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Unexplained death in confined space

Issue 294, December 2023

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Incident

Bhopal revisited – a story of neglect

Fiona Macleod

In August 2023 I travelled to Bhopal, India to revisit the abandoned site of the former Union Carbide Factory.

In the almost forty years since the world's worst industrial accident there has been no clean-up of the site and much of the old equipment remains standing.

I had just started my working life as a chemical engineer when news of the tragedy hit the headlines, but some of you weren't even born in 1984. So, let's take a step back and remind ourselves.

Just after midnight on the night of 2-3 December 1984, thousands of people died, and hundreds of thousands were injured by a release of gas from a pesticide factory in Bhopal, India. A runaway reaction in a tank containing 40 tonnes of MIC (Methyl Isocyanate – an intermediate in pesticide production) led to the release of toxic gas into the neighbourhood.[1]

I last visited Bhopal almost ten years ago while working in India. At that time, I was unable to enter the Union Carbide factory site and could only inspect it from the outside — you get a good view from the elevated Vidisha Bypass Road. This time I obtained official permission from the Madhya Pradesh District Controller, but the afternoon spent in government offices proved unnecessary as the single security gate was unlocked and I was able to walk directly onto the abandoned site unchallenged.

It is a strange place to visit, a piece of overgrown land the size of thirty football pitches (55 acres) bounded by two main roads and a major railway line. The scent of mint gets stronger as you progress from Berasia Road, bordering the busy JP Nagar district and delve deeper into the overgrown site full of trees and whooping, swooping birds. The main paths are clear, but the side routes are carpeted in mint, which release a fresh aroma as you crush them with your safety boots. There are butterflies everywhere — little yellow ones and large ones — orange, red and black. The vegetation clears towards the former waste dumping ground in the north-east corner and white storks rise up from the shallow pond as you approach. Dragonflies dart along the paths where streams and pools drain the monsoon rains.

The site is surrounded by houses, some of which back directly onto the factory land.

The structures that held the flare tower, the pipe bridges, the Sevin plant including MIC (Methyl iso-cyanate) distillation column and vent gas scrubber, all appear to be holding up although there

Figure 1 – Equipment at the former UCIL pesticide factory in Bhopal, India, August 2023

Figure 2 – Path at the entrance to the former UCIL site in Bhopal, India, August 2023

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Figure 3 – Former dumping ground in the former UCIL site in Bhopal, India, August 2023

is advanced corrosion right through some of the vessels. It is quite extraordinary to see parts of this factory exactly as they were on the night of the accident, untouched for almost four decades.

Given the poor security and the poverty level of the surrounding communities, it was unsurprising to see signs of habitation inside the abandoned factory — bed rolls and cooking equipment inside otherwise empty concrete buildings. I met several people looking after their grazing animals: herds of cows and goats.

Outside the site, on the other side of the railway line, unfenced and open to all, lies a huge abandoned lake covered in water lilies and hyacinths. This was a solar evaporation pond (SEP) where liquid waste from factory operations was concentrated.

Figure 4 – Pipe bridge inside the former UCIL site in Bhopal, India, August 2023

The soil and groundwater inside and outside the factory are known to have been contaminated by the factory activities. While much of the contamination may not be directly linked to the 1984 accident, the failure of the polluter to clean up after themselves is most definitely a direct result. The fragility of the gas affected population and their children makes them especially vulnerable to further assaults.

The victims, their families and neighbours have been neglected and forsaken. There has been a complete abdication of responsibility: by the company that ran the site at the time of the accident, by its US parent company at the time, all the later companies that acquired its assets, by the police and the law courts for failing to investigate or prosecute effectively, by the central government for settling too hastily and for insufficient compensation, by the local state government for failing to provide adequate relief or restitution to those affected. The more I dig into this tragic case the more shocked and angry I become.

When I visited ten years ago, the CSE (Centre for Science and the Environment), an Indian public interest research and advocacy organisation based in New Delhi, brought together technical experts and community representatives to outline an Environmental Remediation Plan for the former UCIL operations.[2]

Since then, things appear to have gone backwards.

It's not hopeless though.

There are good people who refuse to look away. I met the fiercely intelligent and articulate activist, Rachna Dingra of BGIA (Bhopal Group of Information and Action). We may differ on how we view the international chemical industry, but as I listened to her talk about her experience, the lack of progress or support and all the petty setbacks, I marvelled at her calmly rational approach and indomitable spirit.

I also visited the Sambhavna clinic and talked with Satinath Sarangi and others. The clinic is unique in that it provides both conventional medicine and complementary Ayurvedic therapies under the same roof. It is free to access and provides a calm and peaceful haven, designed not to look, feel or smell like a hospital, a fascinating model of care, compassion and participatory management.

Bhopal itself is an extraordinarily beautiful city, and the upper town is booming. Capital of the Tiger state, Madhya Pradesh,

Figure 5 – Solar Evaporation Pond outside the former UCIL site in Bhopal, India, August 2023

engineering and design

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Figure 6 – Sambhavna Clinic in Bhopal, India, August 2023

Bhopal is stuffed with lakes, gardens, wonderful museums, extraordinary palaces and one of the largest mosques in India. There are two UNESCO world heritage sites within easy reach — the prehistoric cave shelters at Bhimbetka and the Buddhist Stupas at Sanchi, and multiple wildlife reserves offering tiger and other safaris.

I arrived at a brand-new railway station – Rani Kamlapati – which links to an ambitious new metro already under construction. Domestic tourism is alive and well and there are several excellent hotels, but foreign tourism — and the money it brings — has been blighted by Bhopal's association with the gas tragedy.

The past can't be changed. But nor will it go away by ignoring what happened. The remediation and redevelopment of the old Union Carbide factory site in Bhopal is a big task, but India has many well-qualified engineers and the expert knowledge needed to solve the technical problems.

The challenge is not a technical one.

The issues are all political.

India is a complicated place with even more complicated politics. But the Bhopal tragedy was never a uniquely Indian event; it should have been a lesson to us all.

Poor operational decisions were made in the 1980s. The factory was uneconomic and was in the process of closing down. Experienced people left. Inventories of hazardous material rose. Equipment ran to failure. Safety systems were compromised.

But the root causes[3] of the accident go back to design decisions made in the 1970s, including:

- Materials of construction (mild steel instead of stainless steel for the vent gas header leading to iron catalysed solid formation which was removed using water);
- Equipment selection (conventional pump seals which leaked on hazardous service);
- Storage of large quantities of a hazardous intermediate (the minimisation principles of inherent safety were applied to phosgene but not to MIC);
- Inadequate instrumentation for measurement, alarm and control.

The wider world has a unique opportunity to learn from what happened and do right by the victims of the world's worst chemical accident, those who suffered and whose children and grandchildren continue to suffer from the effects of contaminated soil and water and a lack of economic opportunity.

We would all benefit from taking a good hard look at the terrible events of December 1984, to gather together the information collected, to review the lessons not learned, to share them transparently and work to ensure that such a tragedy can never happen again.

What needs to be done

The following action is needed:

- Make secure
  - Immediate improvement of security to prevent access to the former UCIL site and Solar Evaporation Ponds (SEPs).
- Make safe
  - Assess the condition of drummed waste:
    - ensure effective containment (transfer to stainless steel drums)
    - prepare a credible destruction plan
    - destroy the waste safely without further harm to people or the environment.
  - Assess the condition of buildings, structures and ponds and make safe as required.
- Remediate
  - Carry out a comprehensive scientific assessment of the ground and groundwater pollution from the factory site and evaporation ponds as well as all the water sources at increasing distances from the site.
  - Construct a predictive model of the spreading underwater plume and develop alternative clean-up options that involve and benefit the people closest to the site.
  - Implement a remediation plan.
- Alleviate
  - Deliver on the promise of free clean piped water to the affected population.
  - Deliver on the promise of free health care to the affected population.
  - Rehouse anyone living on the site or using it to graze domestic animals.
- Redevelop
  - Evaluate alternative redevelopment options with the full involvement of the affected population.
  - Implement a redevelopment plan that will involve and benefit the affected population and the people of Bhopal.

References

1. *For more information see: LPB special edition 2014*
2. *Action Plan CSE India Environmental Remediation http://cseindia.org/userfiles/Action%20Plan_Environmental%20Remediation%20in%20and%20around%20UCIL,%20Bhopal.pdf*
3. *Rethinking Bhopal by Kenneth Bloch, Elsevier (2016), ISBN-13 : 978-0128037782*

Incident

Post accident remediation and decontamination: a plea for Bhopal

Ken Patterson

This edition of *LPB* is published close to the 39th anniversary of the accident at Bhopal. Despite the passage of so much time, the aftermath of the Bhopal accident in 1984 continues to harm the living and the unborn, shortening lives and malforming children[1]. Following other major accidents, we have spent huge quantities of effort, skill and money recompensing the bereaved and injured, clearing up the environmental effects and setting right the damage done. BP has — quite rightly — had to spend huge sums on the environmental clean-up required after the Deepwater Horizon accident (estimates of the total cost of the accident to BP are over $50 billion) and it seems that the Gulf of Mexico is now returning to its pre-2010 condition.

What about other accidents?

Flixborough

I was a student in June 1974. My then girlfriend (now my wife and also a chemist) lived in North Lincolnshire and had a motorbike. I visited her early that month and she drove us both round the perimeter of the destroyed and still gently steaming Flixborough site. For both of us it was a stark introduction to the potential dangers of the chemical industry that we were about to join. Maybe it is no accident that we both ended up as SHE Managers.

The pictures of the destroyed site are familiar to many — but now? As an HSE inspector, I visited a paint factory on the site in the late 1980s. If I had not known where I was, I would not have known what had happened. Today the site is a light industrial complex on the banks of the River Trent in North Lincolnshire, UK.

Flixborough 2022 (Google Earth)

Trinity Mirror / Mirrorpix / Alamy Stock Photo

Flixborough 1974 (Alamy)

knowledge and competence

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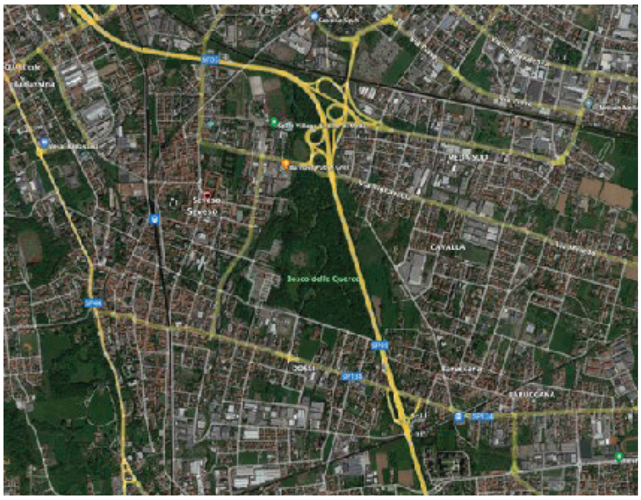
Chloroacne affected child, Seveso 1976

The 'Bosco delle Querce' park, Seveso, Italy, present day (Wikicommons)



Aerial view showing the park's location (Google Earth 2021)

Seveso

What of Seveso, the site which gives its name to the EU (and is the basis of the UK's) Major Hazard legislation? There are no pictures of the plant wrecked in 1976 for there was no wrecked plant. The reactor's emergency relief venting system had been well sized and coped with the runaway reaction. But it had not been designed to contain the release, and what it released to the environment were extremely toxic dioxins. Though there were no direct human deaths, many were affected (for example with chloracne), thousands of animals died, and an enormous area of land was contaminated.

The solution was to entomb the contaminated plant in a concrete sarcophagus and to incinerate the contaminated land returning the soil, over time, to beneficial use. Today, the site of the Seveso plant is an attractive — and safe — public park, the "Bosco delle Querce" (Oak Wood), in the middle of the Seveso built up area.

Toulouse

A third example is the Grande Paroisse chemical plant in Toulouse, 2001. The explosion of 300-400 tonnes of off-spec ammonium nitrate caused 31 deaths, roundly a third off-site (by far the worst off-site death toll in Europe since the middle of the 20th century). The explosion occurred on a large chemical site in a populated area, near to a major motorway intersection. It left a warehouse-sized crater, up to 7m deep and 40m long, and wrecked a large part of the surrounding chemical plant.

Today the site has been cleared and what was a chemical plant is a large, green space with a memorial to those who died at its centre. The crater, where the explosion occurred, is kept as a reminder of what happened. Twenty-two years later, the site is partly parkland and includes a research centre and one of the City's bus depots, and is bounded by a large solar farm.

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Vincent Dargent/ Abaca Press / Alamy Stock Photo

A huge explosion ripped through a chemical fertilizer plant AZF in Toulouse, France, on September 21, 2001

Of course, our first duty is to prevent accidents occurring. But we know that sometimes, despite our best efforts, things will go wrong. Then our first duty is to care for the injured and our second is to restore the environment as far as we can. The three examples above show what can be done. Tragically, the story of Bhopal is quite different.

Like Seveso and Grande Paroisse the Bhopal plant was in an urban area and the area around was densely built up. There are no useful Google Earth images going back to 1984/85 but the site of the plant is the green area in the upper central part of the left-hand aerial photograph (the area labeled "Arif Nagar"- see page 8). The right-hand picture (from 2023) shows part of the former site at much higher resolution, with decaying chemical plant and buildings, and the site's road layout still visible. The pictures in Fiona Macleod's article show what the site is like at ground level. Nature is reclaiming the ground but the plant lives on, not yet made properly safe and on land still toxic with abandoned plant, chemicals and waste.

Most readers of LPB are probably familiar with the accident at the Union Carbide India Ltd (UCIL) site in December 1984. Water entered a tank containing methylisocyanate (MIC) and an exothermic reaction ensued, boiling the MIC which was ejected as a deadly, toxic cloud. The cloud killed over 5,000 people that night and injured many, many more, thousands of whom have since died. The site has been abandoned and left un-decontaminated for nearly 40 years, with toxic materials leaching out into the ground water. The result is contaminated water and high numbers of children in the area nearby born with deformities — and often short lives. The grandchildren of those harmed on the night of the accident in 1984 are still being harmed in 2023[1].

Understanding what happened and the problems that led up to it is important, as is the question of who bears responsibility. But neither of those questions is any justification for harming people — children — nearly 40 years after the event. Chemical engineers and chemists know how to stop the pollution. Indeed, India has great expertise in decontamination, as shown in the improvements made in (for example) Vapi in Gujarat,

Grande Paroisse, Toulouse, 2002 (Google Earth)

Grande Paroisse, Toulouse, 2022 (Google Earth)

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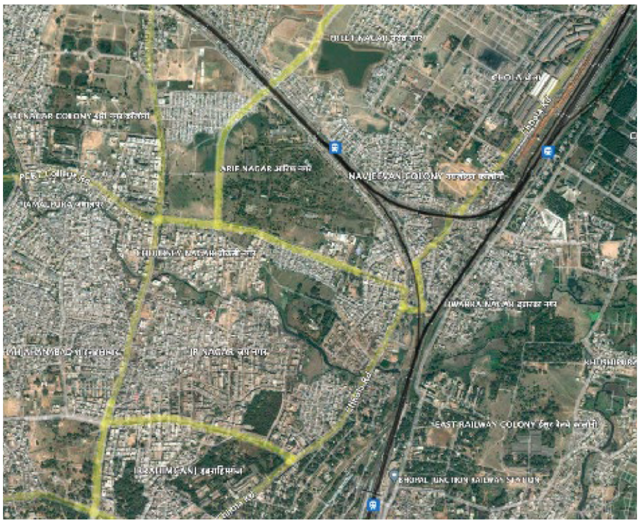
View of the abandoned Industrial gas leakage site in the Union Carbide Factory at Bhopal, Madhya Pradesh, India



Central Bhopal, including former UCIL site and Junction (main) railway station (Google Earth 2022)

Part of the site becoming overgrown but with plant and buildings still visible (Google Earth 2023)

once sixth on the Blacksmith Institute's[2] list of the ten most polluted places in the world.

The site needs comprehensive and fully effective remediation, which with goodwill and determination could be done. We know that many groups, organisations and individuals across the world are ready to help. As we enter the fortieth year since the world's worst industrial accident, let us all raise our voices in the hope that we can make it the last one before the harm comes to a stop.

References

1. *The harm still being done by the toxic material on the Bhopal site has been widely discussed. Two useful sources are:*
   - *The report of an expert roundtable discussion in 2013 which discusses the materials left on site and the way they are leaching off-site:*

     https://www.jstor.org/stable/resrep38062
   - *A discussion of the longterm health effects around the site, published this year:*

     BMJ Open 2023;13:e066733. doi:10.1136/bmjopen-2022-066733

     Summarised at:

     https://www.chemistryworld.com/news/repercussions-of-bhopal-disaster-found-to-echo-on-down-through-generations/4017672.article

2. *The Blacksmith Institute is now know as Pure Earth:*

   www.pureearth.org.

   Their Toxic Sites Identification Programme (TISP) is described at:

   www.pureearth.org/our-projects/toxic-site-identification-program-tsip

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Incident

The senior executive visit on the eve of the 2010 Macondo disaster

Lee Allford and Ken Patterson

The visit

Several hours prior to the 2010 Macondo blowout and the subsequent catastrophic oil spill in the Gulf of Mexico, the drilling rig hosted a delegation of senior executives from both the well operator and the rig owner. The visit formed part of a programme of management visibility tours whose purpose was for senior executives to meet the crew, share lessons, and both give and receive feedback. It is a feature of high reliability organisations that senior executives are regularly visible to the workforce, and both demonstrate, and crucially *are seen* to demonstrate, their commitment to front line workers (sometimes described as "felt leadership"). To be truly effective, this demonstration needs to show commitment to the company's safety performance, and for safety it needs to include both personal safety and process safety.

The senior management delegation also came to congratulate the crew as the drilling rig had an exemplary personal safety record having suffered no lost time injuries in the previous seven years. The senior executives clearly wished to learn how this impressive feat had been achieved and transfer lessons to other operations across their respective organisations. Although the visit was informal in nature, the senior executives wished to focus on specific topics including those related to personal safety such as risks posed by working at height and dropped objects.

In the build up to the Macondo blowout and whilst they were aboard the rig, the senior executives seemingly possessed a window of opportunity to contribute to the critical decision making that was playing out on the drill floor. The delegation comprised former drilling engineers and rig managers, who had the necessary understanding and possessed the necessary authority, to make an intervention. Unfortunately, the opportunity was not taken and a few hours after they boarded the delegation along with the crew would be fighting for survival in an emergency evacuation.

Warning signals

Andrew Hopkins, who has written about the organisational and cultural aspects of several major accidents, has offered his view as to why the delegation missed the warning signals in the countdown to the explosion. Hopkins contends that they and the companies they represented were focused on high probability but low impact events, typically associated with aspects of personal safety. This focus on preventing personal safety accidents crowded out proper consideration of process safety and the prevention of low probability but high impact incidents. The lack of focus on process safety is somewhat counter intuitive because process safety incidents have the potential to endanger both an entire asset and its workers, whereas the effects of personal safety incidents are limited, often to the injured party only.

At a corporate level, one reason for the pre-occupation with personal safety is that it is readily measured, tracked, and reported within organisations. On the front line, workers and casual observers alike will understand what constitutes unsafe conditions and behaviours whereas during a safety tour, compliance to good process safety practice in the workplace is not readily observable even to relatively specialist observers.

Despite the contrast between personal safety and process safety, many organisations still view personal safety as the definitive indicator for workplace safety. This point was noted after an earlier onshore explosion at Texas City in 2005 which led to 15 fatalities and an independent review of safety culture across several US refineries. The subsequent report (The Baker Report) into the incident specifically found that "Reliance on the low personal injury rate at Texas City as a safety indicator failed to provide a true picture of process safety performance and the health and safety culture". It called for the company to "develop, implement, maintain and periodically update an integrated set of leading and lagging performance indicators for more effectively monitoring [the Company's] process safety performance".

Invariably, a company's safety culture will be set by the things senior managers show interest in and ask about. If senior managers do not ask about process safety and only focus on personal safety, the workforce will understand that personal safety is what is important. It is essential senior managers have suitable reporting systems to help them to understand how a company is performing in process safety and, equally, to show an interest in process safety during site visits.

One of the problems of discussing accidents in the past, perhaps especially process safety accidents, is the clarity that 20/20 hindsight vision gives. It is always possible to see how things might have been done differently; how a slightly different decision could have led to a very different outcome. The danger in that is that this can easily lead to "blame" being attributed - quite wrongly - to individuals doing their best in the circumstances. On the other hand, we have a duty to learn from what has gone wrong and consider how accidents could have been prevented; and we recognise that senior managers have special responsibilities in safety, health and environmental performance in all its forms.

The question, then, is, could the senior executives have

culture

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acted differently during their tour and might that have affected the outcome?

The tour

During their tour the executives dropped in on the drill shack where there was a tense debate on the results from the critical negative pressure test to verify well integrity. A member of the visiting party was sufficiently concerned to ask a member of the rig-based team escorting the visiting party, to stay behind and help with the decision making. This escort was a former drilling engineer with many years' experience. When the executive caught up with the escort a little later and asked about the discussion, the question was loaded in such a way as to suggest that they anticipated a good news response. Unsurprisingly, the executive received a thumbs up and the matter was probed no further.

At this point there could have been an open exchange about the results of the negative pressure test and an acknowledgement that uncertainly remained. The uncertainty could have suggested that further tests were required, accompanied by a "time-out" in the well abandonment and convening a meeting with those at the sharp end of the operational decision-making. A meeting might well have proved a useful challenge to any crew's natural tendency to assume success, in this case by interpreting test results to be in line with their presumption that the well was indeed properly plugged.

Even if a pause for a rethink had not happened at this stage, such an exchange may have concluded that the crew should only proceed *with care* to the next stage of temporary abandonment and that the well should be placed under a close watch during sea water displacement. Such advice could have helped to direct the crew's undivided attention to well monitoring. In the event, it appears the issue was deemed closed and the crew was distracted by the pressure to finish up the temporary abandonment of the Macondo well.

During the tour, the senior executives also took pains to visit the rig bridge to meet the captain and marine crew, a typically overlooked group on such management tours. Once disconnected from the well, a rig is classed as a ship and command passes from the drilling operation to the rig captain. This welcome visit to the marine crew provided an opportunity to discuss how command passed from the drilling management to the marine captain. Given that disconnection is a moment of heightened risk, this could have included a discussion about command in an emergency and clarity about the passing of authority to take necessary action if an emergency occurred. It emerged from the investigation into Macondo that better communication and more incisive decision making could have resulted in swifter shutting down of equipment during the release, thus avoiding a source of ignition. There was also confusion over who had the authority to disconnect the rig from the riser and blowout preventer. The delay may have resulted in damage to this circuit, which consequently failed to work and contributed to the tragic events which subsequently unfolded.

Lessons for senior executives

The Macondo blowout holds important lessons for senior executives and especially those who are visiting major hazard facilities. The safety culture of a company will reflect the things senior managers show interest in, and those issues they ask questions about while visiting sites and doing safety tours. If process safety is ignored and management solely focuses on personal safety, the company's safety culture will reflect this choice. By asking open questions senior executives can show their interest in process safety while providing a safe space for discussion. They can reinforce this by being prepared to probe if they find process safety issues during their visits. It is also important that senior executives recognise that they possess the authority to halt operations when they happen across circumstances on the ground which create a sense of unease and that, in the face of impending danger, they have the power to bring people together to agree on a risk-informed plan of action.

References

1. *Baker Panel Report, released January 16, 2007*
2. *Andrew Hopkins, Management walk-arounds: Lessons from the Gulf of Mexico oil well blowout*
3. *Safety Science, Volume 49, Issue 10, 2011, Pages 1421-1425, ISSN 0925-7535, https://doi.org/10.1016/j.ssci.2011.06.002.*

Thoughts for further discussion

Personal safety hazards can often be seen and stopped by anyone - a contractor working at height without a safety harness can be told to stop work and descend to a safe place immediately. Process safety hazards, such as non-functioning pressure relief valves or poorly maintained safety trips, are not easily visible even to specialist process safety observers. None the less it is essential for senior executives to show their interest in process safety during safety visits, and thus emphasise to all staff its importance to the company.

LPB readers' views and experience in this area would be welcomed.

The following questions may help focus discussion:

- What approaches can senior non-specialist personnel use when visiting high hazard facilities to show their concern for process safety and process integrity, and emphasise their importance to the business?
- How can senior executives become aware of worst-case accident scenarios and then convey, during site visits, their determination to avoid such incidents?
- How can senior executives gain the necessary confidence to explore any process safety concerns that they may come across during site visits?
- If senior leaders feel uneasy, or become aware of a sense of unease among site staff, about safety critical conditions or activities, then how should they respond and what approaches should they adopt?

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2019 Philadelphia Energy Solutions Refinery Explosion

Aabid Bala, Maram Alotaibi, Kyle Bradbury and Unais Ejaz

Summary

The Philadelphia Energy Solutions (PES) refinery explosion of 2019 resulted in several injuries and forced the evacuation of thousands of people. The explosion had a significant impact on the local community, including environmental damage and economic disruption. Given the plant at the time was the biggest oil refinery on the east coast of the United States, the scale means it received significant media coverage and public attention. Due to the recency of the accident, it is timely and relevant to discuss the explosion with relatively up to date safety standards and procedures. The lessons learned can provide valuable insights to prevent future incidents.

Keywords: Explosion, refinery

Introduction

This paper focuses on the release of hydrocarbons and subsequent fire and explosions that occurred in the early hours of 21 June 2019 at PES. The incident injured five employees and eventually led to the bankruptcy of the refinery within two months, suffering financial losses of $750m and 1,000 workers being laid off[9]. This accident will be examined in depth to understand how and why it happened and what lessons can be learned.

The PES refining complex was based in Philadelphia, Pennsylvania, USA and was made up of two refineries (Point Breeze and Girard Point). It processed 335,000 barrels of crude oil per day and was the largest oil refining complex on the US East Coast. At the time of the accident there were 1026 employees at PES.

The refinery complex covered an area of about 1,400 acres and was in operation since the late 1800s. The complex was situated along the Schuylkill River, a major waterway that flows into the Delaware River and ultimately into the Atlantic Ocean.

The safety record of the PES refining complex had been a matter of concern for many years. The complex had a history of safety violations and accidents, including fires, explosions, and chemical releases. In 2015, the PES was fined by the Occupational Safety and Health Administration (OSHA) for several violations related to the handling of hazardous materials, including failure to properly label containers and failure to provide employees with appropriate protective equipment. In 2018, the U.S. Chemical Safety Board (CSB) released a report on a fire that occurred at the PES refining

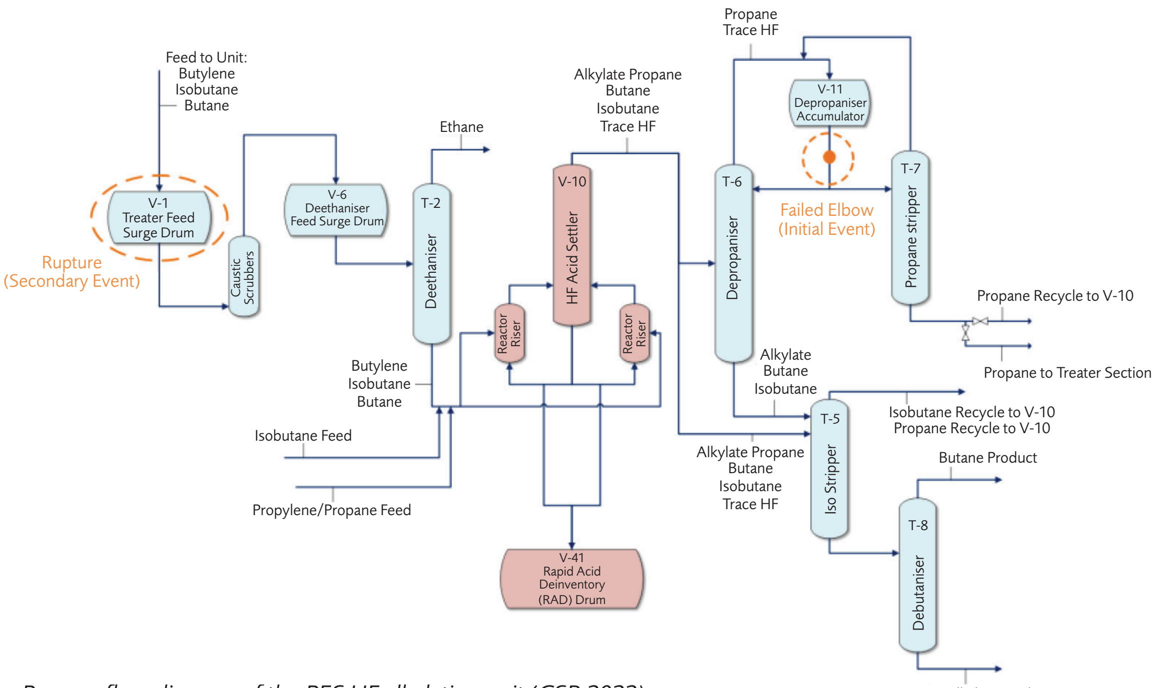

Figure 1 – Process flow diagram of the PES HF alkylation unit (CSB 2022)

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complex in 2015. The CSB found that the fire was caused by a corroded pipe that released a flammable gas, and that the PES management had failed to adequately maintain and repair the pipework[5]. The CSB also found that the PES management had not properly trained employees on the hazards of the materials being processed at the complex.

Process flow

The PES Refinery HF Alkylation Unit (HFAU), as depicted in Figure 1, was a crucial part of the refinery's production process. It used hydrofluoric acid (HF) as a catalyst to convert light olefins and isobutane into high-octane blending components for gasoline[6]. The alkylation process involves reacting isobutane with olefins, such as propylene or butylene, in the presence of a HF catalyst to produce isooctanes and other alkylate products. It begins with the feed preparation process which involves the delivery of isobutane and olefins from storage tanks to the HFAU, which are then fed into the reactor.

Accident description

At around 3.30am on 21 June 2019, a dangerously corroded pipe elbow ruptured on HFAU, releasing process fluids, which then ignited causing a fire and series of explosions. This caused the release of over two tonnes of HF into the environment, a highly toxic substance. A 17-tonne vessel catastrophically ruptured and fragments of the vessel landed off site. The estimated loss to the company due to the accident was approx. $750 million.

The incident occurred when a plant operator took a series of operational measures to raise the propane stripper feed from 73 to 80 barrels per hour. This led to the vibration and rupture of the process line, causing uncontrolled release of HF and hydrocarbons from the alkylation unit. The rupture occurred within seconds, with a flurry of operational alarms going off. The CSB report shows pump vibration alarm activation 2.8 seconds after the flowrate was raised from 78 to 80 bph, with the low stripper feed alarm activating 0.1 seconds after that[5].

Releases to environment

This release arose when the control room operator increased the feed to T-7. This led to the elbow on the outlet of T-7 connected to pump P14-B rupturing catastrophically.

The three operators in the alkylation unit at the time reported hearing a loud bang followed by a 'roaring noise'. One of the operators described it as though something under high pressure 'let go'. Another operator described witnessing a vapour cloud up to 10 feet high surrounding the alkylation unit[5].

Based on the design on the process, the composition of this vapour cloud is thought to have been composed of approximately 95% propane and 2.5% HF.

The field operator who witnessed the vapour release went immediately to the control room to report it and to the emergency response line.

Figure 2 shows the location of the failed pipe elbow (yellow star) and the path the field operator who reported it took to the control room.

PES estimated that 2.3 tonnes of HF were released to the environment with only 0.9 tonnes being suppressed by the mitigation water cannon system and the rest was not

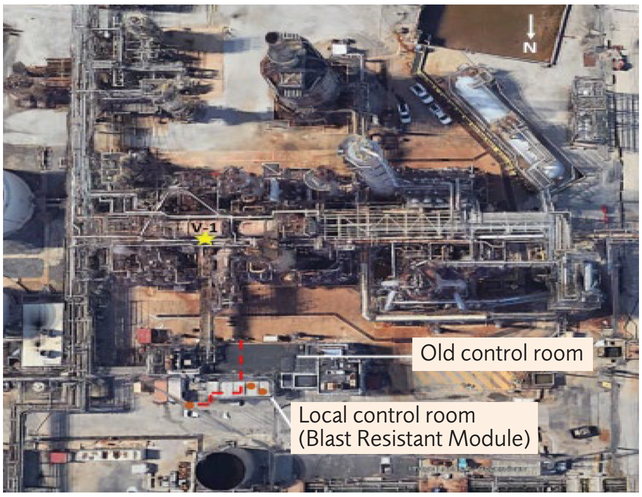

Figure 2 – Location of failed elbow and operator path (Google Earth with annotations from CSB)

contained. They also stated that 306.6 tonnes of hydrocarbons were also released, with 275 tonnes being combusted by the fire and explosions that followed[4].

Fire

At around 4.00am, the escaping vapour cloud found a source of ignition, and a control room operator, who was watching the security cameras at the time, reported seeing a flash, and flames entering the doorway of the control room which quickly went out[5]. This fire is thought to have caused the failure of the HF mitigation water cannons. The fire was not extinguished until the following day at around 8:30 am, approximately 28 hours after it began[9].

Explosions

PES and the CSB jointly established that three explosions occurred during the accident and the evidence indicates that

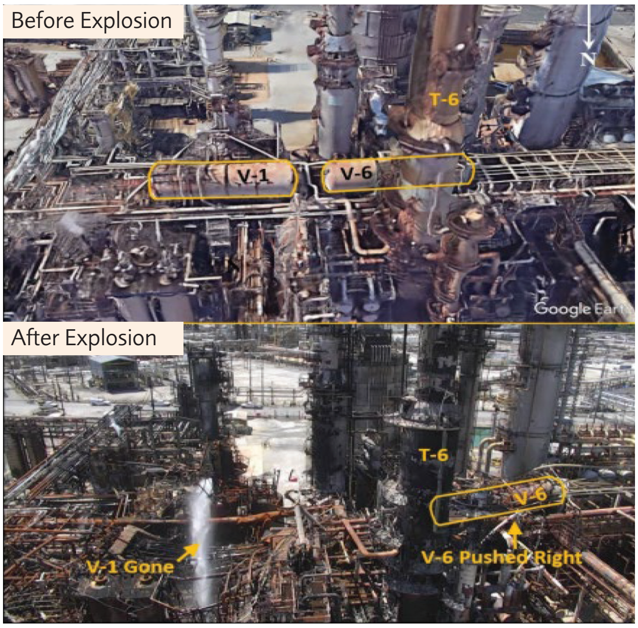

Figure 3 – V-1 location comparison (CSB)

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Figure 4 – Fragment recovery positions (CSB)

they were secondary events caused by the initial fire[5].

The first explosion occurred at 4:15 am with another shortly thereafter at 4:19 am. The last explosion being the largest occurred at 4:22am when the vessel V-1, containing flammable hydrocarbons such as butane and isobutane at about 53% capacity, ruptured[5]. This caused a BLEVE - Boiling Liquid Expanding Vapour Explosion. The Centre for Chemical Process Safety (CCPS) definition of a BLEVE is: The "sudden loss of containment of a pressure-liquefied gas existing above its normal atmospheric boiling point at the moment of its failure, which results in rapidly expanding vapour and flashing liquid. The release of energy from these processes (expanding vapour and flashing liquid) creates a pressure wave"[3].

A large fragment of the vessel V1, weighing 38,000 pounds (approx. 17.2 tonne), projectiled across the nearby Schuylkill River and two more fragments weighing 23,000 pounds (approx. 10.4 tonne) and 15,500 pounds (approx. 7 tonne) landed on the refinery site. Figure 4 above shows the positions the fragments were recovered from relative to where V-1 was pre-accident as well as the condition of each one post-accident.

The CSB concluded that the initial failure of the elbow caused a jet flame to impinge on V-1. This subsequently led to the BLEVE. Furthermore, V-1 was also not equipped with thermal protection from the fire. Figure 5 taken from the CSB report shows their model of the piping circuit containing the failed elbow and its proximity to V-1, including the suspected area of fire induced thinning and the arrangement of the fragments that were recovered.

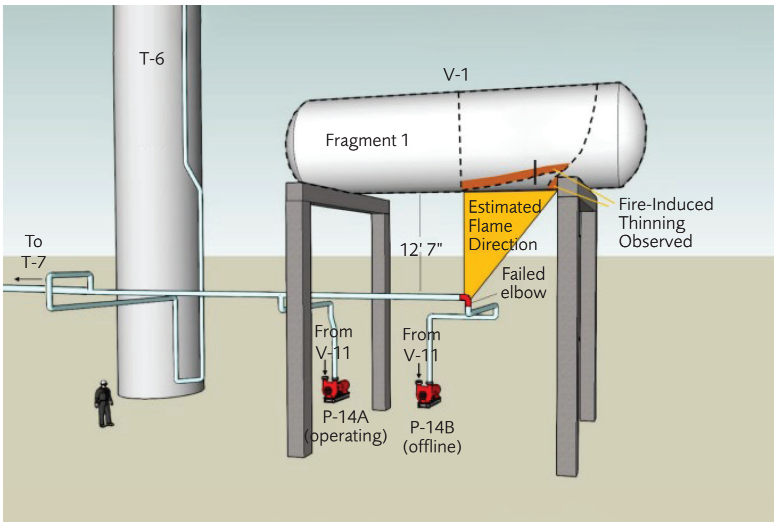

Figure 5 – Model of failed elbow piping (CSB)

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IChemE

Causes of the accident

Underlying causes

The causal factors that attributed to the explosion and eventual closure and bankruptcy of the plant arose from unidentified high levels of corrosion on an elbow pipe transporting process fluid (containing propane 95%, hydrofluoric acid 2.5% and other hydrocarbons).

The corrosion led to the rupturing of the elbow, which created a large release of the fluid in the alkylation unit. The elbow was of different metallurgical composition (manufactured in 1973, at a time when ASTM standards did not have specifications for the amount of copper and nickel that could be present in carbon-steel piping) to the neighbouring sections, which was why the elbow corroded at a higher rate. The released fluid created a ground-hugging vapour-cloud that ignited two minutes later, beginning a series of fires and explosion events on the plant. The subsequent actions attempted to mitigate the fires and explosions were generally ineffective due to the damage done earlier by the fire and explosions. As some of the safety elements were not operational, the fire would go on to last over a day (from 4am on 21 June to 8.30am on 22 June) ceasing the production of 2% of the United States' gasoline.

Root causes

The final report by the CSB noted the root causes at play, that instigated the tragedy; included:

- insufficient monitoring with respect to the mechanical integrity of the pipework, including the elbow bend;
- insufficient monitoring of safety equipment after changes made to design standards following the introduction of recognised and generally accepted good engineering practice (RAGAGEP);
- absence of remotely operated emergency isolation valves;
- HF alkylation unit was not adequately protected, in that the control system suffered damage;
- poor inherently safer design.

Poor management led to this accident. The management needed to have updated their procedures and design when new information and technology had become available from learnings of other similar accidents in the world elsewhere.

Cause descriptions

Mechanical integrity

The primary failure related to the mechanical integrity of the plant, that was related to the carbon-steel corrosion of the elbow pipe. This pipe had been installed in 1973 and purposely contained high amounts of residuals, such as copper and nickel. Carbon-steel, common in alkylation units in refineries is known to be susceptible to HF corrosion over time. It produces a protective film (of iron fluoride) for the steel. The high concentration of the said residuals resulted in a weakened protective film and higher levels of corrosion. PES, nor the previous owners of the refinery, inspected the piping circuit components at any point.

Remotely operated emergency isolation valves

The absence of remotely operated shutoff valves (ROSOVs) was to blame for the third and largest explosion. A violent jet flame impingement, sustained over approx. 20 minutes, stretched and thinned vessel V-1 (located above the pipe elbow). Ultimately, this led to the flame igniting the hydrocarbons pouring out of V1, and thus causing an explosion (BLEVE). The absences of ROSOVs meant the hydrocarbons were unable to be diverted elsewhere to minimise the impact of the jet flame.

Safeguard reliability in HF alkylation units

In the event of a fire, PES had a safeguard in place, such as a water spray mitigation system; unfortunately, this could not be remotely activated due to the damage caused upon ignition of the fire. This negative outcome demonstrated clearly that safeguards that rely on humans or technology can fail in operation. One of the major purposes of the water was to act as a vapour-suppression mechanism to prevent gaseous HF from drifting off-site and become a threat to the locality.

Inherently safer design

As new technologies are being introduced which are safer, many companies like PES had not converted to alternatives such as composite and acidic ionic liquid and solid acidic catalysts. However, there is not the federal legislation to require refineries to consider these alternatives – 46 out of the 155 petroleum refineries in the US have HF alkylation units. As an alternative, had sulphuric acid been used, instead of HF, it would not have created a vapour cloud and be a danger off-site, as it would have remained a liquid.

Violation of Regulations

The U.S. Department of Labor's Occupational Safety and Health Administration (OSHA) cited PES for serious violations of safety and health hazards related to Process Safety Management (PSM) following the fire and explosions at the refinery. The total penalty charge levelled at PES was $132,600. OSHA discovered several shortcomings in the refinery's PSM program, especially in relation to their handling of HF and flammable hydrocarbons. These deficiencies included: failure to establish written procedures; inadequate hazard analysis; and insufficient inspection of process equipment[15].

There were ten specific items included in the citation[12]. A number of these related to more specific failures, such as lack of testing for corrosion or failure to adjust control system set points, but more generally OSHA identified that the PSM system at PES did not address major refinery site hazards (such as BLEVEs); and that the site's testing, inspection and maintenance systems did not comply with current good engineering practice.

Process Safety Management systems themselves require management to ensure they are effective. That management includes the duty to keep company engineering standards fully in line with RAGAGEP.

There appears to be a shared industry opinion that the American regulators carry out less frequent regulatory visits than their European counterparts. Furthermore, in several

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European countries there is a duty to regularly update safety technology.

Lessons learned

As noted earlier, the explosion occurred due to a violation of a set of safety standards. The lessons learned from this accident plays a critical role in lowering the chances of such accidents re-occurring.

Among the lessons learned from this accident includes, ensuring that:

- The safety guideline provided on any equipment by the manufacturer should be followed, to ensure that the equipment is used properly within the design parameters specified.
- Metallurgical inspection of the pipework, including corrosion, could have provided PES with vital information about the condition of the elbow. Such an inspection could have provided timely information on the poor condition of the elbow section.
- A safety emergency isolation valve is important in a plant like the Philadelphia refinery. After the elbow had ruptured, the content inside the pipe continued to flow out and caused more harm. If a ROSOV had been in place, the flow could have been stopped which in turn would reduce the devastation caused by the accident.
- Re-marking on the equipment should be avoided as it creates confusion because the properties of the pipe were inferior compared to the properties expected from steel pipe fittings meeting ASTM A243 WPB standard. This standard affords limits on the composition of copper-nickel in the pipework to minimise corrosion.
- As technology advances, equipment should be considered for an upgrade to meet improved industry standards as they help to improve safer performance and use.
- PES needed to have made better use of information and technology, such as the implementation of control systems to continually monitor the corrosion rate within the elbow.

Conclusions and recommendations

The PES oil refinery in Philadelphia suffered from a fire and series of explosions, including a BLEVE, on the morning of 21 June 2019.

The investigations into the accident highlighted the main causes of the events, including lax maintenance and safety checks.

There was an absence of isolation valves in the alkylation unit pipe network downstream of the pumps. An isolation valve would have cut off feed and this could have prevented the BLEVE from occurring at V-1. This vessel had no thermal insulation protection and as such could not be protected from direct flame impingement in the event of fire threatening V-1. It also did not have any water deluge system to protect the surface of V-1 in the event of a fire. The water mitigation cannons also suffered communications interruptions. To activate these cannons, the operators had to put themselves in harm's way.

Fortunately, no loss of life resulted from the accident, and only five people sustained minor injuries.

An investigation from the CSB concluded the main cause of the accident was management failure for not updating procedures and not introducing plant safeguards when industry standards were being revised and updated.

- There are many facilities like PES across the world where the recommendations proposed here should be considered for implementation to prevent similar accidents occurring elsewhere.
- Importance of installing emergency isolation valves downstream of pumps and other equipment should be considered. This would allow for quick and automated isolation of large hydrocarbon sources in the event of a pipe failure.
- The need for a comprehensive emergency response plan is imperative, which should include implementation of detailed procedures for manual and remote activation of mitigation systems.
- Regular risk assessments of hazardous processes, particularly when using highly toxic chemicals like HF should be carried out. This includes proper equipment maintenance and regular operator training.
- Further hazard studies to highlight where emergency isolation valves are required should be carried out to minimise the risk of fire and explosion hazards.
- Any vessels found to be at risk of a BLEVE event should be considered for relocation. It should be afforded adequate thermal protection by way of intumescent coating and/or water-cooling spray systems with pressure relief valves for the vessel concerned, with proper controls and plans in place to maintain these barriers.
- One recurring issue seen during this accident is the failure of automated systems such as the water mitigation cannons from activating and then needing manual intervention. Multiple layers of activation on such critical systems should be implemented to reduce failures when they are needed.
- All operators should be given proper training and have a thorough understanding of safety protocols and emergency response plans.
- Refineries should also invest in regular equipment maintenance and identify potential safety hazards with corrective actions.
- Best practices and lessons learned from the PES refinery explosion should be shared with other refineries.

References

1. *Abernathy, B. and Thiel, A. (2019) A Close Call and an Uncertain Future: An assessment of the past, present, and next steps for Philadelphia's largest refinery. City of Philadelphia.*
2. *API (2021) Mechanical Integrity Standards. American Petroleum Institutehttps://www.api.org/oil-and-natural-gas/health-and-safety/refinery-and-plant-safety/process-safety/process-safety-standards/mechanical-integrity-standards Accessed 1 May 2023.*
3. *Centre for Chemical Process Safety, (2010). Guidelines for Vapor Cloud Explosion, Pressure Vessel Burst, BLEVE, and Flash, New York: American Institute of Chemical Engineers*

0260-9576/23/$17.63 + 0.00

and John Wiley & Sons, Inc.

4. Coyle, D.(2019) PES Refinery Explosion: Deadly Catastrophe Adverted By Quick Action, Trenton, NJ: New Jersey Work Environmental Council.
5. CSB (2022) Fire and Explosions at Philadelphia Energy Solutions Refinery Hydrofluoric Acid Alkylation Unit. U.S. Chemical Safety and Hazard Investigation Board.
6. Fitzgibbon, T. (n.d.) Alkylation unit. McKinsey&Company https://www.mckinseyenergyinsights.com/resources/refinery-reference-desk/alkylation-unit/ Accessed 14 April 2023.
7. Hussain, N. (2022) Alkylation Process In Petroleum Refinery. The Petro Solutions https://thepetrosolutions.com/alkylation-process-petroleum-refinery/ Accessed 14 April 2023.
8. Industrial Fire World (2020). OSHA Fines Closed Philadelphia Refinery for Process Safety Hazards. IFW, https://www.industrialfireworld.com/539295/osha-fines-closed-philadelphia-refinery-for-process-safety-hazards Accessed 23 April 2023
9. Kearney, L. & Renshaw, J. (2019). Philadelphia Energy Solutions files for bankruptcy after refinery fire. Reuters https://www.reuters.com/article/us-pes-bankruptcy/philadelphia-energy-solutions-files-for-bankruptcy-after-refinery-fire-idUSKCN1UH0O9 Accessed 22 March 2023
10. Marsh (2019) 100 Largest Losses in the Hydrocarbon Industry 1974-2019. Marsh JLT Specialty.
11. National Center for Biotechnology Information (2023). PubChem Compound Summary for CID 14917, Hydrofluoric Acid PubChem, https://pubchem.ncbi.nlm.nih.gov/compound/Hydrofluoric-Acid. Accessed 14 April, 2023.
12. OSHA (2019) Citation and Notification of Penalty - Philadelphia Energy Solutions. U.S. Department of Labor 1 (1).
13. Sasko, C. (2019). PES Explosion Released Highly Toxic Chemical Into Atmosphere, Investigators Say, Philadelphia: City Life - Philadelphia.
14. Shreve, R.N. and Brink, J.A. (1977) Chemical Process Industries. McGraw-Hill Companies.
15. U.S. Department of Labor (2020) U.S. Department of Labor Cites Philadelphia Refinery for Process Safety Management Hazards after Fire and Explosions. Occupational Safety and Health Administration 17 January.
16. Valero (2020) Alkylate Safety Data Sheet. Valero Safety Data Sheets Valero.

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Safety practice

Identifying and managing weak signals – the platypus philosophy

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Summary

Weak signals occur around us every day, in our facilities and generally in life. Most of the time we either fail to notice them or fail to take them seriously. If left to escalate, they can result in an incident, and during investigation it will be obvious which weak signals were missed. Looking for weak signals can be compared to looking for a platypus. The platypus is special type of mammal called a monotreme and is endemic to Australia. The platypus is evidence that the unlikely can actually occur, and that it can be difficult to pinpoint what is going on. It is one of only two mammals that lays eggs, it has the bill of a duck, the tail of a beaver, the claws of an otter and the fur of a seal. It lives by fresh water in burrows and swims to find prey using electronic pulses. It is also one of only a few mammals that produce a toxin for defense. It is also mainly nocturnal, making them very difficult to find in the wild. Why then should we look to something as unlikely as a platypus?

Catastrophic events are a combination of smaller unlikely events that culminate in a consequence. For example, you may have had a corrosion issue that led to a pin hole leak, that found an ignition source that then caused a fire that impinged on structural steel, resulting in larger collapse of equipment feeding into the fire. This is a plausible sequence of events but relies on us noticing that the corrosion management may be failing in some way. We may just look at the corrosion issue and determine we have it managed and would not lead to a massive equipment loss. Even if it leaked, we then discount the chance of ignition etc. Each step along the way we are seeing signals that we can have the event, but we are discounting them or deciding they are something else.

We may see a splash of a tail in the water and think we have seen a beaver, or we may see the tip of a bill and think it is a duck. In both instances we need to investigate further to see if indeed we have a platypus. Searching for a platypus in a facility is all about finding the weak signals and piecing them together to see what we actually have, not making assumptions based on single points of evidence. Not all platypuses are hazardous, the females do not have any toxic capability, but the males have a spike on their back legs that can envenomate a human. Finding and managing the platypuses hiding in our facilities will mean that we manage our weak signals before they become incidents. This paper will explore some of the biases we have to seeing the platypuses and discuss a framework to identify the weak signals so you can actively manage them. You need to find your platypus today, so it does not hurt you tomorrow.

Keywords: Risk awareness, leadership, weak signals, black swans

The concept of the Black Swan

In 2007 Nassin Taleb published his book *The Black Swan: The Impact of the Highly Improbable*[1]. This book defined a Black Swan event as being unpredictable, having a major or significant impact and being able to be rationalised in hindsight as predictable. The concept was largely used to describe failings in the economic realm, but the Black Swan quickly gained popularity in high hazard industries as a way to rationalise significant or catastrophic incidents.

But there is a fault with this application in high hazard industries in that simply because an event may be unpredictable to one person, does not mean it is actually unpredictable to those that ought to know. The hazards with products used in high hazard facilities are well known, such as flammability, toxicity, reactivity etc. If those substances are put into specific circumstances the outcome is easily predictable. For example, if a combustible dust cloud is released, it will possibly explode if it finds an ignition source. What is less predictable is the circumstances that can lead to the consequence, but even these are not truly unpredictable. If they were then the activity surely should not be undertaken as the risk would be too great. For example, it is known that corrosion can lead to loss of containment, which can then result in catastrophic consequences. Rationalising an event as a Black Swan is an attempt to minimise culpability for it occurring and is not helpful in preventing the incidents occurring.

The implausible is possible – the platypus?

The platypus is an unlikely creature. The scientific name for the platypus is Ornithorhynchus anatinus, which roughly translates to "duck-like bird-snout"[2].

The platypus is a monotreme, or an egg laying mammal. There are only five living species of monotremes today, making the existence of the platypus highly unusual. A monotreme is a mammal that lays eggs and then suckles the young when they hatch. It is covered in fur, like a seal or a water rat, claws like an otter, a bill similar to a duck, a tail similar to a beaver and the males have a toxin they can inject when threatened.

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While the toxin is not fatal to humans, it is extremely painful, can last for days and there are no know pain killers or nerve blockers that can alleviate the pain. It is an amphibious animal and is predominately nocturnal-crepuscular. All these elements combined make the platypus very unlikely, but they do exist. It is also very difficult to see a platypus in the wild, as they are also quite shy creatures. Mostly you may only just catch a glimpse of them, such as a tail splash, a quick view of a bill or a trail of bubbles on the surface of the water. In that instance, if you are not expecting a platypus, you may think it is a different animal, a beaver or perhaps a duck or an otter. So not every sighting of a tail might be a platypus, but until you investigate further you won't know if it is a platypus or another animal.

It is these unlikely traits that make it a good metaphor for searching, identifying and preventing weak signals from becoming incidents. Not every weak signal will lead to an incident, and some may seem very unlikely, but the platypus reminds us that the improbable it possible.

How the platypus is like a weak signal

Weak signals have been defined as a series of seemingly unconnected inputs or data, that may appear to just be noise in the system, but when viewed though different frameworks, may be interconnected[4]. The presence of weak signals in a facility is a chance to identify a future incident before it occurs and intervene to prevent it. To do this, the weak signals need to be identified. The challenge in this is that we often don't look for them specifically through different frameworks, so they end up being seen as unconnected data or just noise. The platypus provides a framework to help identify the weak signals.

Sightings of parts of a platypus can be viewed as a weak signal. When you see the whole platypus, this would be like the incident occurring, all the weak signals have come together. If it is a female platypus, they are harmless, with no toxin, so that is more like a near miss, but a male platypus has the ability to envenomate, so that would be an incident.

Weak signals are things like lead indicators, as they highlight when the system is breaking down, before the incident occurs. These could be things like a false or spurious alarm, or a failure of a safety critical element on test. There are several other lead indications which could also be used as weak signals. These can be found in the IChemE Safety Centre Guidance document Lead Process Safety Indicators[5]. Weak signals can also be an indicator of something positive. These weak signals, if missed can represent a lost opportunity.

Why is the platypus hard to find?[3]

The most important part of looking for your weak signals through the platypus framework is to be open to seeing them. There are a number of cognitive biases[6] that can inhibit our ability to find our platypuses. These biases are listed in Table 1 with examples and ideas to overcome them. Being aware of the possible cognitive biases at play when considering data can assist in creating strategies to overcome them.

The platypus philosophy

When something unusual occurs, the platypus philosophy can be applied to manage the biases, enabling intervention before an incident occurs. The platypus philosophy[3] is a framework to seek out information when a weak signal occurs, analyse the information and then manage the situation.

Table 2 describes the steps in the platypus philosophy, with both an analogy of finding a platypus and the application in a facility.

The 'PLATY' part of the word is the initial basic input screening. If at that stage it looks like it might be a platypus, then you move onto the 'PUS' part, or the analysis of the risk to determine how to manage the weak signals and prevent the incident.

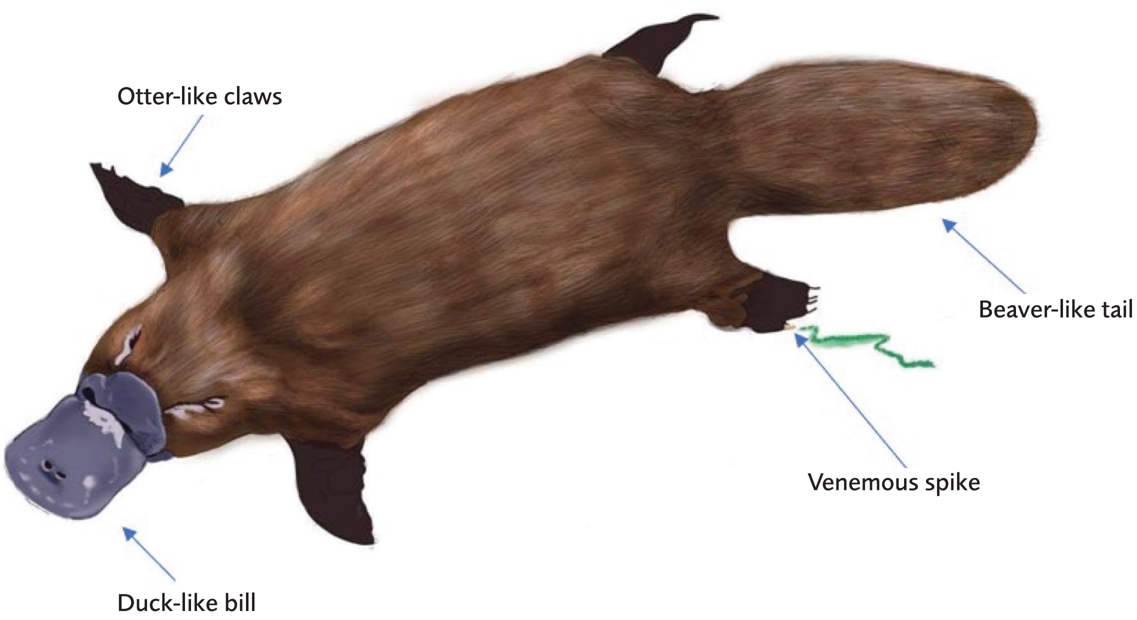

Figure 1 – The platypus[3]

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Bias	Example	Ideas to overcome
Ostrich effect	Avoiding negative information so you don't have to deal with it ("We don't have platypuses here").	Encourage a culture of curiosity and reward people asking questions and seeking to understand.
Confirmation bias	Search for information that confirms your beliefs, sometimes called "what you look for is what you find" ("We only have ducks, so that is what I saw").	Ask someone else to look at the same data to see if they reach a different conclusion. This must be done without clouding their judgement, so avoid giving your interpretation first.
Anchoring	Decisions made based on previous reference points ("Platypuses exist in other places, never here").	When ideas are being put on the table to discuss outcomes, ask everyone to write down their thoughts first. That way they won't anchor to someone else's already voiced opinion.
Framing or priming	Choosing options based on whether they are presented in a positive or negative light ("Platypus are cute and harmless, so nothing to worry about").	Discussing the specific hazards and consequences that are possible allows the brain to be primed to notice the weak signals – this is a bias that can be used positively.
Illusory truth effect	Repeated exposure to false information leads us to believe it is correct ("We have partial sightings all the time, but never a full platypus, so there is nothing to worry about").	When presented with metrics, drill into them to ensure they are correct and not the classic "watermelon" effect, where data is presented in a positive light, but upon investigation is found to be false.
Curse of knowledge	Assumption that others have the same level of knowledge ("Everyone here knows about platypuses and how to handle them so we don't need any new information").	When discussing important issues, have the person explain the situation back to you, to ensure they have the same understanding as you.
Pareidolia	Patterns or objects are seen where none exist ("I have seen some signs, but all I see is a duck").	Insight can be obtained from data sets when they are viewed in different ways. Looking at the data one way might not show any meaning, but when viewed differently, such as a different plot, they can reveal insights.
Anecdotal fallacy	Understanding is based on personal observations in a non-systematic manner ("I have never seen one, so I don't believe they exist at all").	The use of standards and reference as well as speaking with others and learning from past incidents can help us see beyond our own anecdotes.
Neglect of probability	There is a tendency to disregard probability in decision making ("It's not likely we have them, they are very rare").	Start the discussion with the consequences, rather than the probability and explore what controls or barriers are in place to prevent or mitigate that consequence. This allows you to focus on the controls rather than dismiss the consequence based on the probability.
Information bias	Seek additional information that does not affect the action to be taken ("Every time I look for them in the desert I can't find them, so they don't exist").	Ask someone else to look at the information you are collecting, and see if they think it is relevant. This must be done without clouding their judgement, so avoid giving your interpretation first.
Illusion of control	Overestimate ability to manage a situation or control events ("If they exist we can manage them, we are in total control").	Apply detailed risk assessment to activities to ensure that the controls or barriers are adequate rather than rely on the assumption that the situation is under control. This includes things like pre-start up safety reviews, and safety systems of work.

Table 1 – Cognitive biases[6] and suggestions on how to overcome them[3]

	Steps	Details
P	*Partial sightings*	The glimpse of a tail or a bill or a claw, evidence suggesting there *may* be a platypus. It is not conclusive, not yet a near miss or an incident.
		This is a weak signal, like a lead metric identifying an issue. For example, a spurious alarm, or a critical device that has failed on test for example. Additionally, it could be an opportunistic sighting that is captured by a stop card observation from the workforce.
L	*Link data*	Look for where the platypus glimpse was observed and collect information on the sighting.
		Look at what occurred and when, what information can be found on the weak signal.
A	*Assess the data*	Is the data suggesting you have a platypus or a duck, what were the conditions when the glimpse occurred?
		Were there any special conditions when it occurred, times, process parameters, different imaging etc. Review the metrics to see what else was occurring at the time. Challenge assumptions and look for evidence.
T	*Tasks and Timing*	What else was happening in the habitat at the time?
		Look at the tasks being undertaken, what is common, what else could be impacted, what simultaneous operations were occurring and what could the impact be? Does the weak signal only occur at a specific time of day or part of a cycle?
Y	*Yesterday and Yonder*	Have there been platypuses in the area before?
		Look at the historical incident reports, is there any commonality in past incidents with the current weak signal? Have similar events led to incidents? Has this happened somewhere else?
P	*Perceive the scenarios*	If it is a platypus, is it a female, who is harmless or is it a male with a toxic spike? Is there more than one platypus here? If you find a female, is there a male or two nearby?
		Understand what the hazards are and what consequences could develop from them. Assess the overall risk. Map out all the scenarios.
U	*Understand the controls*	Prepare for capturing the platypus – how will you handle the male versus the female?
		Identify the necessary controls based on the scenarios and put them in place. Ensure there are established performance criteria for the controls, so you know they are working.
S	*Secure the platypus*	Trap and secure the platypus so it can be tagged and tracked, making sure to avoid the spike on the males.
		Document the scenarios with the controls and provide feedback to the workforce, especially those who identified the weak signal. Embed the learning in the knowledge management systems and processes. Then review and audit the process periodically.

Table 2 –The platypus philosophy[3]

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Each of these stages needs active participation from people within an organisation and should be planned with an awareness of the biases that can impede the process[3].

The platypus philosophy can be applied as a framework in multiple different circumstances. For example, as a periodic review of lead metric data to identify trends and manage them before an incident occurs. This could be done on a monthly, quarterly or six-monthly basis, focusing on safety critical lead metrics. It can also be applied at an ad hoc frequency when a weak signal is identified, such as an observation that an operator documented in a stop card program. In this instance it is a part review, part incident investigation type process. It can also be applied to prevent lost opportunities, where the signal may actually be a sign of something positive. These applications are designed to identify the key issues and implement controls to prevent escalation. Importantly there is also a feedback loop to ensure that learnings are captured for further reference and to prevent a different incident developing in the future.

Conclusion

As Ferris Bueller said "Life moves pretty fast. If you don't stop and look around once in a while, you could miss it."[7] Time moves fast in an operational facility, and there is always time pressure to make decisions and keep the plant operating safely. Even under this pressure there must be processes established to review available data to ensure that hazards are adequately managed. The platypus philosophy provides a framework to follow to ensure all elements are captured. It also has the benefit of being memorable because of the bizarreness effect, a cognitive bias that makes it more likely to remember something that is unusual, funny or bizarre. The use of stories and unique metaphors like the platypus philosophy help to encourage curiosity and an inquisitive culture in a facility. This type of culture helps to prevent incidents because people look for what can go wrong and take steps to intervene.

If you don't find your platypus today, it can hurt you tomorrow.

References

1. *Taleb, N., 2007. The Black Swan: The Impact of the Highly Improbable. New York: Penguin Books.*
2. *Shaw, G. & Nodder, F., 1799-06. The Duck-Billed Platypus, Platypus anatinus. The Naturalist's Miscellany, 10(CXVIII), pp. 385-386.*
3. *Kerin, T., 2023. The Platypus Philosophy - identifying and managing weak signals. Melbourne: Kindle.*
4. *Schoemaker, P. & Day, G., 2009. How to make sense of weak signals. MIT Sloan Management Review.*
5. *IChemE Safety Centre, 2015. Lead Process Safety Metrics - selecting, tracking and learning, s.l.: IChemE Safety Centre.*
6. *Benson, B., 2017. Cognitive Bias Codex. [Online] Available at: https://www.visualcapitalist.com/wp-content/uploads/2017/09/cognitive-bias-infographic.html [Accessed 19 July 2020].*
7. *Ferris Bueller's Day Off. 1986. [Film] Directed by John Hughes. USA: Paramount Pictures.*

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Incident

Mysterious (and unexplained) death in confined space

Ivan Vince, UK

Summary

An accident occurred on the general cargo vessel Baltiyskiy-107 resulting in the death of a seaman on 10 September 2000 while on passage from Latvia to the UK. The ship's bosun discovered the lifeless body of a seaman at the bottom of the access hatchway. An investigation revealed that the oxygen level in the hatchway was insufficient to sustain life. There were several possible causes for the oxygen deficiency in the hatchway and it was not possible to identify the exact mechanisms. There was no clear and apparent reason as to why the seaman had decided to enter the access hatchway.

Keywords: Confined space entry

The incident

The cargo vessel Baltiyskiy-707 was on passage from Riga, Latvia, to Poole UK with a cargo of sawn timber and bundles of pallet timber. With the holds full, cargo was secured on top of the three hatches and covered with waterproof tarpaulins secured to the hatch coamings by individual rope lines. No other cargo was carried.

At 12:30 on Sunday 10 September 2000, when about 110km north-north-west of the Hook of Holland, a seaman who was working with the bosun in the forecastle, went aft, saying he was going to the toilet. About 15 to 20 minutes later, the bosun was passing No 2 hold on the port side, when he noticed that two of the waterproof tarpaulin ties at a point opposite the deck space between Nos 2 and 3 holds were loose and hanging. Since he had checked them earlier that day, he decided to look under the tarpaulin before re-securing them. He then saw that the lid to the access hatchway to No 2 hold was half open and held in that position by a wooden wedge. As this hatch had been closed since departure from Riga, he realised that somebody had recently opened it. He shouted, but received no response, so he climbed through into the deck space to check the hatchway himself. He looked down the hatch and saw the shape of a body or an object. He was conscious of a sharp unpleasant smell in the hatchway, but thought that it might have been due to the timber cargo having been sealed in the hold for a number of days. He immediately backed out and ran to the accommodation to tell the mate who was in his cabin.

The bosun told the mate he had found the seaman at the bottom of the access hatchway to No 2 hold, and that he needed urgent help. The mate immediately ran to the bridge to inform the master, while the bosun went to get a self-contained breathing set. The master sounded the alarm and ordered all available off watch crew to proceed to No 2 hold area. He remained on the bridge while the mate ran back down to No 2 hold access hatchway to organise a rescue. As part of the vessel's standard emergency procedure, the INMARSAT system was prepared for immediate transmission.

The bosun, in the meantime, put on the SCBA set, entered the hatchway and climbed down, while other crew members illuminated the shaft using their torches. On reaching the bottom, the bosun tried to give oxygen to the seaman, but it did not appear to make any difference. He shouted up to the mate that there was no pulse or breathing, and that first-aid was difficult due to the cramped conditions. The crew lowered a rope down so that he could be pulled up, but this failed initially because the rope kept slipping off. The bosun decided that the quickest and only way was to tie the rope around his legs, and pull him up that way. With the bosun lifting from below, and the crew pulling from above, they managed to get him up to the hatch and out on to the deck. By 1335, the seaman's body had been retrieved and was laid out on the deck while attempts were made to revive him. When there was no immediate response, he was moved clear of the hatchway and brought out on to the open deck. Resuscitation recommenced, but there was no breathing or pulse; his face was a bluish colour, and his pupils did not react to light. At 1350 the master was told, despite the crew's resuscitation attempts, there were no signs of life.

The investigation

On arrival at Poole, a police investigation began and an industrial chemist was appointed to check the atmosphere in the hatchway to No 2 hold. The results of this test confirmed that it was too dangerous to enter without proper ventilation, as well as suggesting to the chemist that there might be, or had been, a smouldering fire in No 2 hold.

The deck cargo of timber was removed. With the fire brigade and police in attendance, the main cargo hatches were opened and a quick survey carried out of the visible timber packages. When No 2 hold was opened, there was a noticeable sharp smell, but no smoke or signs of a fire. With the main cargo hatches to No 2 held open, the access hatch to that hold was fully opened and an inspection of the access shaft was carried out by police and customs. Nothing was found apart from two empty black polythene sacks in the access shaft, one halfway up, the other at the bottom of the shaft.

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IChemE

An inspection of the hold, following completion of the discharge, found no evidence of any chemical or oil spillage, nor any residue from previous cargoes. (The master stated that the immediate previous cargo had been stone from Rotterdam to Riga followed by two hold wash downs using salt water). The hold bilge wells were clean, although partly filled with water. Two torches were found at the bottom of the access shaft. The crew identified one of them as probably belonging to the dead man, but they did not recognise the other. Both were broken.

Apart from a Code of Safe Practice for timber deck cargoes which relates to the stowage and securing of the cargo, there are no specific requirements for the stowage of palletised or bundled timber.

What does affect the carriage of any cargo, including timber, are the regulations relating to the entry into enclosed or confined spaces. Cargo holds are defined as such in the Code of Safe Working Practices for Merchant Shipping as well as in the Maritime Safety Card, issued by the International Maritime Organisation (IMO). The guidance states that enclosed spaces should only be entered if an authorised person, such as the master or a responsible officer, has carried out the appropriate safety checks. These checks are listed on the card. Under *General Precautions* it states:

The atmosphere in any enclosed space may be incapable of supporting human life. It may be lacking in oxygen content or contain flammable or toxic gases. This also applies to tanks which have been inerted.

The master or a responsible officer should ensure that it is safe to enter an enclosed space by:

1. ensuring that the space has been thoroughly ventilated by natural or mechanical means;

2. testing the atmosphere of the space at different levels for oxygen deficiency and harmful vapour where suitable instruments are available; and

3. requiring breathing apparatus to be worn by all persons entering the space where there is any doubt as to the adequacy of ventilation or testing before entry.

Test readings of the access shaft to hold No 2 at 2-2.5 metres depth showed oxygen levels of 0.7-2.5% and carbon monoxide concentrations of 220-235 ppm. The level of oxygen available within the access shaft to No 2 hold was insufficient to sustain life.

The cause of this oxygen deficiency has not been identified and could have been by several reactions, including chemical/biological reactions and a combustion process. An examination after discharge had been completed confirmed, however, that there was no evidence of any combustion process within the timber packages.

To go into No 2 hold using the deck access hatch, the seaman would have had to unlash a number of rope tails securing the tarpaulin covering the deck cargo on the hatch coaming, and then crawl inside. From there he had to move across the deck; crouching under the timber deck cargo which was secured on top of the main cargo hatch covers to reach the access hatch to No 2 hold. It was then necessary to release the two dog handles securing the access hatch lid shut, and to then raise it. With the timber deck cargo above, it was only possible to raise the lid some 600 mm. This would allow very restricted access to the shaft through a wedge-shaped opening. To prevent the hatch from closing, a piece of timber dunnage had been jammed across the hatch at the hinge end.

With all these obstacles preventing easy access to the hatch, there needed to be a very strong reason for the seaman to push ahead and gain entry. There were no technical or ship operational reasons for entry, and there is no evidence to show he had received any instructions from the bosun or any officer on board to do so. It seems it was purely a personal decision for an unknown reason.

From the available evidence given in statements by the crew, the actions taken by the bosun, chief officer and other crew members followed the recommended procedures.

In a previous MAIB investigation into the cause of oxygen deficiency in the hold of a vessel carrying timber, the Timber Research Association suggested that fermentation was a possible cause. They gave three possible options:

1. A reaction involving water combined with temperature. This reaction is more likely where sapwood is involved, but it requires quite high temperatures. Under certain conditions carbon monoxide is given off.
2. A fermentation process where there is a known enzyme degradation. This is a breakdown of cellulose to possibly carbon monoxide with the reaction taking place at about 37°C. Other gases given off are hydrogen and methane. Rotting wood will also give off carbon monoxide.
3. The use of sapwood stain on the end grain of timbers. There are stringent Health and Safety Executive requirements on these, particularly in relation to the possible generation of toxic gases. There is no control of what sap treatment is applied to the timber abroad, and there exists the possibility that toxic gases could be given off from an unknown sap stain treatment.

According to the certificates sent with the cargo and dated 4 September 2000, none of the timber had undergone any form of chemical treatment.

To try to identify what, if any, timber treatment had been applied to the cargo despite what the paperwork stated, a piece of wood from one of the suspect timber packages was retrieved after discharge, for inspection and testing.

Examination showed that the wood beneath the surface was not coloured and very clean. There were no obvious distinctive odours prior to or following cutting into the sample.

Tests were then carried out in accordance with BS 5666: part 2: 1980 *Wood preservatives and treated timber; qualitative analysis*. Tests for seven separate preservatives were carried out, none of which were detected.

Conclusion

With the bilges being confirmed as clear after discharge, and no evidence found of toxic timber treatment, the cause of low oxygen and high carbon monoxide readings in the access shaft to No 2 hold, remains speculative.

There remains the possibility that some commodity, other than timber, was stowed in the access hatchway. Whatever it was, the seaman probably knew it was there.

As the crew were the only witnesses to the retrieval of the body and the subsequent actions, and can offer no explanation

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to why he entered the hold access, it is unlikely that this theory can be supported with any evidence. If there was any other commodity within the space, it probably went overboard before arrival in the UK.

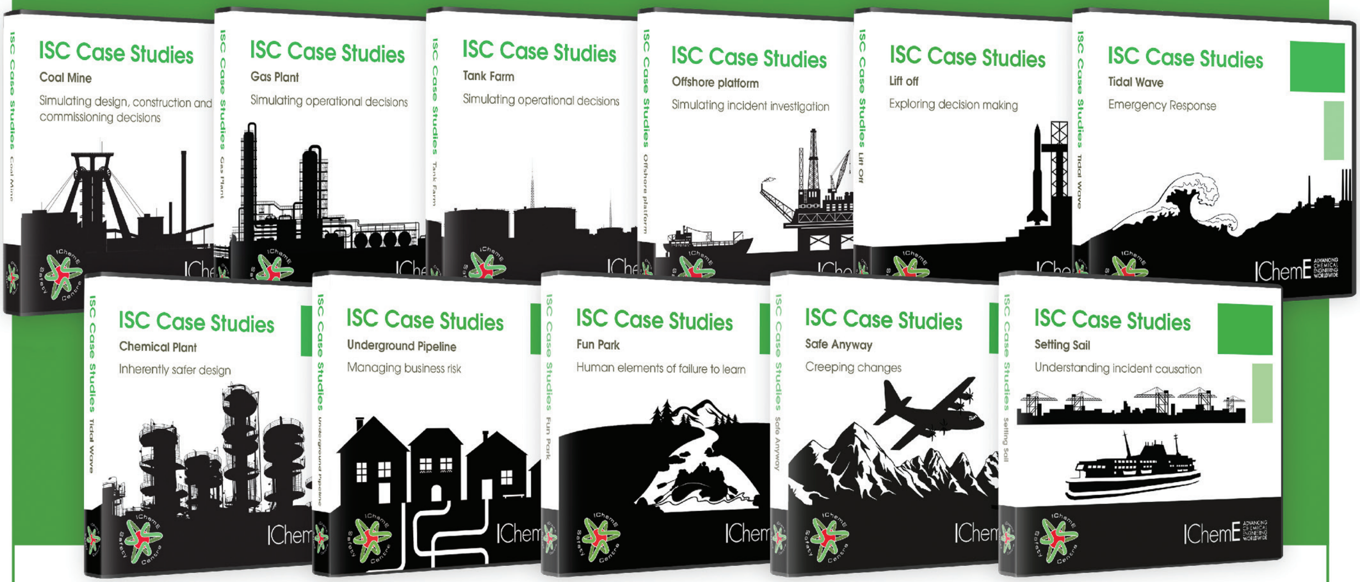
MAIB's recommendations to the shipping company and its managing agents were to ensure that the master and crew are fully aware of the dangers and requirements of entering confined spaces as given in the Maritime Safety Card issued by IMO, and that company regulations in this respect are rigorously applied.

Editorial note on lone working

The victim was engaged in a secretive activity unrelated to his work, as the report makes clear. From the correct actions of the crew in his attempted rescue and recovery, it appears unlikely that lone working in a confined space would have been sanctioned. Within UK jurisdiction, this is implicitly forbidden by regulation 5(1) of the Confined Spaces Regulations 1997: "…no person at work shall enter or carry out work in a confined space unless there have been prepared in respect of that confined space suitable and sufficient arrangements for the rescue of persons in the event of an emergency, whether or not arising out of a specified risk."

Acknowledgement

This paper is a summary of the Marine Accident Investigation Boards's Report on the investigation of an accident on the general cargo vessel Baltiyskiy-107 resulting in the death of a seaman on the 10 September 2000 while on passage from Riga, Latvia, to Poole, UK (Entry to a confined space on general cargo vessel Baltiyskiy-107 with loss of 1 life - GOV.UK (www.gov.uk))



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Senior leader's page

Areas of managerial accountability — improving process safety

Deborah L. Grubbe

It's been almost forty years since the Bhopal, India, incident, and we have learned much about process safety (PS); however, we need to ask ourselves, "Why are these incidents continuing to occur? Are we missing something?" Upon reflection, the answer is yes. We need to constantly focus on a critical piece of process safety management (PSM) leadership effort — our line management. This article will look at five areas where managers are directly accountable for the continuing and underlying causes of process safety incidents. We all know that process safety work is constant, and this short article will focus on the manager's role in PS execution, in an effort to keep PS sustainable in an ever-changing world. Managing all change lies with the management team of the high hazard asset, site and business. Management allocates time, resources and monies, and also sets priorities for daily operation; management also establishes, by their leadership and decisions, the culture within which process safety will be executed.

This article will offer some context and reflections in five areas of process safety leadership — workload and resources; investigations; knowledge management; new technologies; and culture.

Workload and resources

Is there one person "in charge" of process safety and if so, what is the size of the team supporting that one person? Does that PS leader have direct access to others with different types of knowledge and expertise, and have the ability to request action of these experts? PSM needs to be thought of as a team sport. One person cannot be fully knowledgeable in all of the needed details around the various elements of PSM, and one person cannot be everywhere at the same time. Even in small companies, the needs are too great, and an integrated team with leader vs. a single contributor may be an upgrade.

Investigations

When we conduct investigations into actual incidents and near-misses, are we actually identifying root causes? Based on experience, that answer will be a big, loud and resounding "NO!" Investigations have a tendency to stop prior to root cause because the journey to fundamental cause can be too painful for some in management, for a number of different reasons. Additionally, some in-house counsels believe in "throwing a cloak of secrecy" over the details of the underlying causes, because confidentiality makes it easier for them to "control the narrative" and to "defend the company." This secrecy, supposedly for "the good of the broader firm," actually holds back the affected organisation's learning and potential prevention of future mistakes.

Knowledge management

Another challenge area lies in the large amount of tacit knowledge that is needed to safely run many high hazard facilities. Additionally, one's experience factor, coupled with the high volume of explicit knowledge (written procedures and data) that may be difficult to read and absorb, forces a company with high turnover into a very challenging and prolonged training effort. To their credit, many firms are working on this via digital twins, videos, and/or virtual reality solutions. However, when we take this experience issue and move it out of the plant control room into the management ranks, we are presented with a different situation. How are managers trained to make decisions around resources for the high hazard facility? With management changing every few years, or even sometimes more often, how we make management selections for high-hazard operations will remain a challenge. The management of change issue for managers is sometimes a part of a major audit, yet may rarely be discussed. However, too much "management change" has been documented in a number of multiple-fatality incidents. This line of thinking can extend all the way up to and including the corporation's Board of Directors.

New technologies

With the advent of big data, smart devices and advanced computing, managers and engineers are awash in data and information, and many times lack the ability to effectively weed through their "data swamp" to find the one or two key items that must be the object of today's attention. Luckily, there are products in the market right now to help managers address daily priorities. One such tool can be found at *Dynamic Risk Analyzer™ – Risk Detection of the Future – Near-Miss Management (nearmissmgmt.com)* . As Artificial Intelligence and Machine Learning tie together the operational risk and hazards, managers will have more tools at their disposal to help them make better decisions, but they must take the time to become familiar with the technologies, the products, what the new tools can do, and most importantly, what the same tools *cannot* do!

Culture

Corporate cultures can be defined in many ways; however, it only takes a few hours for an astute observer to discern a firm's

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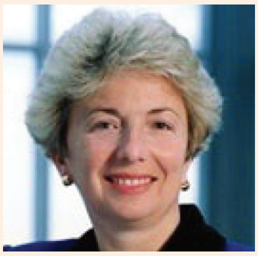
culture. It generally comes down to whether managers operate and make decisions to protect themselves and enhance their careers, or do they operate with the welfare of the company as their top concern. If new managers are never given direct insight on how senior leaders would like them to set priorities and make decisions, then the variability may be too great to assure a consistent culture that may ensure good process safety performance. Thankfully, many engineers and managers do not have the experience of living through the growing pains of a serious process incident; however, that absence in itself may create a false sense of security. It is important to effectively codify better practices so that managers do not have to learn the decision tradeoffs "the hard way." Fewer incidents over time could send false signals about competence when it could actually be "luck." In essence, a good process safety culture requires direct management interest and engagement at every level. There is no "auto-pilot" for a positive process safety culture.

In summary, getting the right person into the right chair is one of the most important managerial tasks in a high-hazard facility. Our process safety body of knowledge, much like our safety standards, has been written in the blood of those who have been hurt and killed. It is incumbent upon us, as the current stewards and as leaders in our firms, to create practices so that managers and directors who are not familiar with what types of decisions are necessary to run a highly hazardous manufacturing operation can better understand the job requirements, be more effective coaches, better role models, and make better personnel decisions. We all know the downside business risk, as the corporate boneyard is littered with the remnants of firms that are smaller in size or no longer in business because of one too many business errors in the process safety arena. Excellent process safety is a competitive advantage, and the very future of our companies may depend on it.

Deborah L. Grubbe, PE, C.Eng.



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culture

Safety practice

Process safety metrics — common management system pitfalls

Adam M Musthafa, Indonesia

Summary

The key objective for process safety is to identify failures, gaps, or conditions and to correct them before they contribute to a major process safety incident. Process safety leading and lagging indicators monitoring and analysis can be powerful tools for managing process safety performance but they have some potential pitfalls when they are not used in a suitable manner or are poorly designed, and organisations should learn how to mitigate and avoid these. The potential pitfalls reviewed include: not asking the correct question or challenging the wrong aspect of the metrics; not making any decision from the metrics; having too many metrics collected and reported compared to what the organisation can reliably handle; and not challenging the number when everything seems to be "perfect".

Keywords: Process safety metrics, leading indicators, lagging indicators.

Introduction

The key objective for process safety is to identify failures, gaps, or conditions and to correct them before they contribute to a major process safety incident[1]. Process Safety Metrics includes both lagging and leading metrics. Process safety lagging metrics are a retrospective set of metrics based on incidents that meet an established threshold of severity[1]. In PSM this includes the number of leakages above a certain threshold quantity or fire and explosion with impacts meeting a certain set of criteria. The lagging metrics are used to indicate the potential of a recurring problem and identify actual weaknesses in the system to be improved. It is used to measure whether a process safety management system is working or not.

Process safety leading metrics are a forward-looking set of metrics that indicate the performance of the key work processes, operating discipline, or layers of protection that prevent incidents[1]. An example of this is the number of challenges to a safety system occurring at the plant (e.g. activation on demand), number of safe operating limit exceedances, actual number of MOCs overdue or HAZOP actions overdue vs planned. The first two examples are used to identify as early as possible the potential weaknesses in safety systems or operational discipline before they manifest into an incident (i.e. become a lagging indicator). The last two related to MOC and HAZOP are used to identify potential weaknesses in the process safety management system which may contribute as a cause of process safety incidents.

When designing the metrics, we need to understand that there are two types of metrics — "activity metrics" and "outcome metrics". Both can be important but have different intentions. Activity metrics are pro-active leading metrics that measure how well a facility is meeting the requirements of an established system[1]. For example, the number of HAZOP revalidations completed as per the PHA plan. This is used to measure and verify the conformance of the implementation to the plan and system expectation/requirement. Another example is the number of inspections completed according to schedule. This measures the compliance of the organisation to the integrity plan periodically developed and approved.

Outcome metrics assess whether safety-related actions (policies, procedures, and practices) are achieving their desired results and whether such actions are leading to a decreased likelihood of an accident occurring and/or lower consequences from an accident. An example of this is the number of "higher" risk scenarios in major accident hazard identification. In this case what is being measured is if the MAH identification process meets the intent of the process which is helping the organisation understand its top risk scenarios. Another example is the number of pressure vessels identified having unacceptable wall thickness based on the performance standard defined. In this case what is being measured is how effective the integrity program is such as ITPM, and chemical injection (e.g., corrosion inhibitor) in ensuring that the wall thickness is within the acceptable limit. Understanding the correct type and use of process metrics is very important as when the metrics are not designed properly, the value of the metrics will be reduced, if not entirely lost.

The use of process safety metrics to help drive process safety performance is not a new practice to identify these potential failures or gaps. However, it is quite common that an operating organisation fails to implement it effectively due to some of the pitfalls explained in this paper. This paper discusses four common management system pitfalls in using process safety metrics.

1. Leaders not asking the "right" question

How leadership responds to process safety metrics will set the tone. How important the metrics are and where the organisation's focus should be, is directly impacted by what the leader says about the reported metrics. One example that many may have encountered in different situations is when leaders are challenging the leak rate being reported which resulted in a higher tier of lagging indicator.

It is true that estimating the acute release quantity may not

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be very straightforward, as it involves many assumptions (duration, actual hole sizes, etc.). However, once the leak rate is calculated by a competent person and validated by their superior following an approved procedure, then the organisation's focus should not be on the number accuracy anymore. Leaders should drive the discussion into what is the root cause of the leak, the potential risks and what can be done to control and mitigate the risk.

Challenging the number will give the message to the organisation that what matters is the number and classification of the leak (Tier 1, Tier 2 or lower), and not the risk. The next time another leak occurs, the team will try to lower the classification by using less conservative assumptions, or by another conceivable method. The organisation will lose the benefit of having LOPC metrics. More energy and time will be spent on playing around with the calculation to lower the classification, instead of preventing similar leaks or assessing and controlling the risk.

Leaders should ask the right question and pay attention to how they respond to reported process safety leading and lagging indicators. People who are providing the information and/ or reporting the metrics may and will be concerned that they will be judged or even prosecuted based on what they are reporting. Leaders should understand this challenge and respond accordingly. At the end of the day, having open and honest communication and reporting in the organisation is more important than having "green" metrics reported.

Trust, open and frank communication can only be established if both management and workers feel that their feedback is being heard. If we want workers to be engaged and provide timely feedback on any process safety and asset integrity issues, leaders should invest in time to listen to them and give positive feedback. Opinions must not only be positively received, but also recognised, and followed up.

2. Stop at showing the number

Gathering data and information for the leading and lagging metrics requires time and resources. However, it is not uncommon to find that the organisation gathering these metrics fails to make decisions and interventions based on it. In one of process safety audits, we found that the metrics are routinely discussed by senior management which is a good practice — however, upon closer examination, no actions or decisions were taken after the metrics review.

The process safety team presented the data to senior management monthly as an agenda item on the HSE committee meeting. However, regardless of what was being reported, no comments were made by the committee. Only the operations team seemed to understand what was being reported. The operations team kept silent as most of the metrics were reporting their performance.

This example shows how important it is to train leaders and managers in process safety basics and PSM (Process Safety Management). Unlike occupational safety metrics, process safety metrics can be too technical if no training is provided. It is not surprising that the percentage of managers and supervisors who have been trained on creating and maintaining a strong process safety culture becomes one of the main indicators for process safety culture and leadership[2].

3. Analysis paralysis — too many metrics

A combination of leading and lagging indicators is often the best way to provide a complete picture of process safety effectiveness[3]. Lagging metrics are normally prescriptive and standardised in the industry. Leading indicators on the other hand may vary and are selected based on the organisation needs. One common misconception in implementing process safety metrics is that having as many leading metrics as possible will lead to more robust process safety management implementation. This is of course incorrect for any type of management system (process safety, occupational safety, quality, operations excellence, etc.). Metrics should be carefully selected and suitable for the type of operations and risk the organisation is facing.

The time and resources required to gather the data and information for the metrics should also be commensurate with the insight, value, and benefit gained by reviewing the metrics. In one company, 30+ metrics were tracked and presented on one management review slide. Three engineers spent a whole two days every week gathering the weekly metrics; but once presented, the sheer number of metrics being tracked diluted management focus. Some metrics are more important than others. For this example, the number of Safety Critical Equipment Deferrals was constantly high at ~10-20% every month. However, there were a further fifteen less important leading indicators which were "green". The committee concluded that since "most" of the leading indicator were healthy, there was no need for intervention.

In another audit, three leading indicators which were the number of risk-based inspection (RBI) unsatisfactory results; the percentage of inspection completed versus RBI planned; and RBI recommendations overdue were always healthy for the whole year. When interviewed it turned out these were "green" because the organisation had not yet implemented the RBI program. If a program has not started then instead of reporting the metrics from the program, the organisation should track the target to implement the program itself. Having three metrics reported as healthy because there were data yet to be collected will not only have zero benefit, but it may also give a false sense of security for the reader who does not understand the full story.

Another important aspect of this is the more metrics reported, the more the reporting system is prone to error or mistakes. In case of any incident taking place, metrics reported may be examined, and any mistakes and error in metrics reporting may place the organisation under unnecessary legal liability. It is true that leading indicators are beneficial for "forward looking" analysis and mitigate potential weaknesses in PSM implementation before it results in a real incident. However, an organisation should carefully determine what leading metrics they can reliably collect and analyse. Having too many leading metrics will cause analysis paralysis where the analyst fails to draw any conclusion due to the number of data available. On top of that, these metrics will be subjected to external audits and even part of incident investigations. Data can be interpreted differently by external parties which may also unnecessarily create a liability to the organisation[1].

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4. Not challenging the "green"

Acutely focus on the "red" and critically challenge the "green". This should be the mindset when reviewing process safety metrics. One may have come across process safety dashboards where everything is "green" and healthy the whole year. An experienced manager or process safety practitioner will evaluate critically when they come across this situation. Perfect dashboards introduce complacency and erode any sense of vulnerability. Metrics should provide a constant reminder on the weaknesses in our asset integrity, system implementation effectiveness and provide warning through near-misses and deficiencies reported[4]. Thus, how leadership responds to this situation is equally as important as when the metrics shows weaknesses.

Typically, when a process safety dashboard shows perfect performance all through the year, there are at least two possibilities. First, the reporting (or parts of it) may be inaccurate or manipulated. In one example, a process safety coordinator was found to train all HAZOP facilitators to avoid assigning "very high risk" scenarios or "high priority" recommendations in the HAZOPs they facilitated. This was done to avoid having an alarming number of leading indicators. In another example, every time a leak occurred and was calculated to have an acute release quantity beyond Tier-2 or Tier-1 threshold, the common process was for the supervisors to intervene and "suppress" the number into a lower tier, to ensure the number reported to management stays green.

Leaders should understand that the system of metrics reporting and monitoring is prone to manipulation if the implementation is not verified. The verification may include an action as simple as the leader showing that the accuracy of the metrics is important by asking the right questions, to a more formal audit by competent and non-biased personnel.

The main concept of management systems is continuous improvement. Performing at "perfect" levels is very rare and should be critically examined before an organisation celebrates the performance. Changes to the regulations, to the process units, to the staffing, and to the management processes will occur over time, and will impact performance[5]. Once the accuracy is confirmed and verified, an organisation should celebrate the teamwork and recognise key contributor efforts, but not the metrics itself. Celebrating the metric could lead to perception that what is important is the "colour" of the dashboard, and thus people stop looking behind the metric to gain the insight.

The other possibility is when the organisation has set the target too low. Having the target too low will demotivate the organisation to do more and improve the overall performance. Even worse is when personnel start to lose trust in the system. They may perceive that the system is only a tool for managers to justify their performance instead of a tool to measure healthiness and improve effectiveness.

Once a leading indicator shows that consistent performance has been achieved, it is good practice for the leadership to consider raising the target. Challenging achievable targets will motivate the organisation to continuously improve and promote innovation. Another way to sustain continuous improvement is to select other leading indicators that measure areas or processes that we know still have not achieved reliable performance. For example, if we feel that there are no longer any high-risk HAZOP recommendations in open status this year, we can change this leading metric to number of emerging risks identified by frontline personnel. This basically moves the measurement from looking into action tracking and closes out effectiveness to how healthy risk discovery is in the organisation.

Conclusions

Process safety leading and lagging indicators monitoring and analysis are amongst the most powerful tools for managing process safety performance. However, these tools also have some weaknesses and potential pitfalls which organisations should learn to mitigate and avoid. These weaknesses typically occur when these tools are not used in a suitable manner or are poorly designed. Some of the pitfalls discussed in this paper include: not asking the correct questions or challenging the wrong aspect of the metrics; not making any decision from the metrics; having too many metrics collected and reported compared to what the organisation can reliably handle; and not challenging the number when everything seems to be "perfect". By avoiding these pitfalls, organisations can improve how they use data and metrics to drive process safety performances.

Reference

1. *Center for Chemical Process Safety. Guidelines for Process Safety Metrics. Hoboken, New Jersey : John Wiley & Son Inc., 2009.*
2. *Essential Practices for Creating, Strengthening, and Sustaining Process Safety Culture. Hoboken, New Jersey : John Wiley & Sons, Inc., 2018.*
3. *Guideline for Risk Based Process Safety. Hoboken, New Jersey : John Wiley & Sons, Inc, 2007.*
4. *International Association of Oil & Gas Producers. Process Safety - Recommended Practice on Key Performance Indicators. 2011. Report No.456.*
5. *Center for Chemical Process Safety. Guidelines for Integrating Management Systems and Metrics to Improve Process Safety Performance . Hoboken, New Jersey : John Wiley & Sons, Inc. , 2016.*

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Information for authors and readers

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