WHY EVERY CHEMICAL ENGINEER NEEDS TO KNOW ABOUT PROCESS SAFETY

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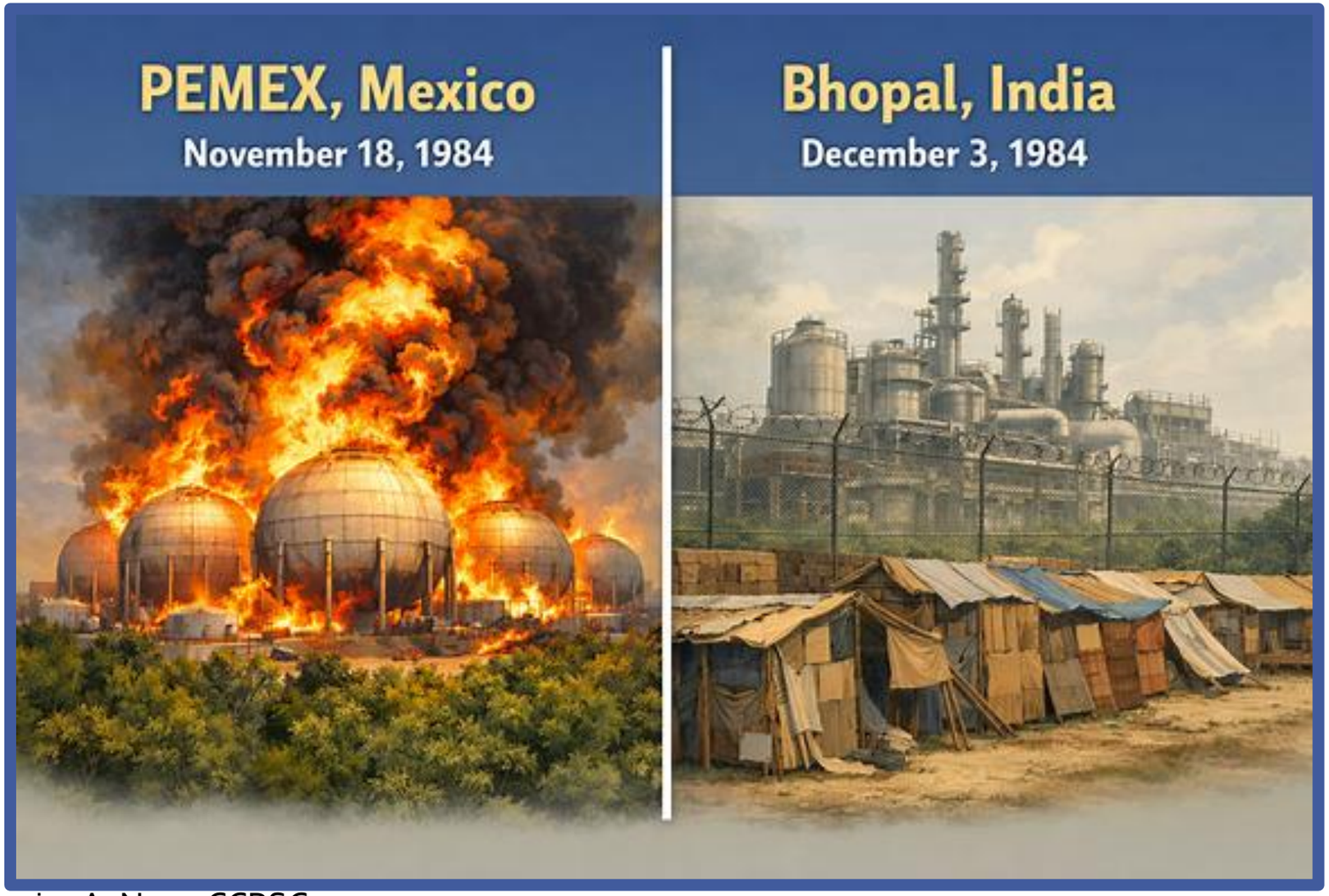
Two Industrial Disasters that Changed My Life and My Career Trajectory



Spotlight on Safety

LOUISA NARA
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Personal Growth and Lessons Learned from Two Global Tragedies

The 30-year anniversaries of two events of significance to the chemical engineering profession, particularly the process safety community, occur in November and December — the PEMEX disaster outside of Mexico City, Mexico, and the Union Carbide Corp. tragedy in Bhopal, India. These two incidents, two-and-a-half weeks apart, molded my professional career and ultimately motivated me to work for the Center for Chemical Process Safety (CCPS) at AIChE, where our mission is to prevent such tragedies from occurring.

After graduating from college in 1981, I accepted a position in Texas as a plant engineer at a facility that produced chlorine, caustic, and chlorinated solvents. With numerous learning opportunities, this was an exciting atmosphere for a new engineer. Lessons I learned in school had new value when applied in real-world situations. My unit operations class came to life when I was able to climb inside a distillation column to install bubble caps made of various metals for performance and corrosion testing.

In the spring of 1984, I was entrusted with what would be one of the most impactful projects of, as well as on, my career — the installation of one of the first computerized spill-response monitoring systems in the U.S. This computer model used real-time data for wind speed, wind direction, temperature, and humidity to calculate the dispersion of a chemical component or compound. Part of the project included evaluating the equipment and pipeline capacities to be included in the database, which would be used for release calculations of anhydrous ammonia, hydrochloric acid, and chlorine. Without the aid of the engineering tools available today, it took over six months just to collect data, perform capacity calculations, and update piping diagrams to provide to the programmers for the calculations. At the time, this was state-of-the-art technology, and it was fascinating to work with.

Successful tests validated our work, but it was put to a real test when we experienced an actual release. Fortunately, the release was small and dispersed out over the Houston Ship Channel. Luckily, no one was injured or exposed.

A post-release, lessons-learned discussion raised the question, "What if the wind had been blowing in the opposite direction?" If the release had not blown out over the water, the likelihood of exposure and injuries would have been much greater. At that moment, I came to the vivid realization that, as a chemical engineer, I was responsible for potentially dangerous chemical processes, and, if the equipment and infrastructure associated with these processes were not designed, constructed, operated, and maintained in a safe and reliable manner, people — including me — could be injured, or even killed.

A few months after realizing the weight upon my shoulders, on Nov. 19, 1984, a leak of liquefied petroleum gas (LPG) found an ignition source (the flare), which triggered a major fire and a series of vapor-cloud explosions at the PEMEX LPG terminal in San Juan Ixhuatepec, Mexico City. Over 500 people lost their lives and the terminal was completely destroyed. This was the worst chemical incident that I had ever heard of, and I struggled to comprehend its implications. (See the Process Safety Beacon on p. 20 for more information on this event.)

While the incident investigation in Mexico City was still underway, another catastrophic incident occurred. This one happened on Dec. 3, in Bhopal, India, at a facility owned by a company I grew up with in Charleston, WV — Union Carbide.

Every year, Union Carbide would invite our school's chemistry class to visit its Global Technical Center for demonstrations and presentations about science and engineering. This company, which later became infamous for one of the worst accidents in the chemical industry, motivated me to pursue a career in chemical engineering — which made a geographically distant accident hit close to home.

The Bhopal incident, as it has come to be known, occurred when 40 tons of toxic methyl isocyante was released from a storage tank. At the time of the incident, the safety systems, which included refrigeration, a flare, and a scrubber, were not functioning, allowing the release to unfold without reduction or mitigation. As a result, thousands of people lost their lives and over a 100,000 were exposed to the toxic chemical. It is difficult to comprehend such consequences. (In the December issue of *CEP,* the Process Safety Beacon, as well as a special section of three articles, will focus on the Bhopal incident.)

As the anniversaries of these tragedies approach, think about how you, in whatever your role is, affect process safety. Remember those who lost their lives as a result of these preventable disasters as you are designing, constructing, operating, maintaining, or dismantling elements of a chemical process. We are all capable of making a positive impact on process safety to eliminate incidents of this kind, and as professionals in the industry, we have an obligation to do so.

Non-Routine Operations Carry Disproportionate Risk

- 5× Higher incident rate during startup vs. steady-state operations — CCPS, 1995
- 45% Of major process safety accidents occur during startup — AIChE/GCPS analysis
- Non-routine operations represent less than <10% of time / 50%+ of incidents

1) Center for Chemical Process Safety. (1995). *Guidelines for safe process operations and maintenance* (p. 113). American Institute of Chemical Engineers.

2) Ostrowski & Keim (2010); CSB (2018)

Why Startup and Shutdown Procedures Fail

- Procedure Designed for Steady State
- Non-Routine Condition Arises
- Operator Improvises Without Guidance
- Multiple Safety Barriers Bypassed
- Loss of Containment Event

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Bypassing a Safety System Can Have Serious Consequences

Safety systems are designed to prevent unsafe operations from occurring, as well as to safely shut down an operation if an unsafe condition does occur. The goal of a safety system is to prevent loss of containment and protect people, property, and the environment.

Safety interlocks and emergency shutdown (ESD) systems are critical and should be connected and operable whenever a process is in operation. In a very small number of scenarios, however, it may be necessary to bypass or inactivate a safety interlock or ESD system for a short period of time using fully reviewed and approved procedures that implement alternative safeguards.

For example, during a process unit startup, it may be necessary to bypass safeguards until certain operating conditions are reached. This action is incorporated into an approved startup procedure and alternative safeguards are implemented. The procedures typically specify the limiting conditions required for operation without critical safeguards and indicate stringent limits on duration and operating conditions.

Examples of situations where it is appropriate to bypass a safety system are few and in each scenario alternative safeguards are put in place. Bypassing a layer of safety removes protective measures, and the consequences can be devastating.

I learned firsthand of the severe consequences of overriding a safety interlock early in my career. During a holiday weekend, when most of the site managers were at home, an operator responsible for running the reactor system used a supervisor's password to override the safety system. The subsequent incident caused an explosion and fire that severely burned the young operator, and he ultimately died from his injuries.

Safety system bypass contributed to an incident at the Formosa Plastics facility in Illiopolis, IL, in April 2004 that caused five fatalities, three serious injuries, and the closure of the site. The site made polyvinyl chloride (PVC) in 24 reactors, arranged in groups of four. Approximately 8,000 lb of flammable and toxic vinyl chloride monomer (VCM) was released when an interlock on the bottom valve of a pressurized reactor (#310) in mid-cycle was manually bypassed.

The interlock was designed to block the air supply to the valve's actuator and prevent a release during operation. The operator may have mistakenly opened the bottom valve and drain valve on reactor #310 when he intended to open the bottom valve and drain valve on reactor #306, which was being cleaned. Better operating practices and equipment design could have reduced the possibility of human error. The site also failed to follow up on recommendations after previous incidents.

These two incidents illustrate the importance of understanding and respecting all safety interlocks, as well as regularly inspecting and maintaining equipment and instrumentation so that it is available for use as intended and when needed. Process hazard analyses (PHAs) and risk assessments (RAs) should be performed regularly. Findings from these investigations should be followed up on to ensure hazards are controlled and contained. PHAs and RAs are particularly important after taking over a newly purchased facility or restarting a plant after extended downtime.

To prevent or protect against unsafe safety system bypasses at your facility:

- Use interlocks and other protective systems as designed. Ensure the system is calibrated and maintained appropriately.
- Report a failure of a critical instrument or alarm immediately so that the appropriate actions can be taken.
- Carry out a management of change (MOC) review before attempting to bypass a safety system.
- Follow procedures as written. If you find that a procedure is incorrect, take the necessary steps to have it corrected.
- During a PHA or other safety review, verify that automatic shutoff systems work effectively and ensure all personnel understand the purpose of the safety systems.
- If a valve will not operate using its control system, do not force it to operate by connecting the actuator to air or another power supply.
- Maintain the confidentiality of passwords for overriding safety systems. Sharing this information with an unauthorized person could be grounds for termination.

Every protective device has a purpose, and it is critical that you understand that purpose. Know what protective actions you need to take before operating equipment. Read the June 2013, June 2003, and March 2002 CCPS Process Safety Beacons for more tips on safety systems. CEP

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Chemical Incompatibility Is a Hidden Hazard

Compatibility Matrix - Tools: CCPS Chemical Reactivity Worksheet (CRW4)

Reactive Hazards - Energetic or unstable reactions can escalate into fire, uncontrolled reaction, or explosion.

Assessment Gap Most PHAs focus on normal operations. Chemical reactivity screening is frequently skipped or incomplete. CCPS Guidelines for Chemical Reactivity Evaluation (2004) remain underutilized across the industry.

Reactive Chemistry Missed at T2 Labs (2007), West Fertilizer (2013), Arkema Crosby (2017) Root: Reactivity screening absent or incomplete

Bottom line: The hazard you never screen for is the one that finds you.

Detecting Weak Signals Before They Become Events

- **Near-misses treated as normal operating noise** rather than precursor data
- **Declining participation in safety reporting** — silence is not the same as safety
- Schedule compression overriding procedure review during turnarounds/outages
- **Loss of experienced operators** without structured knowledge transfer — institutional memory erosion
- **Management of Change** — changes implemented before hazard review completes
- **Audit findings recycled year** after year without root cause closure — the appearance of compliance without its substance

Patterns That Repeat Across Incidents

- **Non-Routine Operations:** BP Augusta (2001), T2 Labs (2007), Dow Plaquemine (2023) Root: Procedures inadequate for abnormal operating modes
- **Management of Change Failures:** BP Texas City (2005), DuPont La Porte (2014), PEMEX Deer Park (2024) Root: Changes made without hazard re-evaluation
- **Deferred Maintenance:** Tesoro Anacortes (2010), Chevron Richmond (2012), USS Clairton (2025) Root: Economic pressure overrides mechanical integrity programs
- **Loss of Containment During Isolation:** DuPont La Porte (2014), PEMEX Deer Park (2024) Root: Isolation procedures lacked independent verification
- **Organizational Drift:** BP Texas City (2005), Deepwater Horizon (2010) Root: Normalized deviance across management layers
- **SIMOPs:** Poor coordination of overlapping work contributed to Wacker Polysilicon (2023) and Evergreen Packaging (2023).

Impact of the US Chemical Safety Board

Link: https://www.csb.gov/

- More than 180 major investigations completed
- Thousands of recommendations issued
- 70M+ YouTube Views
- Landmark safety videos
- Catalyst for regulatory and industry change
- Independent voice for workers, communities, and first responders
- $14M Approved by Congress for 2026
- Videos and reports are used worldwide

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What is Safety Worth?

The U.S. Chemical Safety and Hazard Investigation Board (CSB) has issued more than 130 investigative reports during its almost two decades of operation. These valuable documents detail investigations of incidents at industrial facilities involving fatalities, injuries, and environmental impacts. The insights and recommendations they provide have helped prevent reoccurrences. I have heard first-hand testimonials at chemical facilities in the U.S. and around the world of the usefulness of CSB investigations and reports in evaluating hazards and risks.

The president's recent budget request, however, seeks to eliminate the CSB entirely. While the tiny agency requires a budget of only about $12 million, the "America First: Budget Blueprint to Make America Great Again" overlooks the value of that small financial investment. The CSB helps to maintain the safety and security of U.S. businesses and citizens, helping to save both money and lives.

The CSB began operation in 1998 as an independent, nonregulatory, federal agency with a mission to conduct investigations of chemical accidents, identify root causes and potential contributing factors, and communicate findings to the American people. Reports of these investigations are distributed for free and are used by industry, emergency responders, and communities to prevent future catastrophic incidents. Many of the CSB's recommendations have been directed at the U.S. Occupational Safety and Health Administration (OSHA), the U.S. Environmental Protection Agency (EPA), and industry trade organizations to improve existing regulations, standards, guidelines, and outreach programs.

What is the value of the CSB?

To people. According to a 2017 Strata report, the EPA set the value of a statistical human life at $6.3 million; the U.S. Food and Drug Administration (FDA) at $6.5 million; and the U.S. Dept. of Transportation (DOT) at around $9.1 million. If recommendations from the CSB save just two lives a year, the CSB would pay for itself.

Asphyxiation in industrial settings is one hazard to human life that the CSB has highlighted. Nitrogen is safe to breathe when mixed with an appropriate level of oxygen, but disrupting the balance in air (78% nitrogen, 21% oxygen, 1% other) can cause nitrogen asphyxiation. Decreases in oxygen concentration can cause impaired judgment, and concentrations below 10% can be fatal. From 1992 to 2002, the CSB investigated 85 incidents of nitrogen asphyxiation that caused 80 deaths and 50 injuries. To share this information with industry and the public, the CSB created a training presentation on the hazards of nitrogen (www.csb.gov/assets/1/19/Nitrogen_Asphyxiation_Bulletin_Training_Presentation.pdf).

To property and the environment. Many of the incidents that the CSB investigates have profound consequences that extend beyond the borders of the facility and affect the surrounding community. Such was the case in West, TX, at the West Fertilizer Co. storage and distribution facility (www.csb.gov/west-fertilizer-explosion-and-fire-). An ammonium nitrate explosion at the facility killed 15, injured 260, and caused widespread damage to the surrounding community. Lack of zoning regulations to restrict buildings near hazardous industrial facilities allowed the town of West to encroach on and overtake a safety buffer zone around the plant.

CSB recommendations based on its investigations of the incident include training and certification programs, hazardous response operating procedures for emergency responders, and updates to regulations and codes that aim to make facilities, personnel, communities, emergency responders, and citizens safer.

In addition to impacting facilities and communities, incidents can have an environmental footprint as well. A toxic release of allyl alcohol vapor at the MFG Chemical, Inc., facility in Dalton, GA, sent 154 people to the hospital and forced the evacuation of nearby residents (www.csb.gov/mfg-chemical-inc-toxic-gas-release). The release also contaminated water at the facility that made its way into two nearby creeks, killing fish and other aquatic life.

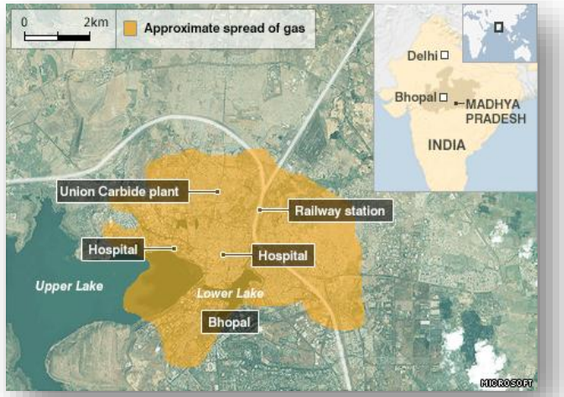
Priceless

Bruce K. Vaughen, a well-regarded process safety professional and coauthor of *Process Safety: Key Concepts and Practical Approaches,* says, "Incidents with fatalities, injuries, environmental harm, and property damage, described in detail in the publicly available CSB reports and videos, provide yet another set of eyes to help us better understand what happened, and additional guidance on how we can prevent the incident from recurring."

Preventing an industrial incident means preventing fatalities, injuries, damage, and environmental impacts. Prevention can be difficult to quantify, especially when there are injuries and fatalities involved. Although I attempted to detail the financial cost, the moral and ethical value is more nebulous. For this reason, when considering the value of the CSB, I would conclude that it is priceless.

CEP

What is the worst accident you could imagine happening to your company?



What are you doing about it?

Is it enough?

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Thank you for your attention and your commitment to Process Safety.

Process Safety Resources — Reference Set

⭐ **FREE RESOURCES**

1. CCPS Free Reference Materials

- **PS Beacon -** https://www.aiche.org/ccps/process-safety-beacon
- **Golden Rules of Process Safety -** https://www.aiche.org/ccps/publications/golden-rules-process-safety
- **Safe Work Practices -** https://www.aiche.org/ccps/publications/safe-work-practices
- **Process Safety Monographs -** https://www.aiche.org/ccps/publications/process-safety-monographs
- **Vision 20/20 – Excellence in Process Safety -** https://www.aiche.org/ccps/excellenceinps
- **Process Safety Book Summaries (incl. 40-page RBPS summary) -** https://www.aiche.org/ccps/resources/publications/process-safety-summaries
- **CCPS Annual Report -** (URL referenced as “CCPS Annual Report | AIChE”)
- **CCPS Body of Knowledge Poster** https://www.aiche.org/sites/default/files/docs/pages/ccps24_process_safety_poster_web_20241202.pdf

Process Safety Resources — Reference Set

2. Free Topic-Specific CCPS Monographs

- **Ammonium Nitrate** - ttps://www.aiche.org/sites/default/files/html/ccps/3548221/mobile/index.html
- **Combustible Dust** - ttps://www.aiche.org/sites/default/files/html/ccps/2405081/V2/mobile/index.html
- **Chlor-Alkali** - https://www.aiche.org/sites/default/files/html/ccps/1815036/V4/mobile/index.html
- **Key Principles for Operating Procedures** - https://www.aiche.org/sites/default/files/html/ccps/3509486/mobile/index.html

FREE CSB Material

Volume 1 - https://www.csb.gov/assets/1/6/csb_incident_reports_volume_one_2025-01-14_rev_1.pdf

Volume 2 - https://www.csb.gov/assets/1/6/incident_reports_volume_2_2025-03-12.pdf

Volume 3 - https://www.csb.gov/us-chemical-safety-board-releases-volume-3-of-chemical-incident-reports-incidents-resulted-in-18-billion-dollars-in-property-damage/

Volume 4 - https://www.csb.gov/us-chemical-safety-board-releases-volume-4-of-incident-reports/

Process Safety Resources — Reference Set

3. Free Training / Courses

- **Risk Based Process Safety Decision-Making for All Engineers (Free, 6 hours) -** https://www.aiche.org/ili/academy/courses/ela401v01/risk-based-process-safety-decision-making-all-engineers

4. Free Webinars

- **Understanding Process for Mechanical Integrity -** https://www.aiche.org/ili/academy/webinars/importance-understanding-process-when-implementing-your-mechanical-integrity-program
- **Process Safety in Operations – What's Missing? -** https://www.aiche.org/ili/academy/webinars/process-safety-operations-whats-missing
- **Whoops! I Made a Mistake Sizing My Relief Device -** https://www.aiche.org/ili/academy/webinars/whoops-i-made-mistake-sizing-my-relief-device-and-then-i-installed-it-incorrectly
- **LOPA: When and Where? -** https://www.aiche.org/ili/academy/webinars/layer-protection-analysis-lopa-when-and-where
- **A Chat with Louisa Nara on Process Safety Resources -** https://www.aiche.org/chenected/2024/06/chat-louisa-nara-on-process-safety-resources-every-level-expertise
- **Benefits of Intelligent Drawing Practices -** https://www.aiche.org/ili/academy/webinars/benefits-intelligent-drawing-practices