beirut, Lebanon, 2020 – Ammonium nitrate detonations with multiple fatalities, primarily firefighters.

### 1.5 Causes, Changing Risk Factors, and Improved Prevention

When looking back at these and a higher number of "near misses" or high potential (HiPo) incidents, one can identify common elements. According to the U.S. Chemical Safety Board (CSB) the PSM elements failing most often are Mechanical Integrity, Emergency Preparedness, and Control of Hot Work.[3]

In the experience of the authors, Management of Change and Training should also be a leading direct cause. The root causes allowing these failures to develop are almost invariably organizational: poor leadership, misplaced priorities, inadequate funding, lack of critical self-examination, failure to respond to reports of inadequacy, a 'normalization of deviation', a 'rationalization' to diminish hazard and risk perception, failure to plan for emergencies and event mitigation.

When applying a “Bow-Tie” Risk Assessment technique, those control measures that are lacking may lead to incidents, and the associated poor recovery measures make the event worse. The chain of events leading up to catastrophic releases and the toll in lives and damage are often remarkable in their chronology, their cascading effects. Often one robust control would have prevented much or all of the event and subsequent damage. This bears out the process safety layers – or ‘Swiss Cheese’ analogy.

So, what about the future?

What changes in products, processes, climate, and demographics could affect the likelihood of Low Probability / High Consequence events at facilities?

Some consideration should be given to:

- Shuttering and repurposing of plants that have exceeded their safe life span
- Aging support infrastructure (e.g. water supply and wastewater disposal)
- Aging primary operating plants, as permits become harder to obtain and replacement capital costs increase
- Operating processes “off-design” at well below or above operational design capacity
- More reliance on large-scale batteries for transportation and electric utilities
- More automation and reliance on sensors and remote operation (telemetry) in addition to the vigilance of operators / people
- Well trained workforces, with controlled multi-tasking of operators, supervisors, and managers
- Pandemics affecting supply chains, product distribution, and workforces
- Residential population positioning near processing and distribution complexes (population encroachment becoming sensitive receptors)
- Higher ambient temperatures; affecting materials of construction, storage of hazardous materials, cooling system designs
- Rising sea levels increasing corrosion in marine environments and flooding risk
- Increased emphasis on cost minimization – use of counterfeit parts; the “race to the bottom” for production costs; “just in time” provisioning of spare parts that may not meet specifications
- Reduction in available and suitably qualified and experience personnel
- Supply chain pinch points and vulnerabilities – customs controls and shipping canals!

What changes to the regulatory scheme are governmental bodies recommending?

In the U.S., the Chemical Safety Board, in its *Process Safety Management for the 21st Century* [3] plans recommended:

- Expanding the list of materials and industrial sectors subject to specific PSM regulation
- Enhancing release consequence analyses
- Adding new prevention program elements including contractor selection and oversight, public disclosure, and automated detection and monitoring
- Providing Stop Work Authority to all employees (instead of just prohibitions against retaliation against ‘whistleblowers’)
- Enhanced Process Hazard Analysis requirements
- Establishing requirements regarding facility and process siting, and human factors
- Requiring coordination with local emergency response authorities

## 2.0 LESSONS FOR HYDROGEN PSM - PRODUCTION, DISTRIBUTION AND USE

### 2.1 Recent Incidents Involving "New" Hydrogen Uses

So, what should the past tell us about the PSM aspects of a hydrogen economy?

We have seen a number incidents involving hydrogen production, storage, and dispensing over the past two years that could give us some indication of what kind of risks we should anticipate, at least as they pertain to transportation-related uses.

- 11 February 2018 – Hydrogen delivery truck fire, Diamond Bar, California, USA – Hydrogen escaping from tanks on a transport trailer ignited and resulted in mobilization of the Los Angeles County Fire Department and evacuation of the immediate area. The U.S. National Transportation Safety Board (NTSB) identified mechanical integrity shortcomings associated with the transportation cylinder pressure relief devices and tubing connections. LA County Fire identified shortcomings in their training and the response plan for hydrogen incidents. No injuries were reported.
- 23 May 2019 – Hydrogen storage tank explosion, Gangneung, South Korea – A hydrogen storage tank associated with a hydrogen production facility undergoing testing exploded, killing 2 workers. The direct cause was said to be the presence of oxygen inside the tank.
- 1 June 2019 – Hydrogen delivery truck fire, Santa Clara, California, USA – Hydrogen leaking from a storage tank hose-to-truck connection ignited and caused an unconfined explosion and fire that involved both the truck being loaded and other trucks in the area. Workers could not reach a shut-off valve due to the fire. No injuries were reported, however the hydrogen supply for California was disrupted for several months.
- 29 June 2019 – Hydrogen explosion at fueling station, Norway – An "assembly error of a specific plug in a storage tank" allowed hydrogen to escape. Its subsequent ignition and unconfined explosion caused airbags in nearby vehicles to initiate with three people being slightly injured.

### 2.2 European Hydrogen Safety Panel (EHSP)

The Hydrogen Incidents and Accidents Database (HIAD) is maintained by the Joint Research Centre of the European Commission (EC-JRC). Through on-going analysis and input into HIAD, the Centre has identified three event categories:

- Non-hydrogen system initiating event
- Hydrogen system initiating event: event triggered directly by a system containing hydrogen and includes as sub-categories: jet fire and explosions, no hydrogen release and unignited hydrogen release. Note: The majority of the events subsequently analysed occurred due to hydrogen system failures.
- False positive: emergency alarm or procedure triggered in the absence of any actual problem

In their 2019 report, the EC-JRC summarized the lessons learnt. The analysis provided and concurrent recommendations included:

- Inspection and Maintenance. Increased frequency of inspections, regular verification of structural integrity, determination of corrosion that required maintenance or change out, leakage tests, pipe tests
- Personnel. Use of enhanced security, working permits, supervision (especially during soldering), regular and refresher training
- Process/plant modifications. Use of mitigation barriers (forced ventilation, concentration detectors, automatic closing valves, system purging with verification, elimination of ignition sources, use of ATEX equipment), design to limit hydrogen inventory, segregation and separation of reactive chemicals, gasket tightening, reviews of pressure control systems (vents,

alarms), fast isolation means, electrical power load protection, electromagnetism protection, passive barriers, and increased use of sensors

- Miscellaneous. Provisions for effective mechanical integrity evaluations (critical component evaluations, corrosion testing, avoidance of flange connections, redundant systems), enforced fire barriers, electrolytic cell controls.

As with many lessons learnt, the above are indicative of failures in PSM that can lead to incidents - and the resultant generation of the lessons to be learnt. Applying these lessons requires a risk-based approach to plant operation and maintenance.

### 2.3 Applying Lessons Learned and Charting a Safe Course

These recent incidents and their systematic collation and analysis appear to indicate that greater attention to mechanical system integrity (including design, manufacturing, assembly and test) and improved training as part of a whole system safety approach might have prevented them.

The prevalence of mechanical integrity issues associated with the incidents identified above are wholly consistent with PSM shortcomings identified throughout the past 80 years of PSM practice. Such shortcomings were noted in findings of a report on a hydrogen-producing electrolysis unit at Ilford, UK, in 1975. This report, generated by HM Factory Inspectorate, concluded that the incident could have been prevented by greater attention to sludge formation and resulting blockage of vent ducts within the electrolysis equipment, and more frequent (e.g., continuous) monitoring of oxygen and hydrogen quality in the process equipment to detect mixing of the two gases.

All ‘new’ technologies have had safety implications both for industry, and consumer safety as a whole. Importantly PSM failures or unintended consequences have often affected society’s acceptance of new or different technology. If the public does not believe that the benefits outweigh the risks or costs, they are likely to reject the technology, regulate it to the point where it is overly expensive, or slow down its implementation or expansion such that investment is not attractive to business. Analogies can be drawn here to the history of nuclear power development in the U.S. Safety issues must be effectively identified, mitigated, and addressed to encourage the adoption of hydrogen as a fuel source by the public.

The following actions should be considered in assisting with the societal adoption of hydrogen as a safe fuel source:

- Thoroughly investigate recent incidents to determine their root causes and implement mitigative measures across the industry. Be prepared to address concerns arising out of these incidents.
- Survey the public to determine what concerns they have about the use of hydrogen as a fuel for motor vehicles, as a space heating fuel, or as a replacement for natural gas or propane in domestic uses such as cooking and provision of hot water. Implement a common approach, to the extent feasible, to effectively address these concerns.
- Anticipate and proactively address the potentially negative aspects of taking what has historically been the industrial and commercial use of hydrogen as a fuel gas, to placement in residential settings. For example, the use of an odorant as good practice for fuel leak detection or the training and qualifications of gas engineers for working on hydrogen systems?

## CLOSING

We can learn from the past and gain the trust of the public, influencers, and regulators. Please reflect on the common factors contributing to safety incidents which have shaped the discipline of PSM and think about how you and your organization can apply them to make our lives, energy systems, and economies less carbon-intensive while promoting greater safety for everyone.

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