

## Case study

# Proactive Process Safety Management - Key to the Prevention of Incidents in Industry

### ABSTRACT

Proactive process safety that works requires a thorough approach that takes into account every area of safety. It entails regular review and monitoring of safety performance in order to pinpoint problem areas and guarantee continued safety improvements. Failure to take proactive measures may result in catastrophic events, such as fires, explosions, or chemical discharges, which could have detrimental effects on nearby communities, the environment, and the workforce. Process effectiveness is continuously ensured through proactive safety, which involves processes, procedures, and people. The purpose of this study was to review the fact that proactive process safety management is the key to the prevention of catastrophic incidents in industry. The method adopted for this study was the use of selected process safety incidents to illustrate latent conditions and active failures using the Swiss cheese model and to identify the barrier failures that will lead to catastrophic incidents in industry. A large disaster caused by the effects of catastrophic discharges of hazardous, reactive, flammable, or explosive substances can be prevented to a great extent by implementing proactive systems to monitor process safety.

*Keywords: Proactive, Process Safety, Catastrophic, Latent Conditions, Active Failures, Swiss Cheese model.*

### 1. INTRODUCTION

Process safety that takes a proactive approach tries to stop accidents and incidents before they happen. It involves identifying potential dangers and using safeguards or preventative measures [1]. Risk evaluations, safety audits, preventative maintenance, and continual improvement are just a few of the operations that make up proactive process safety [2, 3]. Industries that deal with hazardous products or operate in potentially dangerous locations must prioritise proactive process safety. Oil and gas production, chemical production, mining, and transportation are a few of these [4]. The public, the environment, and company continuity are all protected by proactive process safety, which is crucial for establishing and maintaining a safe and healthy work environment [5].

Process safety certainly did not start with the BP Texas city refinery accident in 2005; in fact, there have been Loss prevention symposium papers on process safety for more than 50 years and process safety symposiums for a long time. The primary management system technologies that we currently employ to guarantee process safety were created in the 1960s. The awareness of human factors and their impact on process safety did not fully begin until the 1970s, when management systems to develop improved operating procedures and maintenance practises evolved quickly through sharing among organisations [6]. In 1985, the AIChE started the Centre for Chemical Process Safety (CCPS), and the first industry standard on Process Safety Management (PSM) was written

Comment [SI 1]: remove

Comment [SI 2]: as

Comment [SI 3]: Prfocess Safety Management system

Comment [SI 4]: prevent

Comment [SI 5]: hazards and risk

Comment [SI 6]: mention some of the preventive measures used as proactive system

Comment [SI 7]: Risk assessment, Safety Inspection, Safety Audit,, management commitment, etc. Then mention the preventive measures, and continual improvemeng

Comment [SI 8]: How/ mention the ways such industries can priotise the proactive process safety management system.

Comment [SI 9]: Who are ' we ' in this context. Please recast the sentence.

then, with the elements of PSM being pulled together by about 20 companies at that time [6]. It involves:

- i. Understanding and identifying potential risks
- ii. Evaluation of consequences, safeguards, and risks
- iii. The addition of layers of protection (safeguards) to prevent and/or mitigate incidents
- iv. The introduction of safeguards to protect the students, the staff, the faculty, the public, the environment, and property [7].

One of the major challenges to key process safety is complacency. Which causes the staff to feel reluctant, thereby ignoring or failing to detect and react to early warnings? [7].

### 1.1 ENERGY INSTITUTE

The Energy Institute identifies four pillars for accident prevention that are effective for the Process Safety Management System, which is a well-structured system that provides clear direction on all elements covering plants, processes, and people. These prevention pillars are working towards the same objective: safe process operations [8]. Figure 1 shows the four Energy Institute accident prevention pillars.

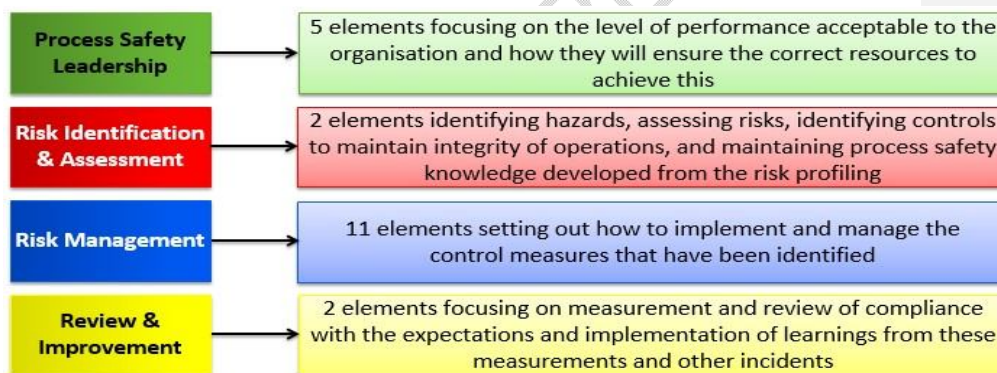


Fig 1: Four Energy Institute accident preventions pillars [8]

### 1.2 PROCESS SAFETY BARRIERS

The process safety barriers fall into three categories: the plant, which guarantees that equipment is rigorously designed, installed, inspected, and maintained so that the facility can be operated safely for the duration of its life; the process, which guarantees that management systems are in place to safely design, install, inspect, maintain, and operate the facility. Thirdly, people responsible for making sure that the facility has enough qualified personnel including contractors who are adequately motivated to implement all the necessary management processes for the facility's safe design, installation, inspection, maintenance, and operation [9].

### 1.3 PROCESS HAZARD ANALYSIS (PHA)

An organised attempt to categorise and assess the risks connected to activities and processes in order to enable their management. Typically, to identify and evaluate the importance of dangers, this study uses qualitative methodologies [10]. The common methods of process hazard analysis are checklists, what-if, Hazard and Operability Study (HAZOP), Failure Mode and Effect Analysis (FMEA), and Fault-Tree Analysis [11].

**Comment [SI10]:** hazards

**Comment [SI11]:** Detail the stages/steps of PHS such as i. Identify the Hazard, ii Who might be harmed , iii Control Measures, iv Recovery measures etc. This will help in good comprehension of what you are saying.

## 1.4 PREVENTIVE MEASURES

This proactive approach includes taking appropriate actions and communicating issues based on:

- i. Reviewing process safety key performance indicators (KPIs), incidents and near-miss investigations, audit actions, and a risk reduction action plan.
- ii. Using a tiered audit approach, including management observations in the workplace.
- iii. Having the right mind-set means looking for areas to improve rather than assuming all is well.
- iv. Creating the right culture: where people will be engaged and report issues because they know they will not be blamed or ignored, and where people know their actions to keep or make the site safe.
- v. Providing process safety expertise and regularly reviewing and revising the site's safety assessment [12].

**Comment [SI 12]:** This is not proactive preventive measure rather reactive/lagging indicator. Use most of the leading indicators as your preventive measures

**Comment [SI 13]:** Right safety culture

**Comment [SI 14]:** Organisational safety culture

These are the common protective measures that represent layers of Swiss cheese. They are ordered sequentially from the initiating event to the ultimate consequence: engineering controls, administrative controls, behavioural controls, and post-incident mitigation [13]. Table 1 shows how seemingly minor errors or brief gaps in judgement may have devastating effects on industry.

**Comment [SI 15]:** Recast. Do you mean site safety risk assessment or workplace inspections/walkthrough. Please expatiate.

**Table 1: Process Safety Incidents**

Year	Place	Cause	Result	References
2020	Beirut explosion On August 4, 2020, at 14:45 UTC (17:45 local), a fire started in Warehouse 12 at the Port of Beirut.	The ammonium nitrate that had been taken from Rhosus was kept in Warehouse 12, which was waterside and next to the grain elevator, along with a cache of pyrotechnics. The fireworks that were likely kept nearby caused the initial explosion, which produced a significant amount of smoke and spectacular pyrotechnics bursts. The primary fire that caused the explosion had been put out by the following morning.	impacted Warehouse 12's structure with a force roughly equal to 1.5 to 2.5 tonnes of TNT. Firefighters and paramedics were sent to combat the fire after the second explosion, which occurred 33 to 35 seconds later and was significantly more powerful. It was felt throughout northern Israel and in Cyprus, which is located 240 kilometres (150 miles) away. It shook the heart of Beirut, sending a reddish-orange	[14 - 21]

			cloud into the sky, temporarily encircled by a white condensation cloud. Nitrogen dioxide, a byproduct of the breakdown of ammonium nitrate, is what gave the smoke its reddish-orange colour.	
2008	Bayer Crop science, Lp Institute West Virginia	<u>Highly flammable solvent sprayed from the vessel and immediately ignited, causing an intense fire that burned for more than 4 hours.</u>	<u>One died from blunt force trauma and burn injuries sustained at the scene; the second died 41 days and Eight Injured.</u>	[22]
1994	The Port Neal fertilizer plant explosion at South of Sioux City, Iowa, United States.	The Port Neal fertilizer plant explosion occurred on in the ammonium nitrate plant.	Four were killed and eighteen injured. Property worth \$321 million were damaged and significant damage was inflicted to the surrounding structures. electricity generating stations were disabled by the explosion, A high-voltage line were damaged, Two 15,000-ton refrigerated ammonia storage tanks were ruptured, releasing liquid ammonia and ammonia vapours which forced the evacuation of 1,700 residents from the	[23 - 35]

Comment [SI 16]: Remove the underlines

			surrounding area.	
1990	ARCO Chemical Explosion , Texas	At 11:21 p.m. CDT,an explosion occurred when the compressor for the wastewater tank was being restarted. The explosion resulted in a large flame that rose at least 100 feet (30 m) over the Houston Ship Channel, resulting in large plumes of black smoke.	Facility in the city block was severely damaged by the explosion. The waste water storage tank was completely destroyed, describing it as having been "flattened like a soft drink can crushed in a vise". The explosion was so powerful that the 48,000-pound (22,000 kg) lid of the tank had been blown. 17 Deaths and 5 Non-fatal injuries.	[36 - 44]
1984	Bhopal Disaster, Madhya Pradesh, India.	Methyl isocyanate leak from the E610 storage tank on the Union Carbide India Limited plant, the cause of which is disputed between corporate negligence or employee sabotage.	Considered the world's worst industrial disaster, over 500,000 people in the small towns around the plant were exposed to the highly toxic gas methyl isocyanate (MIC).With at least 3,787, over 16,000 claimed non-fatal injuries at least 558,125.	[45 - 51]

1984	San Juan Ixhuatepec Explosions, Tlalnepantla de Baz, State of Mexico	The disaster was initiated by a gas leak on the site, likely caused by a pipe rupture during transfer operations, which caused a plume of LPG to concentrate at ground level for 10 minutes. The plume eventually grew large enough to drift on the wind towards the west end of the site, where the facility's waste-gas flare pit was located.	500–600 victims killed, and 5000–7000 suffering severe burns. The disaster was one of the deadliest industrial disasters in world history.	[52 - 57]
------	--	--	--	-----------

## 2. METHODOLOGY

The method adopted for this study is to analyse the latent conditions and active failures using the Swiss cheese model, which identifies the barrier failures for selected real life process safety incidents as case studies. The three important questions on process safety management that can be linked to the four pillars of accident prevention are stated as below:

- i. Do we understand what could go wrong (Identification of risks and assessment)?
- ii. Do we know what our systems are to prevent this happening (Risk Management)?
- iii. Do we have information to assure us that they are working effectively (Review and Improvement)?

When answering these questions, the objective is to perform only the level of analysis necessary to reach a decision, because insufficient analysis may lead to poor decisions and excessive analysis wastes resources [58].

### 2.1 Using Swiss Cheese Model to Identify the Barrier Failures in Process Safety-Hypothetical cases.

#### 2.1.1 Case Study 1 – Explosion of Ethylene Oxide in Ontario, California, and Sterigenics

The Antares control system warned the operators of an EO injection failure during a cycle in Chamber 7 on Thursday, August 19, 2004, at around 1:30 AM. To confirm that the alert was accurate, the operator quickly performed a number of standard system checks in the control room, but was unable to find any issues. He then got in touch with the lead operator, and the two of them decided to stop the cycle. They pressed the cycle abort button on the console in the control room, following corporate practise. Following the abort cycle, the operators, who then left the chamber open while waiting for repair staff, transferred the chamber's contents to an aeration room. The maintenance supervisor arrived at the plant at approximately 7:30 AM and immediately assigned two technicians to work on the gas injection problem. The technicians ran a series of tests, including an abbreviated test cycle that injected approximately 4 pounds of EO. The cycle performed as designed, and the technicians did not identify any problems. Before returning the chamber to production, the technicians ran a final calibration cycle that utilized 125 pounds of EO. This cycle progressed through its gas injection phases with no problems. Thinking that they had ruled out the injection system as the problem, and eager to get the chamber back on line, the technicians asked the maintenance supervisor for permission to skip the final gas washes

**Comment [SI 17]:** Recast the sentence: The method adopted for this study is the swiss cheese model in analysing .....

**Comment [SI 18]:** Stated below:

**Comment [SI 19]:** Are these your research questions or hypothesis?

**Comment [SI 20]:** Dis you use Swiss Cheese model to identy or to analyse. Please make it clear

and advance the cycle to complete. Witness interviews indicated that the technicians believed because the chamber was empty of products being sterilized the single end of cycle evacuation had removed the explosive concentrations of EO, and therefore, there was no reason for the gas washes because no residual EO remained in the chamber. The maintenance supervisor agreed with their logic and agreed to advance the cycle to completion. To advance the cycle to complete the maintenance supervisor verbally gave the required password to a maintenance technician.

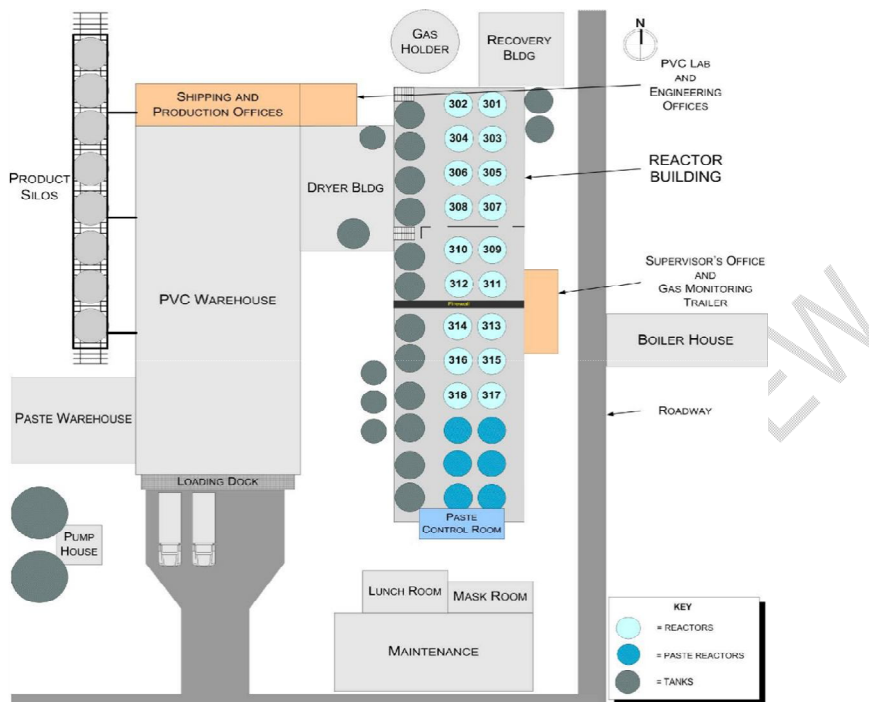
The technician typed the command into the Antares system, thereby skipping the gas wash phase. Minutes later, the technician cracked the sterilizer door to the pre-determined ventilation level, which automatically opened the back vent and caused approximately 50 pounds of EO remaining in the chamber to move into the ventilation system. EO immediately began to leak out of the chamber door into the building, causing nearby LEL monitors to alarm.

The alarms, however, did not allow sufficient time to shut down the oxidizer or evacuate the facility before the EO-laden air reached the oxidizer and ignited. The flame flashed back through the duct to the chamber and ignited the remaining EO, resulting in a powerful explosion. The explosion occurred shortly after 2 PM on August 19, 2004. There were no employees working in the chamber area at the time of the explosion [59].

### **2.1.2 Case Study 2 – Vinyl Chloride Monomer (VCM) Explosion at Formosa Plastics (Illinois)**

Pre-Incident Activities: Operations at the plant were normal in the hours before the incident. At approximately 10:30 p.m., just moments before the incident, all PVC1 reactors were making PVC except for reactor D306, which was being cleaned see Figure 2. A few minutes after 10:30 p.m., workers throughout the plant heard a very loud rumbling and some smelled Vinyl Chloride Monomer (VCM). The deluge system had activated in that region, according to the paste section deluge alert heard by the shift supervisor and operators in the south (paste) end of the reactor building. In order to examine the VCM gas detection system reading, the shift supervisor exited the Paste control room. The shift manager reported that two regions had readings that were higher above the instrument's quantifiable limit, indicating a significant release. He said that on his way to investigate the release, he walked past an open doorway in the PVC1 area near reactor D310 and saw material spraying from the bottom of D310 and a foaming mixture on the floor about 1.5 feet deep. He immediately climbed the stairs to the upper level. According to the shift supervisor, operators on the upper level of PVC1 reported that the pressure on the reactor D310 was rapidly falling. He informed two operators that he had seen material spraying from the bottom of D310 and they immediately began checking the valves and controls for D310. The supervisor and one operator tried to go to the lower level through an interior stairwell, but high Vinyl Chloride Monomer (VCM) concentrations forced them to retreat. The shift supervisor instructed operators to open vent valves on reactor D310 to relieve pressure and slow the release. At this point, he saw that the reactor pressure had already dropped to 10 psi, further indicating a large release. Attempting again to go to the lower level, the shift supervisor descended an exterior stairway when a series of explosions occurred. Two 3,000 gallon VCM recovery tanks were knocked over, several tonnes of dryers were pulled off of their supports, and the engineering, safety, and lab offices were completely damaged by the explosions. The resulting fire, which burned for many hours and spewed a plume of foul smoke into the neighbourhood, started in the PVC warehouse to the west of the reactor building. The explosions claimed the lives of four operators: two on the lower level

**Comment [SI21]:** Please bring out your analysis of this case study in line with proactive process safety management system. Show your findings from this case study. Align them with your research questions.

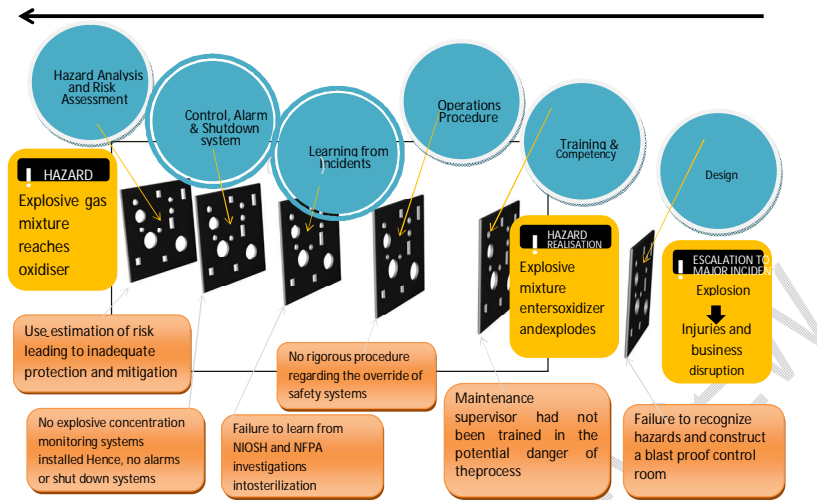


**Fig 2: Formosa-IL Plant Layout [60]**

and two near the top of the reactor. Two weeks later, the fifth operator passed away in the hospital. Four workers received treatment on-site, while the shift supervisor and two other employees were taken to the hospital. The shift manager claimed that neither the blaster operator nor anyone else was informed that the operator had overcome the interlock, which was required by procedure. As a result, those in charge of controlling the leak probably thought there had been a failure or some other error and attempted to lower the pressure inside the reactor to delay the release. While the operators were at the controls of the reactor, the VCM vapour cloud caught fire and exploded [60].

### 3. RESULTS AND DISCUSSION

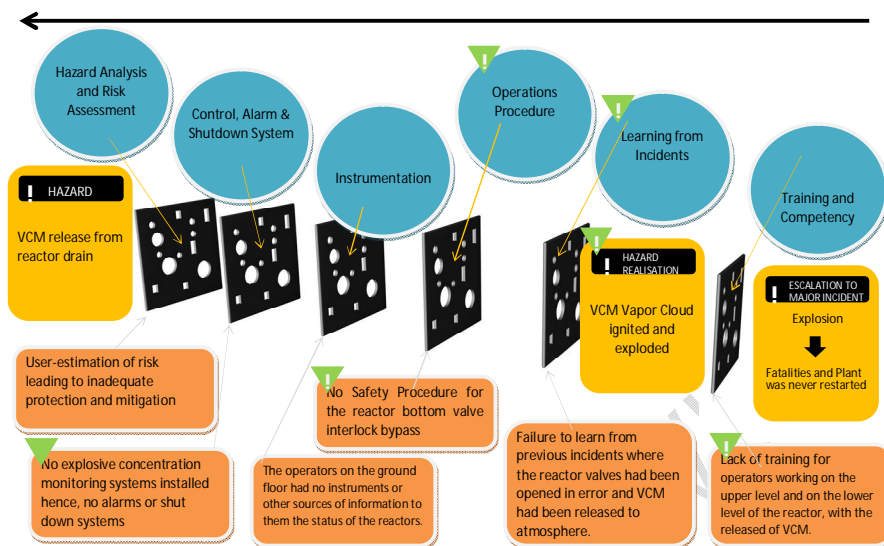
The Swiss Cheese Model was used to identify the barrier failures in Ethylene oxide explosion incident at sterigenices, Ontario, California as shown in Figure 3.



**Fig 3. Swiss Cheese Model Used to identify how the barrier failures take place during ethylene oxide explosion incident at Sterigenics, Ontario, California**

The Swiss Cheese Model was used to identify the barrier failures in ethylene oxide explosions. There was no proper hazard analysis and risk assessment to understand if the gas chamber was working effectively and what could go wrong before skipping the final gas washes. No alarms or shut-down systems, failure to learn from previous incidents, no operational procedure for system override, no training for technicians and maintenance supervisors on the importance of the final gas washes, and failure to construct a blast-proof control room during the design.

The Swiss Cheese Model was used to identify the barrier failures of Vinyl Chloride Monomer (VCM) explosion at formosa plastics corp. illiopolis, Illinois as shown in (Figure 4).



**Fig 4. Swiss Cheese Model Used to Identify how the barrier failures take place during the Vinyl Chloride Monomer Explosion**

The Swiss Cheese Model was also used to identify the barrier failures of Vinyl Chloride Monomer (VCM) explosion. There was no hazard analysis and risk assessment before the release of the Vinyl Chloride Monomer (VCM) from the reactor drain, no alarms or shut-down system, no instruments of information between the upper level and lower level operators, no safety procedures for valve bypass, failures to learn from previous incidents on valve bypass, and a lack of training for operators.

#### CONCLUSION

In conclusion, proactive process safety management is critical for preventing significant industrial incidents. These occurrences may result in fatalities, property damage, environmental destruction, and harm to a company's brand. The correct controls are implemented as part of proactive process safety management techniques to reduce potential risks. This helps to ensure that operations are reliable and safe, protecting both the environment and the personnel. It has been demonstrated that placing a high priority on process safety management increases operational efficiency and profitability while reducing potential risks in a number of industries. Every manufacturing facility must develop a strong and proactive process safety management plan in order to prevent serious incidents.

#### REFERENCES

1. National Safety Council, (2018). Proactive Safety: The Key to a Successful Safety Program. Retrieved from <https://www.nsc.org/work-safety/safety-topics/proactive-safety>. Accessed July 2022.
2. Occupational Safety and Health Administration. (2016). Process Safety Management (PSM) Standard (29 CFR 1910.119). Retrieved from <https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.119> .Accessed September 2022.

3. Center for Chemical Process Safety, (2010). Guidelines for Safe and Reliable Instrumented Protective Systems. Hoboken, NJ: John Wiley & Sons.
4. International Association of Oil and Gas Producers, (2018). Process Safety Performance Indicators. Retrieved from <https://www.iogp.org/bookstore/product/process-safety-performance-indicators/>. Accessed February 2023.
5. American Society of Safety Engineers, (2014). Introduction to Process Safety for Undergraduates and Engineers. Des Plaines, IL: American Society of Safety Engineers.
6. UK Energy Institute. (EI's). Process Safety Management - an overview. Retrieved from <https://publishing.energyinst.org/topics/process-safety-management/process-safety-management-an-overview>. Accessed August 2022.
7. National Fire Protection Association, (2019). Process safety management. Retrieved from <https://www.nfpa.org/News-and-Research/Resources/Fire-Protection-Handbook/General-Fire-Protection-and-Life-Safety/Process-safety-management>. Accessed August 2022.
8. Energy Institute. (2010). The management of process safety: Lessons learned from the Texas City refinery disaster. Energy Institute.
9. Health and Safety Executive, (2015). Process safety performance indicators: Developing process safety metrics. Retrieved from <http://www.hse.gov.uk/pubns/guidance/gs7.pdf>. Accessed June 2022.
10. Kletz, T., (1999). Hazop and Hazan: Identifying and Assessing Process Industry Hazards. CCPS (Center for Chemical Process Safety) (First Edition).
11. Center for Chemical Process Safety (CCPS), (2001). Guidelines for Hazard Evaluation Procedures (Second Edition). John Wiley & Sons.
12. Health and Safety Executive, (2012). Process Safety Leadership: A guide for senior leaders. Retrieved from <https://www.hse.gov.uk/pubns/books/hsg65.htm>. Accessed September 2020.
13. Reason, J., (2000). Human error: models and management. BMJ: British Medical Journal, 320(7237), 768-770. doi:10.1136/bmj.320.7237.768.
14. BBC News. Beirut explosion: What we know so far. August 6, 2020. <https://www.bbc.com/news/world-middle-east-53668493>
15. The New York Time. Beirut Explosion Live Updates: Officials Say at Least 100 Dead and 4,000 Injured. August 5, 2020. <https://www.nytimes.com/2020/08/04/world/middleeast/beirut-explosion-blast.html>
16. CNN, (2020). Beirut explosion: 154 killed, more than 5,000 injured in port blast. August 14. <https://www.cnn.com/2020/08/14/middleeast/beirut-explosion-intl-hnk/index.html>
17. Reuters,. Beirut blast a year ago still felt by victims amid probe stall. August 3, 2021. <https://www.reuters.com/world/middle-east/beirut-blast-year-ago-still-felt-by-victims-amid-probe-stall-2021-08-03/>
18. Al Jazeera. Beirut blast: One year on, Lebanon's political and economic crises deepen. August 3, 2021. <https://www.aljazeera.com/news/2021/8/3/beirut-blast-anniversary-lebanons-deepening-economic-political-crisis>
19. The Guardian. Beirut blast: one year on, victims' families still wait for answers. August 4, 2021. <https://www.theguardian.com/world/2021/aug/04/beirut-blast-one-year-on-victims-families-still-wait-for-answers>
20. Associated Press. Lebanon marks year since horrific blast with solemn silence. August 4, 2021. <https://apnews.com/article/middle-east-beirut-lebanon-explosions-business-7973c4b9000adfe471bd57f977c28638>
21. United Nations. One Year After Beirut Explosion, UN Underlines Importance of 'Prompt, Thorough' Investigation. August 3, 2021. <https://www.un.org/press/en/2021/sgsm20716.doc.htm>

22. Chemical Safety Board. Report No. 2008-07-I-WV, Investigation: Fatal Fire at Bayer CropScience Facility in Institute, WV, August 28, 2008.
23. Emergency Management. Deadly Explosion Occurs at VF Fertilizer Plant in Iowa". March 28, 1994.
24. The Des Moines Register. Fertilizer Plant Explodes, Kills Four". March 29, 1994.
25. Los Angeles Times. Fertilizer Plant Blast in Iowa Causes \$321 Million in Damage". April 7, 1994.
26. The New York Times. Blast Damage Counted in Iowa Towns". April 3, 1994.
27. Engineering News-Record. Iowa Plant Explosion Cripples Local Power, Gas Supplies".. April 4, 1994.
28. The New York Times. Officials Focus on Causes of Iowa Explosions".. April 5, 1994.
29. Engineering News-Record. Ammonia Leak Forces Evacuations in Iowa". April 11, 1994.
30. The Des Moines Register. Hundreds Evacuated as Ammonia Leaks from Port Neal Tanks". April 11, 1994.
31. National Fire Protection Association. Emergency Response Plan Helped Limit Damage After Iowa Fertilizer Plant Explosion". October 2, 2014.
32. USA Today. Iowa fertilizer plant explosion was preventable, feds say". January 29, 2016.
33. Chemical Safety Board. The West Explosion: Lessons Learned from a Deadly Disaster". April 16, 2016.
34. NPR. Iowa Town Remembers Deadly Fertilizer Plant Blast 25 Years Later". March 27, 2019.
35. Chemical Safety Board. Releases final report on Iowa fertilizer explosion". KCRG. July 18, 2019.
36. Houston Chronicle. ARCO Chemical Explosion. 6 Nov 1990.
37. Chemical Hazards Emergency Medical Management. Explosion at the ARCO Chemical Plant, Channelview, Texas. 13 Apr 2021.
38. The New York Times. Fierce Blast at Texas Chemical Plant Kills at Least 7. 7 Nov, 1990.
39. ABC News. ARCO Chemical Plant Explosion: The Blast That Killed 17. 7 Nov, 2020.
40. Houston Chronicle. ARCO Explosion Caused by 'Overpressure' in Tank, Official Says. 8 Nov, 1990.
41. Los Angeles Times. ARCO Plant Blast Toll May Reach 18." 8 Nov, 1990.
42. Chemical Engineering News. ARCO Chemical Explosion: 27 Years Ago Today, 7 Nov, 2017.
43. Occupational Safety and Health Administration. Fatal ARCO Explosion in Channelview, 9 Aug, 1991.
44. U.S. Environmental Protection Agency. ARCO Chemical Explosion Response, Houston, TX." U.S., 17 Dec, 2020.
45. BBC News. On this day: Poison gas leak at Indian plant. Retrieved from: <https://news.bbc.co.uk/onthisday/default.stm>. 1984.
46. History. "Bhopal disaster." Retrieved from: <https://www.history.com/topics/1980s/bhopal-disaster>. Accessed 15<sup>th</sup> September 2022.
47. Britannica. "Bhopal disaster." Retrieved from: <https://www.britannica.com/event/Bhopal-disaster>. Accessed 15<sup>th</sup> September 2022.
48. National Geographic. "Bhopal disaster." Retrieved from: <https://www.nationalgeographic.com/environment/habitats/toxic-waste/bhopal-disaster/>. Accessed 15<sup>th</sup> September 2022.
49. World Health Organization. "Bhopal disaster." Retrieved from: [https://www.who.int/environmental\\_health\\_emergencies/methyl\\_isocyanate.pdf](https://www.who.int/environmental_health_emergencies/methyl_isocyanate.pdf). Accessed 15<sup>th</sup> September 2022.

50. The Bhopal Medical Appeal. "Bhopal Gas Tragedy: The Numbers." Retrieved from: <https://bhopal.org/the-bhopal-gas-tragedy-the-numbers/> [accessed 15<sup>th</sup> September 2022].
51. The Guardian. Bhopal: The world's worst industrial disaster, 30 years on." Retrieved from: <https://www.theguardian.com/global-development-professionals-network/2014/dec/03/bhopal-the-worlds-worst-industrial-disaster-30-years-on>. 2014.
52. Wikipedia. San Juan Ixhuatepec Explosions". Retrieved on August 25, 2021 from [https://en.wikipedia.org/wiki/San\\_Juan\\_Ixhuatepec\\_explosions](https://en.wikipedia.org/wiki/San_Juan_Ixhuatepec_explosions)
53. The New York Times. Industrial Disaster Killing 500 Reported in Mexico City Suburb." November 22, 1984. Retrieved on August 25, 2022 from <https://www.nytimes.com/1984/11/22/world/industrial-disaster-killing-500-reported-in-mexico-city-suburb.html>.
54. MSN. Worst industrial disasters in history. April 1, 2021. Retrieved on August 25, 2021 from <https://www.msn.com/en-us/money/markets/worst-industrial-disasters-in-history/ss-BB1cbqVd>.
55. Complex. The 15 Most Devastating Industrial Accidents In History. April 17. Retrieved on August 25, 2021 from <https://www.complex.com/pop-culture/2013/04/the-15-most-devastating-industrial-accidents-in-history/san-juan-ixhuatepec-1984>
56. Mechanical Engineering, 1986. May, page 11
57. Los Angeles Times. Tragedy Marks Common Legacy of Two Presidents. November 24, 1984. Retrieved on April 18, 2022 from <https://www.latimes.com/archives/la-xpm-1984-11-24-me-6115-story.html>
58. International Organization for Standardization. ISO 31000:2018 Risk management – Guidelines. Retrieved from <https://www.iso.org/standard/65694.html>. 2018.
59. United States Chemical Safety and Hazard Investigation Board, (2007). Investigation Report: Improper handling of ethylene oxide sterilization waste caused explosion at Medisca Inc, September 13, 2006. Washington, D.C.
60. United States Chemical Safety and Hazard Investigation Board. Investigation Report: Formosa Plastics Corporation, Illiopolis, Illinois, Explosion and Fire. Retrieved from [https://www.csb.gov/assets/1/19/Formosa\\_finalreport.pdf](https://www.csb.gov/assets/1/19/Formosa_finalreport.pdf). 1990.