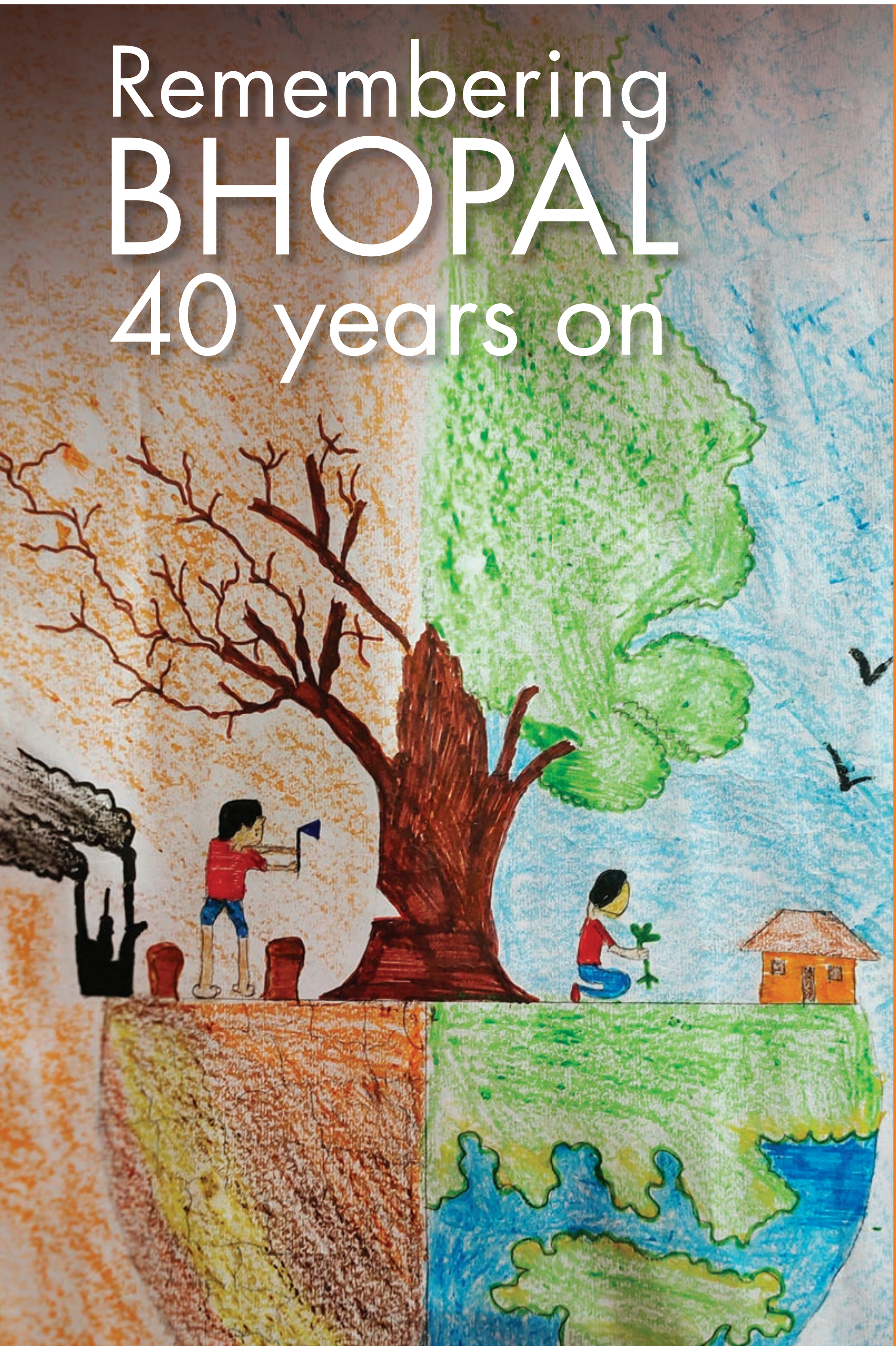
Loss Prevention Bulletin

Improving process safety by sharing experience

Issue 299, October 2024



Remembering BHOPAL 40 years on

Overview of the worst industrial accident in history

Bhopal Root Cause Analysis

Recalling the night of the gas disaster

Bhopal – my United Nations experience

Remembering the people behind the numbers

Butterflies of Bhopal

A local story from the Chingari Trust

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Contents

Loss Prevention Bulletin

Articles and case studies from around the world

Issue 299, October 2024

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2 **Editorial**
Iqbal Essa introduces this special issue marking the 40th anniversary of the Bhopal tragedy

3 **The worst industrial accident in history – Union Carbide, Madhya Pradesh, Bhopal, India, 1984**
Fiona Macleod and Richard Shone outline what happened on the night of 2-3 December 1984 and the events running up to and following the catastrophic accident.

6 **Bhopal Root Cause Analysis**
Fiona Macleod explains Kenneth Bloch's water washing theory, as outlined in his book Rethinking Bhopal.

11 **Recalling the night of the gas disaster**
Nazia Farooqui recalls the night when her family were forced to flee the toxic gas cloud and reflects on the forty years that followed.

17 **Bhopal – my United Nations experience**
Richard Shone recalls his secondment to work at the United Nation's International Labour Organisation to assist with their post-Bhopal work and shares his reflections on the main lessons that he took from this work.

19 **Remembering the people behind the numbers**
Professor Geraldine Lee shares a medical perspective on the long-term chronic effects of the disaster on the local population.

20 **Background to Butterflies of Bhopal**
Ramin Abhari introduces his new graphic novel exploring the causes of the disaster.

21 **A local story from the Chingari Trust**
Syed Tabish Ali interviews a survivor of the gas tragedy about the help his family has received from the local Chingari Trust for his two children who were both afflicted with health issues resulting from the disaster.

22 **OECD Chemical Accidents Programme**
Mark Hailwood gives an overview of the work undertaken by the Organisation for Economic Cooperation and Development following the Bhopal disaster to develop standards of expectations for good practice.

25 **The safe use of bolted flange joints in the major hazard industry**
Chris Mellows describes the most common failures of bolted flange joints, discusses possible reasons for a decline in UK craft standards, and calls for a return to best practice.

With thanks to the children of the Chingari Trust for sharing their artwork with LPB. The selected cover image was created by Disha Tiwari.

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Editorial

Bhopal – 40 years on

Following my editorial in LPB 240 commemorating the 30th anniversary, it is deeply concerning that not much progress has been made to address the aftermath of the tragic incident at the Union Carbide India Limited (UCIL) pesticide (Methyl Isocyanate) production plant in Bhopal, India, on 03 December 1984.

Despite widespread concerns, the site remains abandoned and heavily contaminated with toxic chemicals. Various cleanup efforts over the years have been insufficient, leaving significant contamination in the soil and groundwater. This ongoing pollution poses severe environmental and health risks to the people of Bhopal.

Furthermore, legal challenges between Dow Chemical Company, which acquired Union Carbide Corporation (UCC) in 2001, and the Indian government over responsibility for the site's cleanup and accountability remain unresolved. This remains a contentious legal and political issue with no immediate solution in sight.

While there have been sporadic efforts made by the Indian Government to initiate cleanup operations, progress has been slow and inadequate. Many survivors of the disaster and their descendants continue to suffer from chronic health issues, including respiratory problems, cancers, neurological disorders, and birth defects. Access to adequate medical care is a significant challenge for many affected individuals, with hospitals facing resource constraints, inadequate staffing, and management issues, limiting their effectiveness.

The social and economic impact of the disaster is profound. Many survivors live in impoverished conditions, and the stigma associated with the disaster affects their employment and social integration opportunities. Long-term demographic impacts must also be taken into consideration. Regrettably, over 10,000 people have died, and many more have suffered from the effects of MIC exposure. Furthermore, around 500,000 people were exposed to the gas, with tens of thousands suffering permanent disabilities, chronic illnesses, and other long-term health issues.

Four decades after the Bhopal tragedy, its sad legacy continues. Despite some remediation and compensation efforts, much more needs to be done to address the ongoing impacts and provide justice and support to the survivors. The 40th anniversary serves as a stark reminder of the need for sustained and effective action.

Two generations have passed since the Bhopal disaster, and it is quickly fading from the memories of people. The new generation of engineers and process safety professionals need to keep this disaster and others like the Flixborough disaster fresh in their minds, reminding them of their tremendous responsibility for the safety of people in their respective industries.

However, it is reassuring that the anniversary has renewed global attention to the Bhopal disaster, with various events, documentaries, and publications highlighting the ongoing struggles of the survivors. Activists continue to call for greater accountability and justice, emphasising the need for comprehensive remediation efforts at the site. Much of this is covered in this special issue of LPB commemorating the 40th anniversary.

As part of the global chemical engineering and process safety fraternity, I see it as our professional duty to push for a just solution in Bhopal. I consider this vital for preventing similar accidents from happening elsewhere in the world.

M Iqbal Essa
(Retired – HSE HM Principal Process Safety Specialist inspector)
Member of the LPB Editorial Panel

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The worst industrial accident in history – Union Carbide, Madhya Pradesh, Bhopal, India, 1984

Fiona Macleod CEng, FIChemE, Professor of Process Safety, University of Sheffield, UK; Richard T. Shone CEng, FIChemE, UK

Introduction

On the night of 2-3 December 1984, the residents of Bhopal woke from sleep with burning eyes and began coughing, choking and vomiting. Some died in their beds. Others attempted to flee the toxic gas that had entered their homes. Families were separated, some trampled to death in the stampede. The main railway station was engulfed[1]. Medical staff in the local hospitals were overwhelmed by the arrival of thousands of dying casualties and a complete lack of information on how to treat them. It is impossible to express in words the full horror of that night or to fully comprehend the following numbers.

The Government of India statistics put the confirmed number of victims as a direct result of the gas release at 15,248 people killed and 554,895 injured[2]. The failure to clean up the site of the now abandoned factory continues to blight the lives of local communities forty years on.

How could such a catastrophic accident have happened? How can we prevent such a terrible tragedy from ever happening again?

Background

Location and history

The Union Carbide India Ltd (UCIL) plant in Bhopal, India produced carbaryl insecticides such as Sevin® using Union Carbide Corporation (UCC) technology along similar lines to a UCC facility in Institute, Virginia, USA. Operation at the Bhopal facility started in 1969, formulating products with imported intermediates. The final section was completed in 1980 to allow the factory to make its own intermediates. The Bhopal plant proved to be oversized, unreliable and expensive to run and a decision was taken to permanently close the loss-making facility by 31 December 1984.

MIC process

MIC (Methyl isocyanate) — an intermediate in the latest[3] UCC process — was produced in a vapour phase reaction between MMA (monomethylamine) and phosgene. The reaction products were quenched with chloroform and fed to a stripping still (to remove excess phosgene) then to a pyrolyzer (to remove hydrogen chloride) and finally to the MIC distillation column where chloroform and heavy byproducts were separated and the refined MIC distillate transferred to one of three large (57m^3) underground stainless-steel storage tanks. From the storage tanks, the MIC was transferred to the derivatives section to make the final product at a rate of up to three tonnes/day.

MIC was well known to be volatile, reactive, flammable and highly toxic. It can react with itself, polymerising in the presence of trace amounts of metallic contaminants and reacts violently with water.

Previous accidents and early warnings

There were multiple loss of containment (LOC) events before 1984; three of which resulted in hospital treatment and had to be reported to the factory inspector of the state of Madhya Pradesh.

- *6am Wednesday 24 December 1981:* A man was killed and two seriously injured during a maintenance activity to remove a slip blind in the MIC/phosgene unit. During the operation, liquid was released under pressure and all three men were taken to hospital. Ashraf Mohd. Khan died the following day.
- *2am Wednesday 10 February 1982:* A leak developed in the rotating seal of a pump. About 25 employees suffered respiratory distress after exposure to toxic gas and sixteen were admitted to hospital for up to five days. The cause was attributed to an incorrect seal fitted to the pump.
- *Wednesday 6 October 1982:* Three employees suffered chemical burns and fifteen others were exposed to a mixture of MIC, chloroform and hydrochloric acid from a piping leak in the MIC unit.

Worker protests for a safer working environment led to the sacking of the three most active union leaders in 1982.

---

[1] The stationmaster Harish Dhurve rushed to work and perished along with other railway employees while attempting to stop further trains arriving in Bhopal.

[2] Indian Supreme Court Affidavit 23.08.2006 Union of India vs UCC

[3] The newest and most efficient process changed the order of reaction, replacing napthylchloroformate with MIC as the key intermediate.

engineering and design
systems and procedures
culture

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A UCC safety audit in May 1982 found multiple safety deficiencies including 'potential for release of toxic materials in the phosgene/MIC unit and storage areas, either due to equipment failure, operating problems or maintenance problems.'[4] A year later, a UCIL action plan claimed that the issues were 'either corrected or in the process of being corrected.'[5]

During 1983 and 1984, there were further LOC incidents with leaks of MIC, chlorine, monomethylamine, phosgene and carbon tetrachloride.

A local journalist, Rajkumar Keswani repeatedly warned of the drift to danger at the factory, but he was ignored.

The 1984 accident

On the night of 2–3 December, about one tonne of water entered the MIC tank E610. In the presence of iron[6], the MIC and water reacted violently, the temperature and pressure increased until the tank safety relief valve opened. The gas abatement systems (a caustic scrubber and a gas flare) were either inoperable or overwhelmed, the community alarms and emergency response were wholly inadequate, and a toxic cloud spread out over the sleeping town.

Timeline

After the decision was made to close down the uneconomic factory by 31 December 1984, a plan was developed to process the remaining raw materials.

In a final distillation operation on 22 October 1984, the MIC storage tank E610 was filled to between 41[7] and 42[8] metric tonnes.[9] The MIC production unit was then shut down.

The intention was to dispose of the MIC inventory by converting it into product, however the assassination of Prime Minister Indhira Ghandi on 31 October 1984 led to a period of civil unrest and a curfew which interrupted operations until the end of November.

Attempts were made to transfer MIC from E610 on 30 November and 1 December 1984, but the tank could not be pressurized[10]. The rupture disc was tested and found to be intact. Nitrogen was reported to be flowing into the tank but even with all outlet valves closed, the pressure would not rise, suggesting that the closed valves on the process vent system were passing.

On Sunday 2 December 1984, the night of the accident, a process operator on afternoon shift was told by his supervisor "to open a nozzle on the pipe and put a water hose in to clean the inside"[11]. After shift changeover, the night shift operators reported an MIC leak and began investigating. Shortly after midnight a rapid rise in the pressure of MIC tank E610 built up until the pressure relief valve opened, releasing the gas that had been building up inside the tank.

After the event, the MIC storage tank E610 was estimated to contain 12.5 tonnes of residue, suggesting that between 28 and 30 tons of toxic chemicals were released into the atmosphere over a two-hour period[12].

Investigation

The Indian Central Bureau of Investigation (CBI) took control of the site immediately after the event. The initial focus was on Operation Faith, the safe disposal of the remaining inventory of MIC.

The first report into the causes of the accident was issued by UCC in May 1985. The investigation was conducted by scientists and engineers but with limited access to plant records and no access to employee eyewitnesses. UCC issued further reports as more information became available through legal discovery during the court cases that followed. UCC presented the conclusion, through consultants Arthur D Little, that an individual act of sabotage caused the disaster[13].

A Government of India (GOI) sponsored investigation was carried out by the Council of Scientific and Industrial Research (CSIR) and delivered to the Indian Parliament in December 1985. The conclusion of this report was that corporate negligence caused the disaster[14].

Both investigations concluded that water reacted with MIC in tank E610, leading to a runaway reaction, however the reports differed in a) how the water had entered the tank and b) the root causes of the accident.

Both investigations agreed that:

- slip blinds had not been installed to prevent water ingress into MIC tanks during washing operations
- the MIC tank alarms were not operational
- the refrigeration system had been emptied of refrigerant
- the flare tower was inoperable, the vent gas scrubber was idle and the emergency water curtain was ineffective.

Root Cause Analysis

In 2016, reliability engineer Kenneth Bloch published a detailed TapRoot© Root Cause Analysis of the Bhopal disaster in an extremely thoughtful and well researched book, *Rethinking Bhopal*[15] which traces the root cause of the accident right back to the design and procurement decisions.

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[4] *T D'Silva, Black Box of Bhopal,P79*

[5] *T D'Silva, Black Box of Bhopal. P81*

[6] *The iron which catalysed the runaway reaction was most probably a contaminant that entered with the water from the rusting carbon steel vent header.*

[7] *UCC Press conference*

[8] *CSIR Report*

[9] *The MIC contained up to 16% chloroform.*

[10] *In the absence of a transfer pump, this operation was carried out by pressure transfer.*

[11] *D'Silva reporting from a New York Times article by Stuart Diamond Jan 25 1985*

[12] *Approximately 1 tonne of water likely entered the tank and it's possible that 1 tonne of liquid was transferred out*

[13] *Arthur D Little report*

[14] *CSIR Report*

[15] *2016 Rethinking Bhopal by Kenneth Bloch IChemE / Elsevier*

In his conclusions Bloch urges us all to:

'Make inherently safer design your ultimate goal'

and

'Talk to your operators. Listen to what they tell you. Ask them to explain how they are operating the process. Is it in accordance with the design or does the process only respond by doing things differently? What issues must they struggle with to make the process work properly?'

Bloch's analysis is more fully covered in another article in this LPB special edition[16].

Conclusion

What's past is prologue[17]. Are we destined to repeat past mistakes in the future? Or is the future ours to shape? And if so, what have we learned from Bhopal Gas Tragedy 40 years on?

The one lesson that always rises to the top is the crucial importance of hazard awareness. Methods for evaluation and control of process hazards will continue to develop. However, hazard potential does not change — condensed phase explosions, fast deflagrations, vapour phase explosions, dust explosions, runaway exothermic reactions etc are all governed by the laws of chemistry and physics. All process safety management must be underpinned by good hazard awareness.

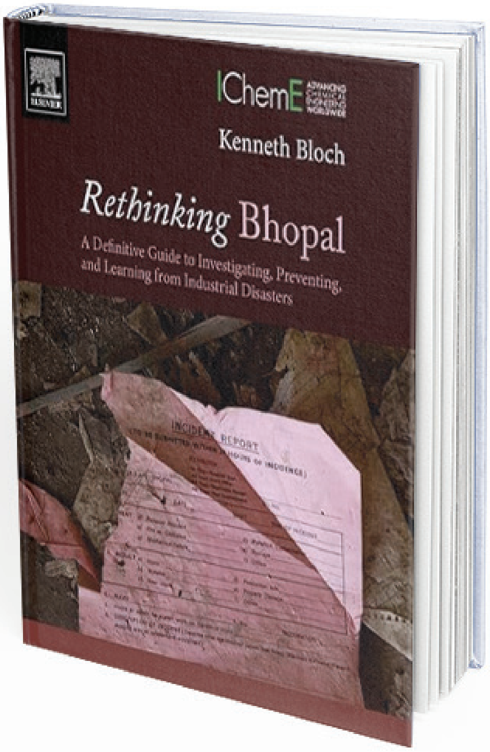
The best time to address the hazards of any installation is before construction

Inherent safety by design

- eliminate
- substitute
- minimise
- simplify
- moderate.

Build in error tolerance to achieve inherent safety by design. What you don't have, can't leak. Build high hazardous facilities far away from centres of population — people who aren't there can't be hurt[18].

Determine the reliability goals and specify the right equipment and maintenance strategy to achieve them.



Once designed and built, the safe operation of a hazardous process can ultimately depend on the knowledge and expertise of the operating crew on a weekend night shift.

Is everyone in your organisation aware of

- What can go wrong?
- The early warning signs and how to deal with them?
- The worst-case consequences and how to mitigate them?
- The emergency response plan and how to trigger it?

A delay to production with the ability to fight another day is a far better alternative to the risk of losing control and triggering a major incident.

Everyone responsible for the safe management of process hazards must maintain a high level of hazard awareness. Those at the sharp end of operations and maintenance need to understand the risks and how they are controlled. They need to know the rules and be supported in following them. Once the process is operational, don't leave process safety to the engineers and safety professionals. Talk to one another across disciplines and across levels.

There is nothing new or revolutionary in these reflections, but sometimes simple lessons can be hidden in plain sight.

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[16] *Bhopal Root Cause Analysis, pg 06*

[17] *William Shakespeare, The Tempest, 1611*

[18] *Paraphrasing Trevor Kletz*

Bhopal Root Cause Analysis

Fiona Macleod, UK

Introduction

In August 2023, I returned to Bhopal in India to visit the former Union Carbide factory *(pictured right)*, site of the worst industrial accident in the world[1]. I wrote at the time[2] of my shock at the dangerous state of the works. The abandoned factory still stands on contaminated ground, and pollution (heavy metals and organochlorides) continues to spread through the groundwater.

To try to understand the current impasse, I believe we need to go right back to the failure to conduct a thorough and independent investigation immediately after the accident, with full access to site, witnesses and records.

For those new to the story of this tragic accident, it may be helpful to first read the partner paper (*The Worst Industrial Accident in History – Union Carbide, Bhopal, India, 1984*)[3].

In the first paper I wrote for LPB ten years ago[4], I examined four different theories as to the critical event that triggered the worst industrial accident in the world.

1. the CSIR water washing theory
2. the sabotage theory
3. the degradation theory
4. the nitrogen mix up theory

Since then, the reliability engineer Kenneth Bloch published his insightful book *Rethinking Bhopal*[5] which includes a detailed TapRooT© Root Cause Analysis and a new theory of what caused the accident.

5. The Bloch water washing theory

Forty years on, why does it matter?

Learn from yesterday, live for today, hope for tomorrow. The important thing is not to stop questioning[6].

If we don't fully understand what happened, how can we prevent such a tragedy happening again?

This paper examines Bloch's conclusions and explains the significance.


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Setting the scene

The Union Carbide India Limited (UCIL) pesticide factory in Bhopal was due to cease operations on 31 December 1984. Some maintenance workers had been laid off and other experienced staff left to find new jobs. Process operators without full training in the MIC section were brought in to compensate[7].

Leading up to the night of the accident on 2-3 December 1984, the operating teams had been trying to transfer the intermediate methyl isocyanate (MIC) from tank E610 to the derivatives section where reaction with alpha-naphthol produced the active ingredient of the pesticide Sevin®.

The MIC storage tanks had been designed and built with pumped circulation and transfer, but the pumps had proved dangerously unreliable, with highly hazardous MIC leaking from pump seals.[8,9]

An alternative transfer method, pressurising the MIC tank with nitrogen, was developed.

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[1] *Pfab, E., "Looking Ahead at the First Ever International Process Safety Week," Chemical Engineering Progress, 119 (12), p. 22 (Dec. 2023).*

[2] *Macleod. LPB 294 https://www.icheme.org/media/25390/lpb294_pg02.pdf*

[3] *The worst industrial accident in history – Union Carbide, Madhya Pradesh, Bhopal, India, 1984 , LPB299, pg 03*

[4] *Macleod. LPB 240 https://www.icheme.org/media/2185/lpb240_pg03.pdf*

[5] *Bloch. Rethinking Bhopal. Elsevier (2016) ISBN-13 978-0128037782*

[6] *Albert Einstein*

[7] *TR Chouhan Bhopal, The Inside Story 1994, P43 – Personnel problems*

[8] *TR Chouhan Bhopal, The Inside Story 1994, P24 – Injuries suffered during these leaks were treated at the plant dispensary, with incidents usually recorded as cases of material loss rather than injuries to workers.*

[9] *T D'Silva, The Black Box of Bhopal, 2006, P73. In February 1982. about 25 employees suffered respiratory distress after a pump seal failed exposing them to toxic gas. Sixteen were admitted to hospital for up to five days.*

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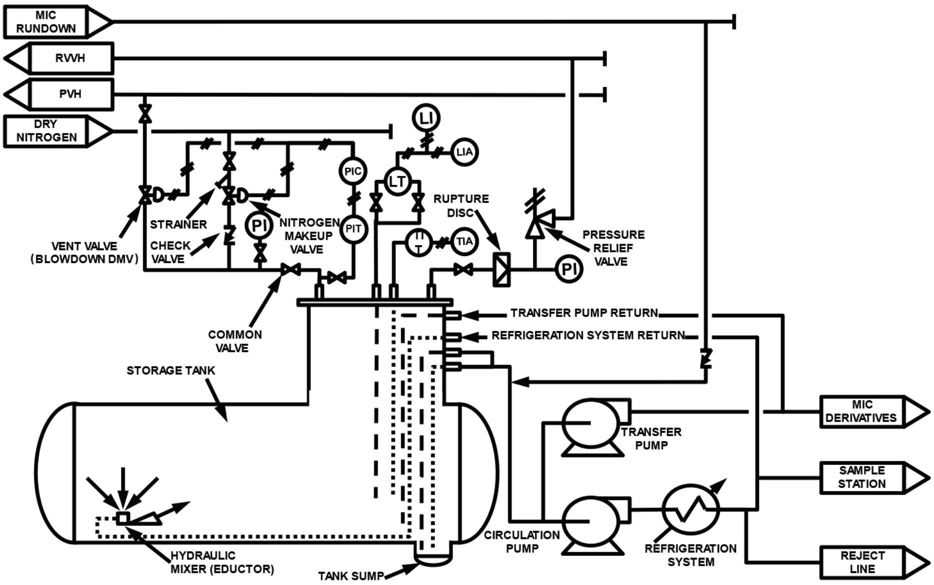
Figure 1 – Tank E610 as designed



Pressure transfer

In order to transfer the intermediate (MIC) from the storage tank to the derivatives section, the valve to the process vent header was closed (1), nitrogen was introduced directly to tank E610 under pressure control (2). Once the pressure reached about 1 barg, the transfer line was opened (3) and liquid MIC flowed to the derivatives section.

When the transfer was complete, the nitrogen and transfer lines were closed and the tank was 'locked in' with the vent valve closed[10]. The vent valve was only opened when the tank was filling from the MIC still.

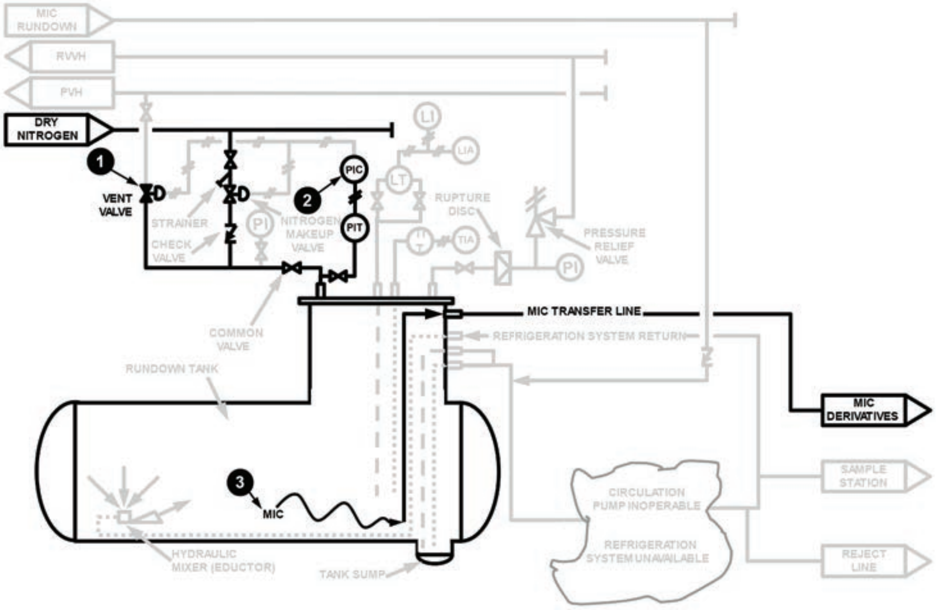
But on the days leading up to the accident, the tank would not hold pressure.

In the second shift of 01 December (14.45 hours to 22.45 hours) attempts were made once again to pressurise tank E-610 without success[11].

Transfer of the MIC to the derivatives section was essential to consume the inventory before the end of the year. In the absence of an MIC pump, pressure transfer was the only option.

The absence of practically any nitrogen pressure on tank 610 for over a month … indicated the possibility of malfunctioning of blowdown DMV [the vent valve][12].

Figure 2 – Tank E610 as operated



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[10] *K Bloch, Rethinking Bhopal, P302*

[11] *CSIR report P19 Timeline*

[12] *CSIR report P80 Analysis*

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There was a long-standing problem with carbon steel[13] valves failing to seal due to build up of solids on the valve seats.

After checking every other possibility, if the operators had concluded that the blowdown DMV – the diaphragm motor valve on E610 vent – was passing, what were their options to resolve the problem on a Sunday night without maintenance support?

Water washing

'Iron, copper, tin and zinc must be excluded from contact with methyl isocyanate (MIC). ...Under conditions of catalysis, methyl isocyanate will form as crystalline trimer or a high molecular weight resin[14].'

By 1984, water washing the carbon steel vent valves and pipes to remove build-up of solid MIC-trimer was already a well-established practice on the Bhopal site.

Such a high-risk activity should never have been left to process operators on shift because it introduced a new hazard.

'Water reacts with methyl isocyanate...(leading to)...a runaway reaction[15].'

The procedure stated that a written plan, authorised before every water washing operation, required the assistance of maintenance to insert a physical barrier (a blank or spade) between the section to be washed and the live process to prevent contact of water with MIC.

However, the plant had been designed with welded joints to reduce leaks and there were not many convenient break-in points or places to connect water hoses — for good reason. The reduction in manning meant there was no longer a maintenance crew on shift

It's no use writing procedures if they can't be followed.

In addition, the very act of inserting and removing blanks in a live system full of leaking isolation valves exposed maintenance personal to toxic chemicals. It was exactly such an operation that caused the death of employee Ashraf Mohd. Khan in December 1981[16]. Two maintenance workers were removing slip blinds in the MIC/Phosgene unit when toxic liquid was released under pressure. Instead of investigating why the isolation valves were passing, the victim was blamed for not using his air mask correctly.

The workaround was to remove instruments (for example, pressure gauges) and use the screwed tapping to connect a hose while relying on isolation valves to prevent backflow[17].

Theory 5 – Accidental introduction of water directly to tank E-610

In *Rethinking Bhopal*[18] Kenneth Bloch explains what he believes happened on the night of the accident.

In order to clear the vent valve at tank E610 (blowdown DMV), the closest place water could be introduced was between the vent valve and common valve, leaving only a single manual valve to protect the MIC tank from water ingress.

The recently transferred shift workers charged with the job of resolving the leaking vent valve on E610 could not have understood the risk of a violent reaction between MIC and water. If they had been aware of the hazard, they would never have relied on a single isolation — the common valve.

The intent was for the water to pass through the vent valve, clean the seat so that it could be fully closed and pressure transfer operations could be resumed.

'Unseen and unknown to the workers at the time was that the common valve, also constructed of iron, was leaking as well. Trimer had accumulated inside the valve body during the final production run...The resistance felt upon turning the valve handle to close the valve probably promoted a sense of confidence that tank E610 was properly isolated from the water washing activity. However, the trimer plug dissolved upon contacting water. This left a gaping entryway for water to drain down into the tank containing 41 tonnes of MIC [19].'

Not only was the common valve leaking but the staff were working blind with both hands tied behind their backs.

If the storage area had been operating as designed, the moment a small amount of water entered tank E610 there should have been a temperature alarm in the control room.

However, the temperature alarm was in a permanent state of alarm ever since refrigeration had permanently stopped in June 1984[20].

As water continued to enter and react, the pressure rose.

The tank pressure in E610 was visible in the control room, but there was no high-pressure alarm installed on the MIC storage tanks. In fact, with the change of operation from design (2psig nitrogen blanket) to full locked in pressure, cycling with ambient temperature, high pressure readings were common.

By the time the increase in pressure in E610 was noticed, it was too late. Once the runaway reaction inside E610 was in progress, passive systems should have prevented tragedy.

The relief valve lifted to prevent the tank from exploding and the gases — likely a mix of MIC, CO_2, chloroform, methylamine and other products of the violent runaway reaction — rushed towards the vent gas scrubber.

Had the scrubber been fully operational (it was not, but was partially restarted during the accident), it would likely have been quickly overloaded, and the toxic gases would have continued to the flare.

Would the flare have coped? We will never know because it was not operational. A corroded section linking the scrubber to the flare had been removed and not replaced.

The site emergency procedure should have kicked in, but water curtains designed for liquid spills were ineffective to stop the release of gas exiting the scrubber[21].

---

[13] *CSIR report P16 'HP nitrogen is admitted into the tank through a make up control valve (make up DMV), the body material of which is carbon steel. In case the pressure is higher than the desired value, nitrogen is vented out into PVH through blow down control valve (blow down DMV), the body material of which is again carbon steel.*

[14] *Union Carbide manual, 1976 as reported on P29 by TR Chouhan*

[15] *Union Carbide manual, 1978 as reported on P29 by TR Chouhan*

[16] *T D'Silva, The Black Box of Bhopal, 2006, P71.*

[17] *Ashok S. Kalelkar, INVESTIGATION OF LARGE-MAGNITUDE INCIDENTS: BHOPAL AS A CASE STUDY, May 1988, Arthur D. Little, Inc.*

[18] *K Bloch, Rethinking Bhopal 2016, Chapter 22*

[19] *K Bloch, Rethinking Bhopal 2016, Chapter 22, P373*

[20] *https://www.icheme.org/media/5829/lpb_issue063p001.pdf*

[21] *1985 UCC report documents that the fire monitor ("water curtain") failed to reach the point of release during the incident due to low water pressure but worked when tested after the incident. It is likely that better emergency response training would have led the team to reduce the number of openings and maximize water pressure where it was most needed.*

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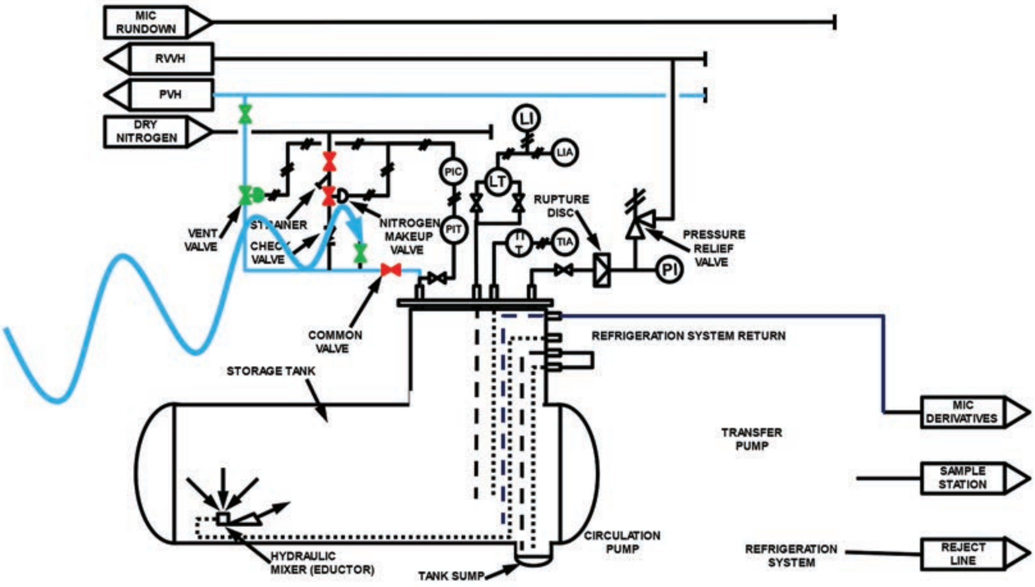
Figure 3 Theory 5 - Were attempts made to wash solids from the vent valve directly above E610?



The public alarm sounded[22] and was then silenced. Chaos and confusion reigned. Instead of rising high above the site to the flare stack, the toxic gases were released from a lower point (30.5m) at the top of the vent gas scrubber. The gases cooled and spread over the city in a toxic fog.

So many people died. So many more suffered life changing injuries. So many are still suffering today.

Investigation

In March 1985, Union Carbide (UCC) published an initial investigation report into the Bhopal incident[23]. LPB63 carried a summary[24] concluding that:

'The reaction which caused the release of MIC was caused by the ingress of ... water into the tank containing MIC ....'

In December 1984, the Madhya Pradesh State Government commissioned a sitting judge, Justice NK Singh, to carry out a full investigation to determine the cause of the tragedy. However, in December 1985 the NK Singh commission was dissolved.

'The decision to wind up the Singh Commission was taken in the best interests of the gas victims[25].'

A few days later, the Council of Scientific & Industrial Research (CSIR) presented its own report to the Indian parliament. The principal author Dr. S. Varadarajan concluded that.

'The needless storage of large quantities of ...(MIC)... in very large size containers for inordinately long periods as well as insufficient caution in design, choice of materials of construction and in provision of measuring and alarm instruments, together with inadequate controls on systems of storage and on quality of stored materials as well as lack of necessary facilities for quick effective disposal of material exhibiting instability, led to the accident [26].'

In May 1988, Ashok S. Kalelkar[27] presented a paper at an IChemE conference on Preventing Major Accidents,

'The results of this investigation show, with virtual certainty, that the Bhopal incident was caused by the entry of water to the tank through a hose that had been connected directly to the tank.'

The only explanation that the UCC sponsored investigating team could come up for this aberration was a deliberate act of sabotage.

In his book, *Rethinking Bhopal*, Bloch makes a convincing case for an alternative explanation : an attempt to wash solids from the vent line directly above MIC tank E610.

Discussion

Why does it matter what final event in a chain of failures triggered the accident? A good accident investigator works back from the initiating event to find the root cause.

If the Indian authorities believed that the 1984 tragedy was directly caused by the actions of the local team on the night of the accident (the sabotage theory), did they fear it would weaken their compensation negotiations with the US parent company?

Would this explain why the original NK Singh investigation was halted and never published?

'Government of India lawyers in the USA...felt that the enquiry's findings might affect the compensation claim...(if it) eventually established that the MP Government, the Union Government and UCIL all shared the blame equally, UCC might have got away with less compensation...(and it was) suggested that the probe had been withdrawn because 'information submitted there was reaching UCC in America[28].'

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[22] *TR Chouhan Bhopal, The Inside Story 1994, P43 – 'The public alarm was modified so that it could only be heard within the factory premises'*

[23] *Bhopal Methyl Isocyanate Incident Investigation Team Report, March 1985. Union Carbide Corporation, Danbury, Connecticut.*

[24] *https://www.icheme.org/media/5829/lpb_issue063p001.pdf*

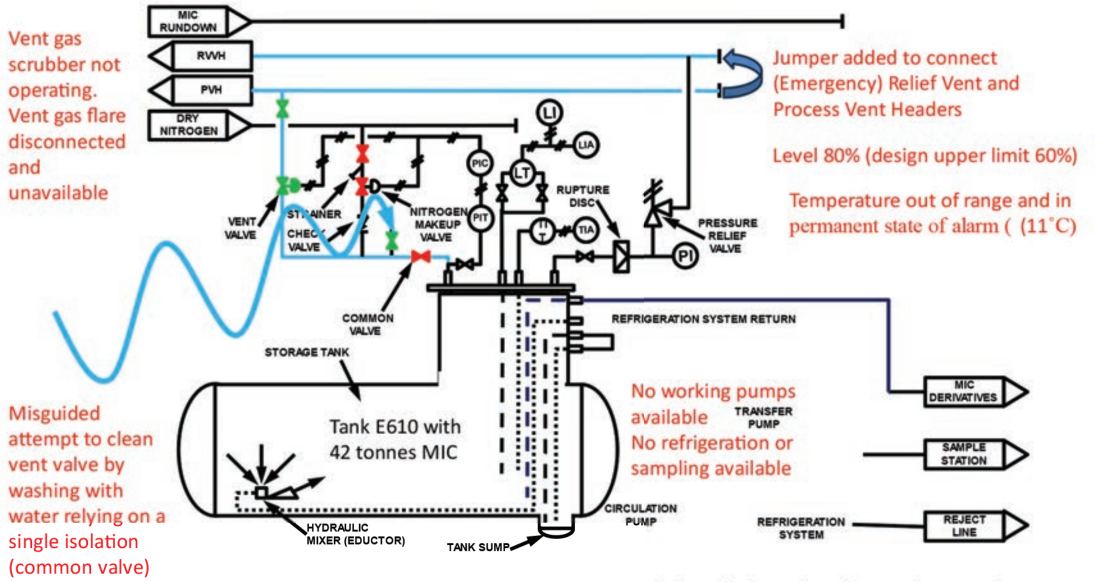
[25] *MP Chief Minister Motilal Vora quoted in The Hindu Newspaper December 18, 1985*

[26] *CSIR report Dec 1985*

[27] *Ashok S. Kalelkar, INVESTIGATION OF LARGE-MAGNITUDE INCIDENTS: BHOPAL AS A CASE STUDY, May 1988, Arthur D. Little, Inc.*

[28] *Tavleen Singh, India Today, January 15 1986*

Figure 4; Theory 5 – Accidental introduction of water directly to tank



Ref: Kenneth Bloch *Rethinking Bhopal* 2016 Elsevier IChemE

Would this explain why the Indian government was so quick to take over all compensation claims on behalf of victims and settle with Union Carbide for such a derisory sum and with no punitive element or money set aside for site remediation[29]?

Had anyone taken the trouble to understand the operational problem that the shift operators were faced with in the days leading up to the tragedy — the previous decisions that led up to their dilemma, the custom and practice on the site, and the intent of their misguided actions — then it would have become clear that the root causes could be traced right back to the original design.

In the case of BP and Deepwater Horizon, there is no doubt that the contract operating staff made bad decisions on the day. But BP still took full responsibility for compensation and clean up.

In the case of Exxon Valdez, there is no doubt that the crew of the ship made bad decisions on the day. But Exxon still took full responsibility for compensation and clean up.

The beauty of the Bloch theory is that it ties together most of the facts reported in the investigations and allows us to consign the sabotage theory to the dustbin of conspiracy theories[30].

Conclusion

Few — if any — major accidents are caused by a single act. Few — if any — industrial disasters appear out of the blue. If you have eyes to see and ears to listen, then there are always early warning signs that, with proper investigation and action, will prevent more serious events. The Bhopal accident is no exception.

There has been much focus on the critical safety barriers that had been allowed to degrade as the plant ran to closure — the refrigeration, the instrumentation, the alarms, the disposal routes, the vent gas scrubber, the flare, the water curtain, the evacuation plan, the emergency response.

However, the multiple failures on the night of accident can only be fully understood in the light of decisions made years earlier.

By failing to address the reliability issues of the MIC transfer pumps, the change to pressure transfer meant that nitrogen was diverted from one of its intended uses (to eliminate oxygen and moisture from the vent header). The piping began to corrode. Iron oxide (rust) catalysed the formation of solid MIC-trimer deposits in the 2-inch carbon steel vent header, preventing valves from sealing, increasing back-pressure in the MIC distillation column and affecting product quality. It became common practice to remove the MIC-trimer deposits by washing with water.

We may never know by exactly what route water and contaminants entered tank E610.

What we do know is that the decision to store such a large quantity of a highly toxic, volatile and reactive intermediate so close to major centre of population and adjacent to a major railway junction led to the worst peacetime industrial disaster in the world.

The original tragedy of Bhopal is that so many early warning signs were ignored. With only 27 days to go before permanent closure, acting on any one of those warning signs might have prevented the catastrophe.

The ongoing tragedy of Bhopal is that by failing to investigate immediately after the accident with impartiality and thoroughness, a reasoned debate about the root causes of the accident is forty years overdue and in the meantime no one has taken responsibility for the wellbeing of the gas affected victims, their children and grandchildren or for the new victims of the ongoing pollution of groundwater from the abandoned and unremediated site.

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[29] *Average of $818 per person (£470 million shared among 574,304 confirmed cases entitled to compensation as a result of loss, injury or death). Settlement took decades and the burden (and cost) of proof rested with the victims. Lung damage initially classified as a minor injury, turned out to cause permanent disability.*

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[30] *Paraphrasing RT Shone BHOPAL – My United Nations Experience*

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Bhopal recollections

Bhopal city today

Paulose NK / Shutterstock.com

Recalling the night of the gas disaster

Nazia Farooqui, Heriot-Watt University Edinburgh, UK

A night of chaos

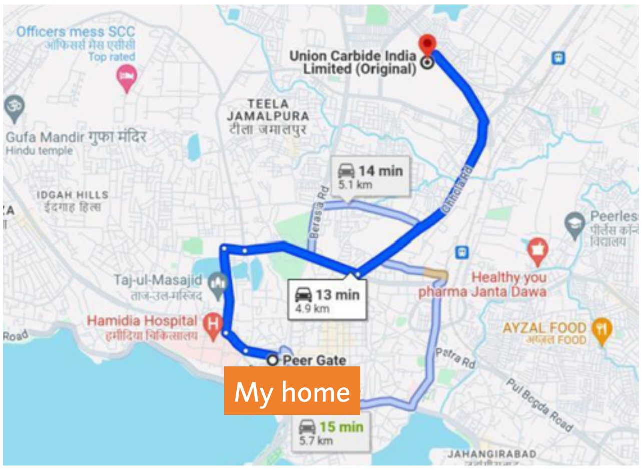
Knock Knock!! Knock Knock!!! In the early hours of 03 December 1984, someone was at the door, my mum said. My dad was sleeping in his bed and responded, "What happened — who is that?" The lady on the other side said, "Bhabhi ji, it's me — Renu ki mummy, apki padosi" (meaning, "Renu's mother, your next-door neighbor"). She then added urgently, "Dange ho gay! Bhagdadh machi hai, Hame nikalna hoga" (meaning "There might be riots! People are running around in panic. We need to get out of here"). My dad opened the door, the lady on the other side was coughing badly, her eyes were red and watery. She looked worried, panicked. She passed on the message and then disappeared into the chaos.

My dad looked around. There was something strange in the air. It was filled with a thick, smoky haze that immediately made our eyes irritated. Breathing became increasingly difficult, as if the very air had turned hostile. The atmosphere was heavy and oppressive, and every breath felt like inhaling sharp, invisible needles. It was clear that something was terribly wrong, and the urgency to escape grew stronger with each passing second. My dad announced, "We need to leave, soon!"

My mum woke up my brother and sister (aged 7 and 6) and wrapped me, just a couple of months old, in a blanket. We had a Bajaj scooter two-wheeler. My brother stood on the front, dad drove, my sister sat in the middle, and my mum held me on her lap at the back. The streets were filled with panic-stricken people, collapsing and disoriented, with no clear direction or sky. Eyes were red and tired, voices hoarse from crying out for help. No one knew where to go. My dad's priority was to get us as far away from the city as possible. He drove us to one of my uncles who had a car, hoping it could take us further to safety. After ensuring we were secure, he turned his scooter back to help others who were suffering on the streets.

The following day, we returned to our home in Bhopal. There was no safeguarding, no signs or guidance on what to do next; we believed it was safe to return and get back to our normal lives. However, senior authorities decided, a week later, to vacate the city.

My Bhopal, the beautiful city of lakes, unfortunately became known as the world's worst industrial disaster. Being a chemist myself, I now understand the aftermath of such a huge quantity of methyl isocyanate (MIC) escaping from the Union Carbide pesticide plant. Chemically, MIC is highly toxic and heavier than air. When leaked, it settles on the ground due to its density. MIC is the smallest and most toxic of all cyanates,



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balajisrinivasan / Shutterstock.com

Bhopal is beautiful. It is rich in culture, reflected in its old architecture, heritage buildings, and the heart of its people. (Left to right) The Upper Lake, The Tajul Masajid of Bhopal – the largest mosque in India and a roadside tea stall in the old town

affecting all forms of life it comes into contact with. Due to its high concentration at ground level, it was easily inhaled, damaging the lungs and leading to severe breathing difficulties and heart problems in just a few minutes. The disaster death toll was estimated to be over 15,000 and produced lasting effects on more than 500,000 residents.

A catastrophic mistake

The case study published in The Ethical Engineer written by Dr. Rhyddhi Chakraborty (https://ethicalengineer.ttu.edu/articles/lesson-from-bhopal-gas-tragedy-1983-84), outlined the occupational hazards at Union Carbide India Limited (UCIL) soon after the plant was established in 1970. In 1977, the plant began importing alpha-naphthol and methyl isocyanate (MIC) in stainless steel drums from the USA to manufacture Sevin (Carbaryl). However, the Bhopal plant later started manufacturing MIC using the know-how and design formula provided by Union Carbide Corporation (UCC) USA. As a result, the Bhopal plant began producing carbon monoxide (CO) and phosgene ($COCl_2$) gas as intermediaries in the production of MIC.

Despite being aware of all the associated hazards, the plant maintained three huge underground 68,000-litre liquid storage tanks — E610, E611, and E619 — for MIC. They claimed to have all necessary safety measures in place, but this decision represented a significant risk at the time and ultimately turned out to be a catastrophic mistake.

Negligence and accountability

Health and safety concerns were raised many times before the actual disaster. Not once, not twice, but repeatedly throughout 1982, there were leaks of either MIC or phosgene. Several workers were exposed, resulting in severe accidents, injuries, chemical burns, and even deaths. Yet, these warnings and casualties, clear signs of negligence, did not prevent the massive disaster in December 1984. I would like to be very clear here: I do not hold UCIL solely responsible for this unfortunate event. This disaster happened on the Indian soil, where there are rules and regulations meant to ensure the safety of the people and the place. These should have been strictly followed and UCL should never have been permitted to operate the plant in the first place, let alone for 14 years in the central location of my beautiful city, Bhopal.

As compensation from UCC, my mum told me that survivors received 200 Indian rupees (£2) per month for up to a year and a half. Then the payments stopped. After a decade, in 1994-95, Rs 25,000 (£250) was provided to the survivors after many appeals. A few hospitals have been opened, which offer free health services if you have a victim's gas card and all the necessary paperwork.

A call to action

Bhopal is beautiful. It is rich in culture, reflected in its old architecture, heritage buildings, and the heart of its people. Bhopali cuisines are popular, and paan and kadak chai (tea) are local favorites. In this densely populated city, the average middle-class citizen strives to survive for their daily bread and butter. The ruins of the UCIL plant are still hazardous, and its campus has become a playground for young children. They lack the time, energy, or money to raise these safety concerns with senior authorities or regulatory bodies. It is the duty of the Government of India and UCC to develop a strategy and take necessary actions to clean up the site. This must not take another 40 years to accomplish.

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Replace hazardous reaction with one of less hazard

- **Use a safer process route. Avoid MIC formation. React alphanaphthol and phosgene to produce chloroformate ester, followed by reaction with methylamine to yield carbaryl**

SIMPLIFY

Eliminate unnecessary complexity to reduce risk of human error

- **Design equipment to totally contain MIC at ambient temperature or the maximum attainable process temperature.**

not evaluated

Allocation of UCIL plant close to densely populated settlements Due to economic advantages

Unrestricted large scale manufacturing and storage of pesticide

Vent gas scrubber **could not handle the large influx of MIC** even if it were in operation.

REDUCED EMPHASIS ON SAFETY

ASSET INTEGRITY AND RELIABILITY

① The refrigeration system was **not in use.**

② Tank temperature was **not logged.**

③ Operators **thought** the tank's pressure meter was unreliable

④ Evacuation tank E-619 **was not empty.**

⑤ **Corroding iron pipelines** were used.

⑥ Vent gas scrubber was **under maintenance.**

⑦ Water curtains were **not tall enough to mitigate the gas leak.**

INSUFFICIENT MAINTENANCE

⑧ **Concentration of chloroform** in the tank was **too high.**

⑨ The tank was not pressurised due to a **leaky valve.**

⑩ The tank's high-temperature **alarm was not functioning.**

⑪ **Flare tower was disconnected** from the plant pipe system.

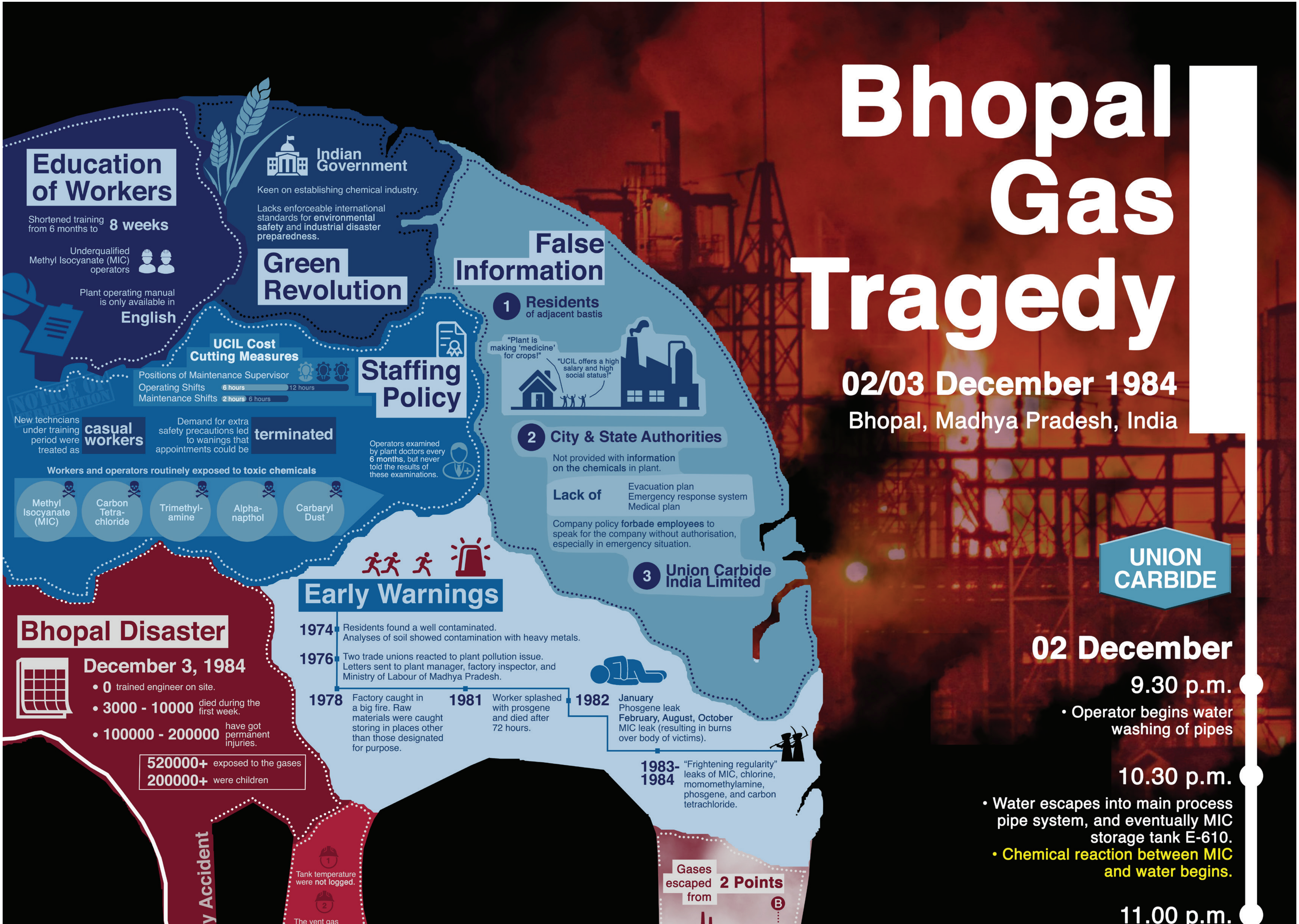
⑫ Many valves, vent lines, feed lines, etc. were in **poor condition.**

BHOPAL GAS TRAGEDY

2 - 3 December 1984

Bhopal, Madhya Pradesh, India.

IChemE



Bhopal Gas Tragedy

02/03 December 1984

Bhopal, Madhya Pradesh, India

02 December

9.30 p.m.

- Operator begins water washing of pipes

10.30 p.m.

- Water escapes into main process pipe system, and eventually MIC storage tank E-610.
- Chemical reaction between MIC and water begins.

11.00 p.m.

Education of Workers

Shortened training from 6 months to **8 weeks**

Underqualified Methyl Isocyanate (MIC) operators

Plant operating manual is only available in **English**

Indian Government

Keen on establishing chemical industry.

Lacks enforceable international standards for **environmental safety** and **industrial disaster preparedness.**

Green Revolution

UCIL Cost Cutting Measures

Positions of Maintenance Supervisor		
Operating Shifts	6 hours	12 hours
Maintenance Shifts	2 hours	6 hours

Staffing Policy

New techncians under training period were treated as **casual workers**

Demand for extra safety precautions led to wanings that appointments could be **terminated**

Operators examined by plant doctors every **6 months**, but never told the results of these examinations.

Workers and operators routinely exposed to toxic chemicals

- Methyl Isocyanate (MIC)
- Carbon Tetra-chloride
- Trimethyl-amine
- Alpha-napthol
- Carbaryl Dust

False Information

1 Residents of adjacent bastis

"Plant is making 'medicine' for crops!"

"UCIL offers a high salary and high social status!"

2 City & State Authorities

Not provided with **information on the chemicals** in plant.

Lack of
Evacuation plan
Emergency response system
Medical plan

Company policy **forbade employees** to speak for the company without authorisation, especially in emergency situation.

3 Union Carbide India Limited

Early Warnings

1974 Residents found a well contaminated. Analyses of soil showed contamination with heavy metals.

1976 Two trade unions reacted to plant pollution issue. Letters sent to plant manager, factory inspector, and Ministry of Labour of Madhya Pradesh.

1978 Factory caught in a big fire. Raw materials were caught storing in places other than those designated for purpose.

1981 Worker splashed with prosgene and died after 72 hours.

1982 January
Phosgene leak
February, August, October
MIC leak (resulting in burns over body of victims).

1983-1984 "Frightening regularity" leaks of MIC, chlorine, momomethylamine, phosgene, and carbon tetrachloride.

Bhopal Disaster

December 3, 1984

- **0** trained engineer on site.
- **3000 - 10000** died during the first week.
- **100000 - 200000** have got permanent injuries.

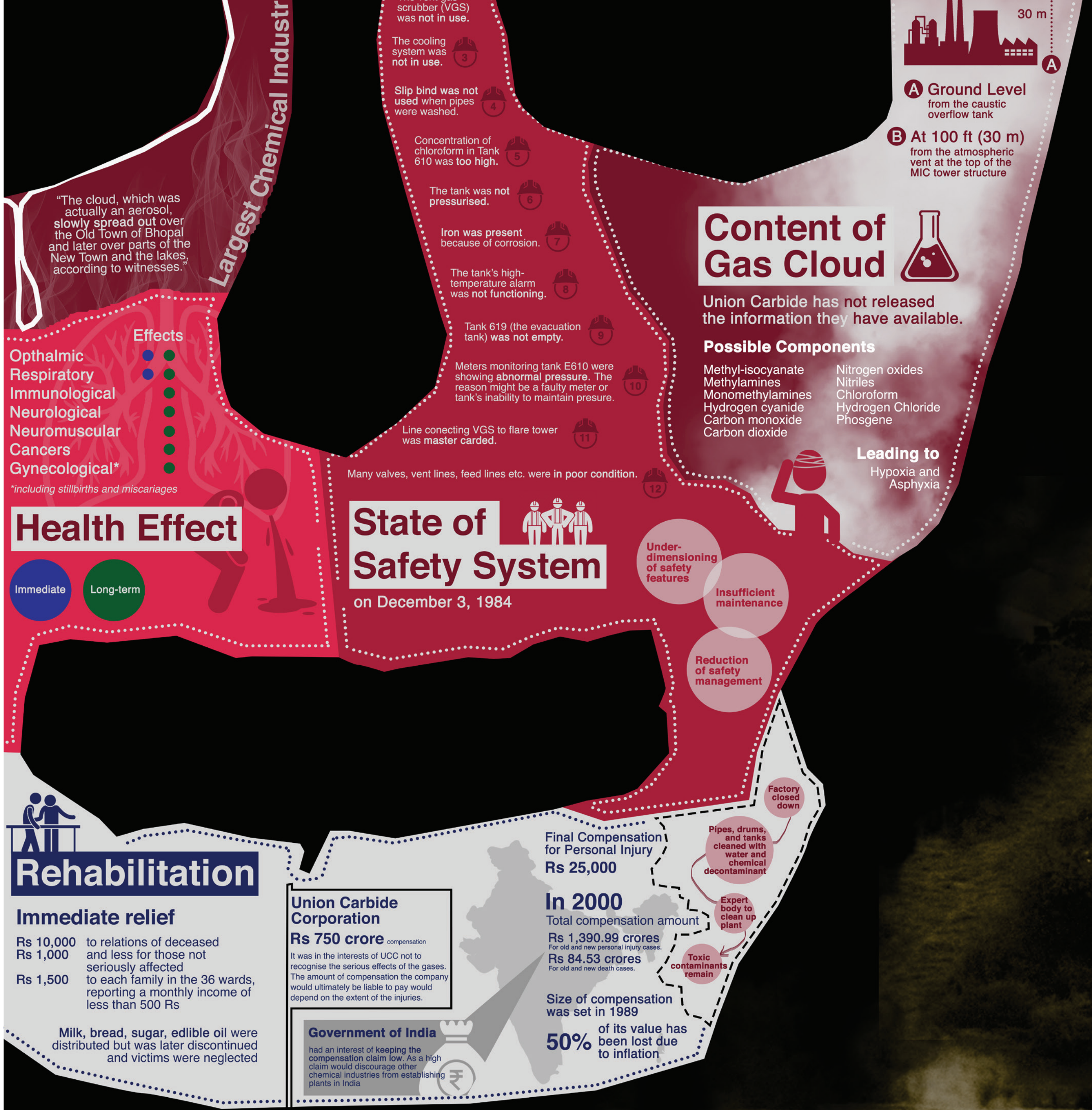
520000+ exposed to the gases
200000+ were children

y Accident

Tank temperature were not logged.

The vent gas

Gases escaped from **2 Points**



Largest Chemical Industr

"The cloud, which was actually an aerosol, **slowly spread out** over the Old Town of Bhopal and later over parts of the New Town and the lakes, according to witnesses."

Effects

	Immediate	Long-term
Opthalmic	●	●
Respiratory	●	●
Immunological		●
Neurological		●
Neuromuscular		●
Cancers		●
Gynecological*		●

*including stillbirths and miscariages

Health Effect

● Immediate

● Long-term

scrubber (VGS) was **not in use.**

3 The cooling system was **not in use.**

4 **Slip bind was not used** when pipes were washed.

5 Concentration of chloroform in Tank 610 was **too high.**

6 The tank was **not pressurised.**

7 **Iron was present** because of corrosion.

8 The tank's high-temperature alarm was **not functioning.**

9 Tank 619 (the evacuation tank) **was not empty.**

10 Meters monitoring tank E610 were showing **abnormal pressure.** The reason might be a faulty meter or tank's inability to maintain presure.

11 Line conecting VGS to flare tower was **master carded.**

12 Many valves, vent lines, feed lines etc. were **in poor condition.**

State of Safety System

on December 3, 1984

Under-dimensioning of safety features

Insufficient maintenance

Reduction of safety management

30 m

A **Ground Level** from the caustic overflow tank

B **At 100 ft (30 m)** from the atmospheric vent at the top of the MIC tower structure

Content of Gas Cloud

Union Carbide has not released the information they have available.

Possible Components

- Methyl-isocyanate
- Methylamines
- Monomethylamines
- Hydrogen cyanide
- Carbon monoxide
- Carbon dioxide
- Nitrogen oxides
- Nitriles
- Chloroform
- Hydrogen Chloride
- Phosgene

Leading to
Hypoxia and Asphyxia

Rehabilitation

Immediate relief

Rs 10,000	to relations of deceased
Rs 1,000	and less for those not seriously affected
Rs 1,500	to each family in the 36 wards, reporting a monthly income of less than 500 Rs

Milk, bread, sugar, edible oil were distributed but was later discontinued and victims were neglected

Union Carbide Corporation
Rs 750 crore compensation

It was in the interests of UCC not to recognise the serious effects of the gases. The amount of compensation the company would ultimately be liable to pay would depend on the extent of the injuries.

Government of India
had an interest of **keeping the compensation claim low.** As a high claim would discourage other chemical industries from establishing plants in India

Final Compensation for Personal Injury
Rs 25,000

In 2000
Total compensation amount
Rs 1,390.99 crores
For old and new personal injury cases.
Rs 84.53 crores
For old and new death cases.

Size of compensation was set in 1989
50% of its value has been lost due to inflation

Factory closed down

Pipes, drums, and tanks cleaned with water and chemical decontaminant

Expert body to clean up plant

Toxic contaminants remain

- MIC storage tank pressure rises to 1.7 bar, which is still within safe operating limits of 1.1 bar to 2.7 bar..

03 December

12.15 a.m.

- MIC storage tank pressure rises rapidly from 3.1 bar to 4.8 bar.
- Operator senses heat radiating and rumbling noises from tank.
- Supervisor starts Vent Gas Scrubber (VGS) circulation pumps.

12.25 a.m.

- Chemical reaction between MIC and water becomes uncontrolled..
- MIC gas starts escaping from VGS stack.

12.45 a.m.

- All plant operations are suspended.

1.00 a.m.

- MIC gas reaches nearby residents.
- Toxic gas alarm sounded by operator.
- Water streams are directed onto MIC storage tank mound.

1.30 a.m.

- Safety valve reseats.
- Tank contents are cooled.
- Nitrogen pumped in to tank to raise pressure to 1.5 bar.

IChemE

UCIL USES A PROCESS INVOLVING THE FORMATION OF THE INTERMEDIATE COMPOUND, MIC, WHICH IS VERY HAZARDOUS.

Small abnormalities **difficult to be detected** ahead of time.

High complexity of MIC storage system installation, safeguarding and control

HUMAN ERROR PREDICTION AND RECTIFICATION

Estimation of human error probability (HEP)

Human error assessment and reduction technique (HEART)

Sensitivity analysis

PRE-STARTUP SAFETY REVIEW

A way to identify, evaluate and control issues proactively before an activity is allowed to proceed

EMERGENCY RESPONSE PLANNING (ERP)

Should cover:

Before leakage
During leakage
After leakage

Three main components:

Prevention
Internal and external communication
Mitigation

Regular Training and Performance Assessment of Employees

MODERATE

Reduce the strength of an effect

- **Separate UCIL plant from people, evacuation points and emergency response facilities.**
- **Store MIC in smaller tanks.**

MINIMISE

Use small quantities of hazardous substances

- **Reduction of MIC intermediate inventory**
- **MIC is not essential as a raw material nor a product.**

PROCESS HAZARD ANALYSIS

Identify, evaluate and control hazards involved in a process.

Should address:

1. **Process hazards**
2. **Engineering and administrative controls**
3. **Consequences of deviation**
4. **Steps required to correct or avoid deviation.**

UCIL FAILED TO DELIVER AN EFFECTIVE ERP.

EMPLOYEE PARTICIPATION

- Period of safety training **was reduced from 6 months to 15 days**
- **Neglection** of specific instructions
- **Failure to** communicate
- Giving orders **without comprehending** the nature of task
- **Not taking** efficient corrective measures
- **Poor perception** of risks severity
- Manpower in safety and maintenance was **reduced to save cost.**

INHERENTLY SAFER DESIGN

REPLACE SOURCE OF HAZARD

SUBSTITUTE

HAZARD ASSESSMENT NOT HIGHLIGHTED BY:

1. UCIL
2. LOCAL AUTHORITY

Feasibility and safety levels of UCIL plant

UNDER-DIMENSIONING OF SAFETY FEATURES

Bhopal – my United Nations experience

Richard Shone, CEng, FIChemE, UK

In 1984, I was working for the UK Health and Safety Executive (HSE) as a Principal Inspector of Factories in charge of the Chemical Group in the West Midlands. As such I had a number of Major Hazard installations on my patch, designated by the relatively new CIMAH Regulations (Control of Industrial Major Accident Hazards). When the Bhopal disaster happened in December that year, aside from my humanitarian concerns over the terrible loss of life, I was professionally concerned to understand how this shocking event had occurred. Was it conceivable that such a major accident could occur in a densely populated area like the West Midlands? I was soon to be involved a great deal more as in May 1985 I was seconded by the HSE to assist the ILO (International Labour Organisation) in Geneva with their post-Bhopal work. Inevitably some of my recollections are a little hazy but I'll do my best to record the key events.

As background, the United Nations had become increasingly concerned about the occurrence of major accidents with off-site consequences. This started with the release of dioxin from the Seveso plant in 1976, followed by the LPG fires & explosions at the installation in Mexico City in November 1984, then Bhopal in December 1984. Accordingly, the ILO, UN's branch whose remit covers Health & Safety, Workers' Conditions etc., was tasked to produce international guidelines on control of major accident hazards. The ILO's modus operandi is a tripartite system of consultation whereby the views of workers, employers and governments are given equal weight. The aim is to develop ILO Conventions, which, whilst not being legally binding, would be ratified by UN member countries to provide guidance for legislation in their own countries.

The start of this process was to hold a special tripartite meeting of consultants in October 1985 to produce guidance on the steps necessary to establish control systems for prevention of major accidents with particular relevance to developing countries. My job was to produce a Working Paper for the October meeting for review and hopefully adoption by the delegates to support the ILO initiative.

The ILO occupies a magnificent building in the UN complex in Geneva, with an equally magnificent support infrastructure including translation services, extensive library, travel agents, top-class restaurants etc., and within all of this, I was to report to the Head of Sec Hyg (Safety & Health). The ILO undoubtedly had expertise in the field of Occupational Safety but virtually none in the field of Process Hazards Management. After a short briefing and introduction, I was given the good old-fashioned resource of a desk, a blank sheet of paper and a deadline for the October meeting. The managerial system at the time was very hierarchical and access to heads of departments was always via rather fierce French-speaking secretaries. This was quite a test for my 20-year old GCE O-level in French, and I had several "mangetout Rodney" moments before my fluency improved!

At the time, even in the ILO, knowledge of the disaster was limited to the following:

- Water had inadvertently leaked into a large storage tank of MIC (Methyl Isocyanate)
- This had caused an uncontrolled runaway exothermic reaction
- This in turn caused a pressure burst of the tank releasing a huge cloud of toxic gases over a slum development that had grown up around the plant
- The toxic cloud had caused an estimated 2500 deaths and a further 30,000 cases of severe respiratory problems
- There had been a widespread failure of control systems.

However, the role of the ILO was not to investigate the incident or apportion blame so the lack of knowledge of the underlying causes was not a hinderance to my task. Indeed, even if the ILO had requested it, access to the site was impossible as it had been placed under strict police and military control.

Accordingly, an agenda was set for the meeting as follows:

Tripartite Ad Hoc Meeting of Consultants on Prevention of Major Hazards in Industry –
15 to 21 October 1985

1. Recent developments in major hazard control methods:

(i) Identification of major hazards in industrial processes
(ii) Assessment and analysis of major hazards
(iii) Management of major accident prevention systems
(iv) Emergency operations

2. Future action to avoid major accidents

These were the days before the advent of emails and mobile phones, so I worked largely on my own, albeit with the long-distance support of HSE specialists in MHAU (Major Hazards Assessment Unit) via the wonders of the fax machine!

This was not a handicap though as my experience of the CIMAH Regulations and my understanding of process hazards as a chemical engineer was more than sufficient to enable me to produce the Working Paper in readiness for the meeting. (If anyone is interested, the *Working Paper*, *Meeting Report*, and *Tripartite Meeting report* can be accessed).

Fifteen consultants were invited to the meeting, five each from workers, employers and government bodies from India, Netherlands, USSR, USA, Australia, Belgium, Nigeria, Venezuela, Norway, France, Canada and Sweden representing quite a global reach. Additionally, there were

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24 representatives of different UN organisations, making 39 attendees in total.

The elected chairman of the meeting was Tony Barrell, Head of MHAU, who would later become a President of IChemE.

The meeting comprised of full days until 21 October and each day my Working Paper was thoroughly reviewed by the delegates. I remember being very impressed by the depth of concern over the disaster and the breadth of experience they brought to the table. My job then was to capture all their comments and suggested amendments. This entailed working with ILO support staff every night until about 3.00 a.m. next morning to have freshly printed copies of the amended Working Paper ready for the next day's discussions.

I am pleased to remember that my Working Paper withstood the overall scrutiny and subject to the above amendments, was formally adopted by the ILO Governing Council as a way forward to developing a Convention.

I had one remaining task in the ILO before returning to my old job. This was to attend an Asian Regional Workshop in November in Bombay (now Mumbai) to advise factory inspectors, labour inspectors and technical specialists from the region on control systems for major hazards and to assist them in setting up national training activities. My Working Paper was used as basis for the Workshop.

I finally returned home in December and the whole, profound experience had certainly changed my horizons. Uppermost in my mind was the belief that with the possible exception of uncontrolled dwellings around the site, Bhopal was not a uniquely Indian incident. Where major hazard potential exists, then without proper controls, a major incident could happen anywhere. Back in HSE, I attended the Arthur D. Little conference in London where they presented their findings on Bhopal. I was dismayed to hear the sabotage theory presented that water had been deliberately diverted into the MIC tank by a disgruntled employee and that the world's worst chemical disaster could not have been prevented. I was appalled that this conclusion even got a standing ovation from some attendees. Much has been learned subsequently about the causes of Bhopal and I won't repeat those here, suffice to say that with so many failures of safety systems on the plant, in my view the sabotage theory can be consigned to the bin of conspiracy theories.

I left the HSE in 1987 to rejoin industry as General Manager, Group Safety & Hazards with Laporte plc, then ten years later I joined Innospec Inc as Vice President SHE. Both companies had global chemical plants with major hazard potential. It is an old cliché but in my role of gamekeeper turned poacher (I prefer ghillie), some key lessons I learned from my Bhopal involvement stayed with me as follows:

Key lessons

1. Through thorough hazard assessment and evaluation, establish a clear understanding of the top tier worst case scenarios and how they can occur.
2. Establish a basis of safety for preventing/controlling these scenarios with clear distinction between the role of engineering controls and procedural controls requiring human intervention.
3. Have robust systems of change control to ensure that inevitable changes on a plant, do not compromise 1 and 2 above.
4. Recognise the importance of technology transfer. Expertise that can deliver 1 and 2 above, may not be so readily understood in a different country and culture.

The devil of course is in the detail, but my experience is that these simple concepts really do work in practice and will develop the understanding necessary to prevent major hazard accidents at all levels.

As a couple of final postscripts — firstly, I was pleased that the ILO Convention was finally produced, now titled Prevention of Major Industrial Accidents 1993 (No 174).

Secondly, I was very concerned to read in Fiona Macleod's paper in LPB issue 294, December 2023 that it appears no action has been taken to remediate the site since the incident. There is evidence of widespread chemical contamination with attendant risks to the health of the local population who have surely, already suffered enough. Clearly, forty years later, there is still work to be done get closure on Bhopal.

Comment

Remembering the people behind the numbers

Geraldine Lee, Professor of Nursing and Chair of Health Services Research, University College Cork, Ireland

In this fast-moving world where news cycles are in real time, the ongoing suffering of victims of disasters is quickly forgotten as the world focuses on the next breaking news story. The appetite to explore and understand the long-term chronic effects of disasters on a population is practically non-existent.

On the 40th anniversary of Bhopal, the town is synonymous and inextricably linked with the deaths of thousands and injuries of hundreds of thousands following their exposure to methyl isocyanate (MIC). The acute presentations relating to MIC exposure were eye damage and breathing problems. With no clinical data available on the long-term effects of chemical exposure, there were no evidence-based guidelines on how to assess or treat these people's symptoms.

Concern about possible carcinogenic and teratogenic effects shifted the focus to examining the surviving generations through the scientific lens. However, the research approach was primarily surveillance so that maternal issues that included birth defects, miscarriages and issues with child development could be recorded. However, record keeping was poor and publishing discouraged.

With no data on the exact composition of the gases released or understanding of the possible long term side effects and no proper monitoring, those complaining of chronic health issues were seen as opportunistic individuals seeking compensation.

Unusually for research, there were no efforts to undertake any interventions or to reduce the risk of birth defects. Critically, this approach did not attempt to reduce the ongoing health issues but is very much a passive approach that does not capture the trauma in the community, for indeed, that is what the people in Bhopal are — survivors of an environmental disaster who have suffered an unimaginable trauma. One paper published the lived experience of those affected by the Bhopal disaster and one survivor stated, quite poignantly: 'I Used To Be Human Once.[1]'

In large scale disasters, it is easy to forget that those affected are fellow humans with aspirations, ambitions and the desire to live long and healthy lives, just like the rest of us. The tragedy of Bhopal is the lack of subjective-based research that would have captured the lived experience of those who had family members who died and those who survived and the daily impact on them. Qualitative research gives people the opportunity to express themselves without any restrictions that are often associated with quantitative research which can have a reductionist effect and reduce people to being a statistic. However, with Bhopal, no record keeping was done and therefore there is no rigorous quantitative research. A recent paper that assessed men who were in-utero at the time of exposure found they had a higher rate of developing disabilities and developing cancer. They also reported that women continued to have gynecological and reproductive issues. Critically, the authors noted the multi-generational effects with lower educational level and higher rates of unemployment highlighting the social cost of the disaster decades on[1].

The focus on examining conditions related to MIC exposure is unquestionably important but it should not detract from the psychological and emotional concerns of the Bhopal community. The organisations that have been working 'bottom-up' inside the local communities, addressing the immediate needs of those affected, identified the longer-term needs for the entire community. Unfortunately, they were often not listened to, and the lived experience of Bhopal residents has only recently been acknowledged[2]. Earlier systematic and focused research into the detrimental effects on Bhopal residents could have alerted the state to funding and improving maternal and child health services.

In the case of Bhopal, the underlying key determinants of health and well-being, poverty was not addressed, and the legacy of Bhopal continues to this day with the practical issues of contaminated groundwater and children born with developmental and congenital conditions and limited healthcare resources. The abandoned factory serves as a daily reminder to the Bhopal people that continues to reinforce their poverty and inability to change their circumstances and improve their health.

'Lessons learnt' is an overused term and the Bhopal disaster clearly highlighted the lack of a community-based approach with poverty remaining a key driver and impacting on quality of life. Some researchers who have undertaken work in Jai Prakash Nagar have suggested that due to the intergenerational health impacts, the children of survivors should have access to free healthcare. Despite the Indian Government promising this, the state of Madhya Pradesh has not complied. This approach would allow better surveillance and ensure early detection of health-related problems. Community based partnerships do not have to be expensive, but they do need to be truly collaborative and engaging partnerships that aim to improve the physical and psychological and social quality of life of the population. Critically this needs to be done whilst ensuring the physical environment around Bhopal is safe, especially with the water supply and the soil.

Bhopal is perhaps unique in that despite the amount of time that has passed since the 1984 accident, the long-term effects remain evident. Amnesty International released a report which outlined the social injustice in detail and made some key recommendations.[3] Through these reports and further research, the legacy of Bhopal can be changed and a voice given to the community.

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[2] *https://brill.com/display/book/edcoll/9789004407947/BP000013.xml*

[3] *Amnesty International: Bhopal: 40 Years of Injustice - Amnesty International*

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Background for *Butterflies of Bhopal*

Ramin Abhari, Chevron Renewable Energy Group, US

In 2018 I posted a graphical short story about the chemistry of Bhopal[1]. It imagined an employee from the Union Carbide Technical Center in South Charleston, West Virginia, visiting the local high school during commissioning of the Bhopal plant to give a talk about the magic of chemistry.

The fictional visitor, "Dr Bruce", chose to talk about how Carbide researchers improved their carbaryl pesticide process by simply changing the sequence of reactions. Instead of reacting phosgene (A) with alpha-naphthol (B) to make *naphthalene chlorformate* that was then reacted with methyl amine (C) to yield the desired carbaryl pesticide (old process), they now reacted phosgene (A) with methyl amine (C) to make *methyl isocyanate* that was then reacted with alpha-naphthol (B) to make the same end-product carbaryl, but at higher yields and with fewer byproducts. This allowed use of much of the same equipment except that they had to store a different intermediate— methyl isocyanate (MIC).

Dr Bruce had just mentioned that they did not store phosgene due to its toxicity. Presented with some chemical safety information, one of the fictional students, Monique, questioned whether MIC wasn't more like phosgene than naphthalene chlorformate, and why they decided to store it like naphthalene chlorformate instead. He responded by describing how the MIC storage tank was designed with multiple advanced safeguards and leaves it at that.

That Union Carbide presentation four years before the tragedy, and their connection to the place that developed and continued to make carbaryl pesticides, encouraged Monique and a fellow fictional student to learn more about what went wrong in Bhopal. Not finding a consistent explanation in books and articles, they decide to travel there to see what they could find out for themselves.

Inspired by Dominique Lapierre *5 Minutes Past Midnight*[2], Themistocles D'Silva *Black Box of Bhopal*[3], Kenneth Bloch's book *Rethinking Bhopal*[4] and Fiona Macleod's articles in LPB[5,6], my new graphic novel, *Butterflies of Bhopal*[7], is the story of two outsiders trying to make sense of the tragedy and its aftermath. In doing so, they imagine the different "theories" play out during the 2-3 December 1984 night shift at the plant to see which was more likely.

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7. *Butterflies of Bhopal: https://www.linkedin.com/pulse/butterflies-bhopal-ramin-abhari-p-e--htawc/*

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A local story from the Chingari Trust

Syed Tabish Ali, India

About the Chingari Trust

The Chingari Trust is a non-profit, non-political organisation that uses all of its available resources for the welfare of community members. As a charitable trust, Chingari does not participate in political activities as its main purpose is to work with the victims of the Bhopal gas disaster and local communities that are affected by the continuous industrial hazards present as a result of the abandoned Union Carbide factory. More specifically, the Chingari Trust supports marginalised sections of society, including women and children, without discrimination on the basis of caste, creed or religion. For further information, see www.chingaritrustbhopal.com and www.bhopal.org/the-clinics/the-chingari-trust/

Perspectives of a Chingari patient

In this article, Mr Tabish interviews Mr Mahesh Tiwari, whose two children have attended the Chingari rehabilitation centre. Mr Tiwari explains:

"When my family and I were exposed to gas on the night of the Bhopal Gas Disaster, I was between five and six years old. Speaking a lot still causes me to experience pain and burning in my throat. We moved to Navjeevan Colony, a community with poisoned ground water, when I was around fifteen. The groundwater here used to smell bad, but at first, we had no idea that it had been poisoned. We later learned that the groundwater at Navjeevan Colony is contaminated through gas survivor organisations. Even after learning that, we had no alternative water supply, so we had to use that water – we had no choice.

My two children are an 18-year-old daughter named Disha Tiwari and an 11-year-old boy named Rishi Tiwari. After surveying Disha's ears when she was five years old, representatives from Sambhavna Trust informed us that her ear pattern suggested an intellectual disability. We told them she looked perfectly fine, although we were shocked at the time. After that, we sought advice at 1250 (Jai Prakash District Hospital), where they verified that she would experience a delay in her mental development due to an intellectual disability.

Similarly, when Rishi (Disha's younger brother) was five years old at that time, he was able to speak simple words like mummy, papa, etc. but was not able to speak complex words with difficult pronunciation and did not socialise with others. We consulted 1250 Hospital once more for him. After a few inquiries about our residence and other details, the staff there asked us to take him to Chingari Trust for therapy. He used to have speech therapy, but he became unwell in between and was unable to walk normally. His physiotherapy has since begun and he has now started talking a lot and has become quite active.

Disha Tiwari – Silver Medallist at the Special Olympics World Games and patient at the Chingari rehabilitation centre.

Before coming to Chingari, Disha could not even hold a pencil, and all her teachers said they would not be able to educate her. However, she learned how to use a pencil and interact with others at Chingari after enrolling there. She couldn't even hold a ball, but she learned how to play and hold the ball at Chingari Trust. She gained so much knowledge there that she travelled to Berlin, Germany for the Special Olympics World Games in 2023 to play basketball — returning with a silver medal!

We are so proud of her and grateful to the entire Chingari Trust personnel for their support. We hope that Disha will be able to impart whatever knowledge she has learned to other kids who will be attending Chingari Trust and that she will maintain a lifelong relationship with them."

There are currently over 1300 special children registered with Chingari Trust; however, due to resource constraints, only 300 of these children can be treated on a regular basis, offering them free physiotherapy, speech therapy, sports, special education, midday meals, pick-up and drop-off services, occupational therapy, and other facilities. If the three hundred children can demonstrate progress, then so can the other children who are registered and the numerous other children who were born into homes affected by gas and water contamination, if provided with proper treatment, love, and care.

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OECD Chemical Accidents Programme

Mark Hailwood, LUBW, Germany

In the aftermath of the Bhopal disaster a range of initiatives were taken up by the international community, in particular by the inter-governmental organisations such as the International Labour Organisation (ILO) and the UN Environment Programme (UNEP), with ILO focussed on an approach closely modelled on the activities within the European Economic Community (EEC) at the time and UNEP focussing on the impacts on the local communities and developing what became known as the APELL — Awareness and Preparedness at Local Level Programme.

Another organisation, the Organisation for Economic Cooperation and Development (OECD), more widely known for furthering the cooperation between industrialised and developed economies, also recognised that action was required. At the OECD Environment Committee that met at Ministerial Level in June 1985, the OECD Governments declared that:

> *"they will ensure the existence of appropriate measures to control potentially hazardous installations, including measures to prevent accidents."*

In December 1986, the committee called on the High Level Meeting of the Chemicals Group (HLMIII) scheduled for March 1987 to provide further guidance on the subject.

HLMIII concluded that there is a need for international action related to chemical accidents. It noted that not only is there a risk that an accident will have transboundary effects, but also that it is critical for policymakers in this area to learn from the experiences of others. The meeting welcomed the offer of the French delegation to host a high level conference on the subject to provide guidance and impetus for OECD efforts, recognising that OECD provides an effective forum for strengthening national and international efforts in light of the experience and expertise that exists in OECD member countries.

Accepting the recommendations of HLMIII, the Environment Committee established a group of national experts to prepare for the conference and elaborate a proposed programme of work, taking into account activities of other organisations.

The conference was held in Paris in February 1988 with the objective of strengthening national and international policies related to accident prevention, preparedness and response.

The conference:

- reviewed measures for improving the safety of hazardous installations;
- agreed on an outline of policies and proposals for national and international action;
- agreed on the content of two OECD Council Acts;
- recommended that a code of good practice be developed;
- agreed on ways to strengthen national efforts and agreed on the general responsibilities that public authorities, operators of hazardous installations and workers have in this respect; and
- called on OECD to establish a forum for international cooperation while identifying an ambitious list of activities.

The Environment Committee agreed with the recommendations of the conference and, as a result, created an "ad hoc Group of Experts" to carry out the work for a three-year period.

The terms of reference for the Working Group specified that the work should be made available to benefit both OECD member and non-member countries; that OECD should work to increase world-wide co-operation in this area, and that the OECD should maintain close working relationships with other international organisations.

Thus, the OECD Chemical Accidents' Programme was initiated. The Programme extensively relies on the technical contributions and expertise of delegates from countries to carry out its activities. This has not limited the willingness and commitment of the OECD Working Party on Chemical Activities to work towards improving the management of chemical accident risk through holding workshops and conferences, developing and publishing guidance and publishing reports.

Guiding Principles for Chemical Accident Prevention, Preparedness and Response

The main publication of the *OECD Chemical Accidents' Programme is the OECD Guiding Principles for Chemical Accident Prevention Preparedness and Response*. The first edition was published in 1992 and brought together a body of knowledge, and recommendations derived from the expertise of member countries as well as through the holding of workshops to bring together representatives of government authorities, industry, academia and civil society. With the publication of the first edition the OECD Working Group on Chemical Accidents, as it was named until 2021, when it became the Working Party, it became clear that there were many aspects of chemical accident prevention, preparedness and response which were not covered in the first edition or were under development and would need to be addressed at a later date.

In 2003 the second edition of the *Guiding Principles* was published. The text was completely revised and extended to take account of a number of workshops which were held to develop good practice and to make recommendations. Workshops were hosted by OECD member countries around the world to address particular topics. These workshops drew together experts and stakeholders from all sectors of society and allowed an open exchange and discussion between the participants, with a focus on involving practitioners and researchers. The workshops usually closed with a list of agreed

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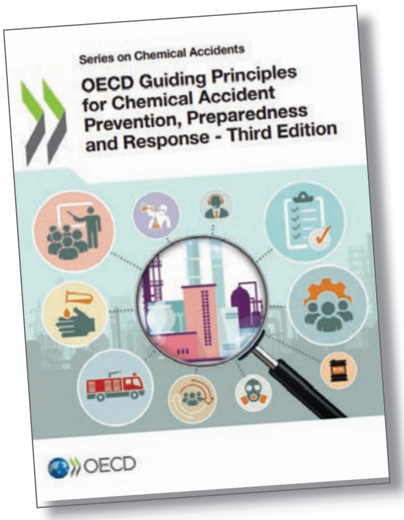
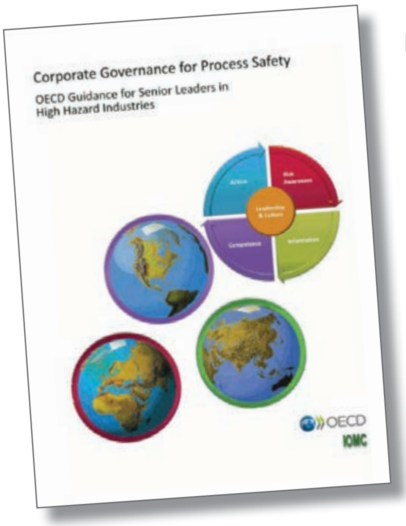
recommendations and a report was published to document the process. This mechanism has been one of the strengths of the OECD Chemical Accidents' Programme and has allowed the programme to address relatively early on some topics which had not reached international attention at the time. The first workshop focused on "Human Factors" took place in Tokyo in 1991, others following in Munich in 1997 and in Potsdam in 2008. The relatively new topic of Natural Hazards Triggering Technological Accidents (Natech) was addressed at the workshops in Dresden in 2013 and in Potsdam in 2018.

In 2023 the third edition of the *Guiding Principles* was published. This edition has concentrated on improving its usability, recognising that the majority of users would not necessarily have English as their native language. In this edition effort has been made to revise the use of language, aiming to improve the consistency of use of terminology. The document has been restructured and illustrated with more diagrams, tables and boxes than in previous editions. As in previous editions, content has been brought up to date and new additions made.


Series on Chemical Accidents
OECD Guiding Principles for Chemical Accident Prevention, Preparedness and Response - Third Edition
OECD

Other guidance documents

Following the banking collapse of 2008, the OECD Working Group faced the challenge of addressing corporate governance and leadership within high hazard industries. The banking collapse was in part attributed to a lack of awareness and oversight of the risks held and managed by the banking institutions. At this time concerns were raised that if a similar situation within the chemical processing industries existed then there was serious potential for a major accident due to lack of corporate governance and leadership. The Working Group established a steering committee and a project group which then developed *Corporate Governance for Process Safety — Guidance for Senior Leaders in High Hazard Industries*. This publication has been translated into twelve languages and influenced several other publications in this field.


Corporate Governance for Process Safety
OECD Guidance for Senior Leaders in High Hazard Industries
OECD
IOMC

Mergers and acquisitions as well as the break-up of larger enterprises raised concerns as to how well chemical accident risk was being managed before, during and after these processes. In 2018 the OECD published the *Guidance on Change of Ownership in Hazardous Facilities*, which considers the whole process from before the organisational change of ownership, through the change process up to and including the post-change period in which many of the impacts may first become apparent.


Guidance on Change of Ownership in Hazardous Facilities
OECD

The webpage for the Chemical Accidents Programme provides further information on the programme and current activities (https://www.oecd.org/en/topics/chemical-accident-prevention-preparedness-and-response.html). The OECD library (https://www.oecd-ilibrary.org/) provides open access to all data, reports and analysis, allowing the sharing of the OECD's work.

Future work

The OECD Working Party on Chemical Accidents continues to work on various aspects of chemical accident prevention, preparedness and response. Two of the next pieces of work, which are nearing completion and will be published soon are:

- *Risks from Natural Hazards to Hazardous Installations (NATECH): A Guide for Senior Leaders in Industry and Public Authorities*
- *Benefits of Regulation for Chemical Accident Prevention, Preparedness and Response - Presenting the Case for Senior Policy Makers and other Stakeholders.*

Both of these documents are directed towards decision makers.

With regard to Natech incidents, it is important that senior leaders in both industry and public authorities recognise that the impact of natural hazards on hazardous installations can lead to serious consequences, and that measures taken early on can avoid such impacts or mitigate their impact.

Good regulation is an important part of chemical accident prevention, preparedness and response. Regulation sets out the minimum requirements, required by society for the siting and operation of hazardous installations. They also form the basis for inspection and enforcement by public authorities. However, regulation should ensure that the responsibility for the safe operation of hazardous installations remains with the operator and is not transferred by implication to the regulator.

In the coming years the Working Party on Chemical Accidents will consider other topics in the field of chemical accident prevention, preparedness and response. Some of these will be new and emerging issues, such as those connected with the increasing use of renewable energy, in particular hydrogen and hydrogen derivatives, including their impact on the risks within port areas due to import and export in large quantities of these products. A topic which is not new, but continues to require attention is learning from accidents. Here, there needs to be a development beyond the reporting and the sharing of information towards learning, which involves change. How this

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can be achieved and what is key to doing so, will be part of the future work programme.

International co-operation

The OECD works in close co-operation with partner agencies. In the field of chemical accidents this is through the Inter-Agency Coordination Group on Industrial/Chemical Accidents, which is an informal forum that brings together international organisations and institutions working on the prevention of, preparedness for, and response to industrial and chemical accidents. The group aims to support co-ordination of the programmes of the participant agencies, improve the use of resources and avoid duplication of work. Along with the OECD, participating organisations include: European Commission (EU), the United Nations Environment Programme / United Nations Office for the Coordination of Humanitarian Affairs Joint Environment Unit (JEU), the Organisation for Economic Co-operation and Development (OECD), the Organisation for the Prohibition of Chemical Weapons (OPCW), the United Nations Economic Commission for Europe (UNECE), the United Nations Environment Programme (UNEP), the United Nations Office for Disaster Risk Reduction (UNDRR), the International Labour Organisation (ILO), and the World Health Organisation (WHO). The European Process Safety Centre (EPSC) also participates as an observer, providing expertise on specific topics.

Conclusions

The OECD remains active in the field of chemical accident prevention, preparedness and response. Through the activities of the Working Party, it has endeavoured to develop standards of expectations for good practice. It has over many years also fulfilled the role of providing a forum and convening meetings to discuss and exchange experience and information. More recently capacity building activities in countries with developing economies have been undertaken.

The OECD knows that the work is not completed. The 3rd edition of the *Guiding Principles and the Decision-Recommendation*, both published in 2023 underline this. Only continued efforts by industry, government policy makers and authorities, and civil society will ensure that major disasters, such as Bhopal in 1984 remain rare events, and that their consequences are limited as far as possible.

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The safe use of bolted flange joints in the major hazard industry

Chris Mellows, Zulu Joint Integrity, UK

Summary

Bolted pipework if designed, installed and maintained properly is very reliable. However, the chemical industry continues to experience accidents as a direct result of process leaks from bolted flange joints. Breach of primary containment has contributed to many serious accidents and environmental incidents.

This paper outlines the most common failures, discusses possible reasons for a decline in UK craft standards, and calls for a return to best practice.

Keywords: Bolted flange joint, leaks, loss of containment

What is a bolted flange joint (BFJ)?

A bolted flange joint (BFJ) is a joining mechanism to maintain a clamping force between two pipes or pipe to equipment. Elements in a BFJ include paired flanges, threaded fasteners (bolts/studs, nuts, and washers), bolt lubricants, and gaskets. The goal of a BFJ is to create a tight leak-sealing load on the gasket material. Typically, BFJs are used for aboveground service for gas and liquids where rigid, restrained joints are needed in pressure system vessels and pipes.

What is the problem?

I am the founder of a specialist joint integrity inspection company and have noticed a worrying trend in the quality of bolted joints in the UK.

We undertake compliance audits and QA/flange inspection — and by doing this we really see the effect of allowing incompetent personnel onto site to work with bolted flange joints. We have seen many bad practices during our fourteen years in business including over-torqued bolts, finger-loose bolts, incorrect size or type gaskets used, no gaskets, three gaskets back-to-back etc. Nothing really shocks us anymore. However, seeing grinding discs used as gaskets on a brand-new project on an upper tier chemical site really made things clear for me in terms of the type of people working on some sites.

An audit of a new powerplant revealed all the above (and worse) - 120 bolted joints failed inspection from a list of 250 flanges. Not good.

And here's a powerful statistic; I've checked all the total numbers of bolted flange joints inspected on COMAH sites in the UK by our company – from 2010 to 2023. It revealed that the percentage defect rate of flanges has significantly increased over the years (see Figure 1), resulting in almost 14% of flanges inspected last year failing QA/QC checks due to the following:

- incorrect size/type gasket

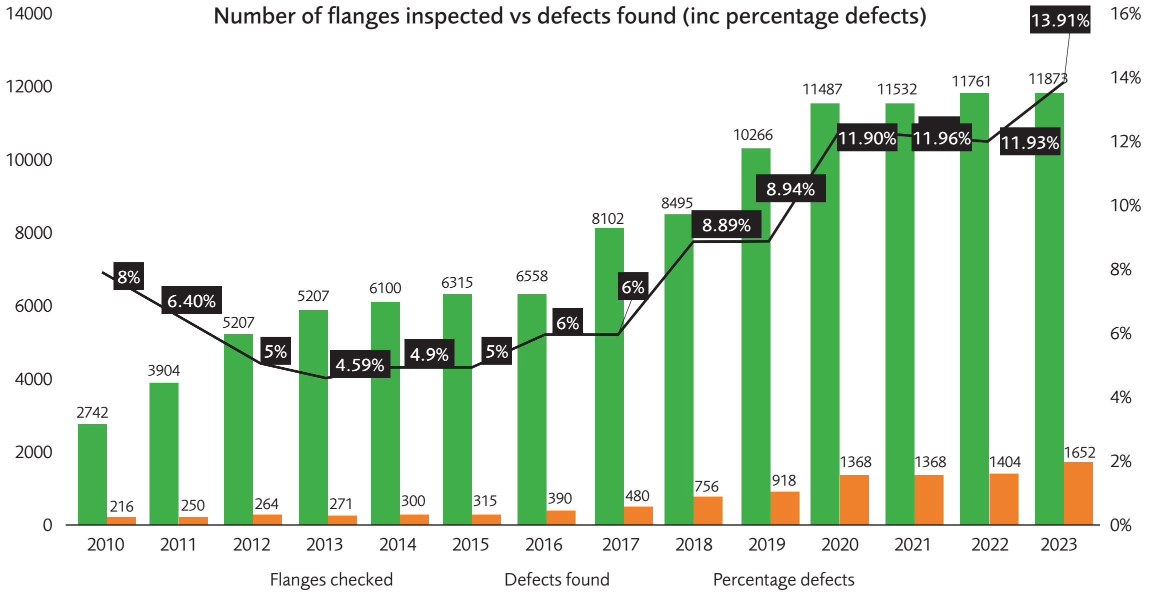

Figure 1: Defects found on bolted flanged joints inspected 2010 - 2023, on COMAH sites in the UK, by Zulu Joint Integrity Ltd

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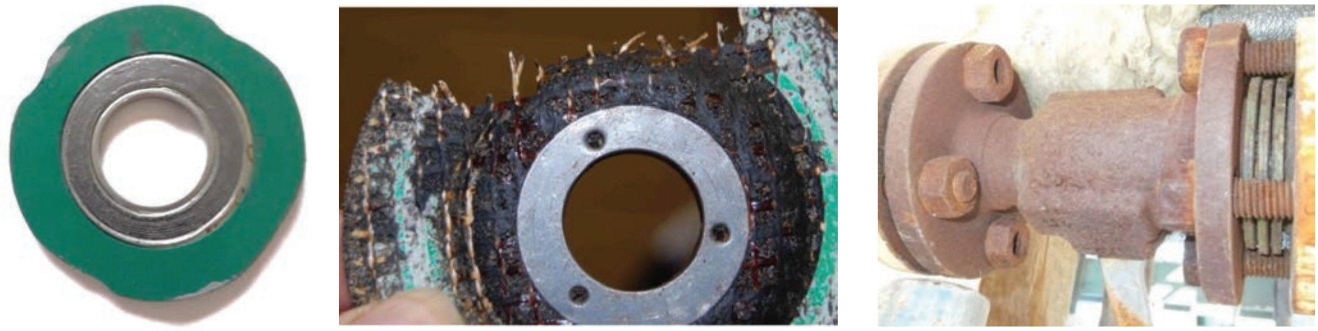

Cut spiral wound gasket *Grinding disc used as gasket* *3 x spiral wound gaskets back-to-back*

Missing bolt *Parallel misalignment*

Overtorqued PTFE envelope gasket *Short bolts* *Over compressed PTFE gasket due to over torquing of bolts*

Figure 2 – Examples of defective bolted flanges on COMAH sites

- no gasket
- more than one gasket in the same flange joint
- dissimilar materials of fasteners
- over-torqued bolts
- under-torqued bolts/finger loose bolts
- no use of bolt lubrication
- misalignment (greater than that outlined by ASME PCC-1 2022).

Corrosion on flange faces also means that flange face re-machining (particularly during turnaround events) is required to ensure the correct sealing surface and seating area for gaskets to perform correctly.

Why is it happening?

COMAH sites are highly regulated. Industry standards and guidelines are readily available and followed. Certified competency-based training courses are available. So why do we see so many non-conformances and defects to bolted joint assemblies and why is UK industry experiencing such a continued number of incidents and accidents directly relating to the mechanical integrity of bolted joints?

The answers are complex. After many years working within the industry and conducting my own research, I conclude that the main reasons are as follows.

Ageing assets (and workforce)

Most sites within the oil, gas and chemical industries in the UK were more than likely built and developed during the early twentieth century. Although new projects have expanded existing sites, most can claim that the first pipework was laid before the 1970s. Both the Grangemouth and Fawley

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refineries can trace their roots right back to the early 1920s. During the twentieth century, these types of industries have provided a solid economy and employed thousands of highly skilled tradesmen and women.

'Time waits for no man' and asset infrastructure such as vessels and associated pipework is no different. As assets get older, the focus on maintenance and integrity should be greater. But is it?

It's not just the equipment that is ageing — the average age of skilled workers (such as welders and mechanical fitters and technicians) has risen over the last ten years. Almost a third of engineers surveyed by IMechE (Institution of Mechanical Engineers) are in their fifties, and in the oil and gas industry alone more than 60% are over the age of fifty. The shortage is exacerbated by the impending retirement of an aging workforce —19.5% of engineers currently working in the UK are due to retire by 2026, leaving a skills, knowledge and experience gap that if not addressed now will have severe consequences[1].

Lack of apprenticeships

In the mid-1960s around 33% of male school leavers aged 15-17 entered some form of apprenticeship program. The decline in engineering apprenticeships from the mid-1970s has almost certainly contributed to today's skills shortage.

It is no coincidence that when it comes to filling permanent vacancies, UK employers have consistently voted engineering and technical in the top three most challenging functions. Figures reported by the Recruitment Employment Confederation (REC) Jobs Outlook monthly report, suggest that concern has been rising steadily over recent years.

Academic learning has been the focus for the last twenty years or so — getting a degree seems to be the route taken over any apprenticeship program.

Who remembers the term 'craft'? Sadly, this is something that is seldom used in industry these days — there are nowhere near enough four year indentured engineering apprenticeships in our UK process industries.

Unskilled workers

In the UK it is anticipated that there is a labour pool consisting of up to 2,500 transient workers — travelling throughout the land working on shutdowns, turnarounds and projects within the oil/gas and chemical industries. Although there will be many competent and well-trained technicians among them, over the past few years there has been a significant increase of unskilled labour.

It is of serious concern that those with no prior experience and little underpinning knowledge of engineering principles are passed off as appropriately trained and competent people to work on assets including pressurised systems.

I remember the days when CVs were altered via a brush of 'Tipp-Ex'; there must have been hundreds of CV's floating around industry with exactly the same layout and content but with different names. It's no different these days — but the forgery is far more sophisticated; I have seen forged HND certificates, CCNSG safety passport ID cards and ECITB mechanical joint integrity qualifications!

My business receives periodic phone calls and emails from potential employers and companies asking for checks on the qualifications of potential employees and although most are fully legitimate and compliant, there have been several checks made over the past two years that revealed forged certificates/documentation.

What does good look like?

Industry approved competency qualifications for bolted joint assembly are as follows;

- ECITB MJI10 (Hand torque bolted connections – dismantle, prepare and secure hand torque bolted connections).
- BS EN 1591-4:2013 Flanges and their joints – (Part 4: Qualification of personnel competency in the assembly of the bolted connections of critical service pressurised systems).
- ASME PCC-1 2022 Appendix A (training and qualification of bolted joint personnel).

The UK Health & Safety Executive (HSE) give extensive guidance on the management of bolted joints (including best practice and data sharing) within several documented guidelines and research reports such as:

- COMAH Competent Authorities – Mechanical Integrity Intervention Tool
- Piping Systems Integrity Management Review – Research Report 253
- Integrity of Pipework Systems Project – UK Refineries
- Offshore Hydrocarbon Releases (2001-2008) – Research Report 672
- Offshore Hydrocarbon Releases (2016-2021) – Research Report
- The safe isolation of plant and equipment – HSG 253

There are several standards and guidelines that relate specifically to joint integrity management and most notably:

- ASME PCC-1:2022 – Pressure boundary bolted flange joint assembly
- The Energy Institute – Guidelines for management of integrity of bolted joints in pressurised systems.
- Step change in safety – Mechanical Joint Integrity: Competence Guidance

These give clear and precise guidance and information for asset owners in all aspects of joint integrity management and the individual elements within that management system such as bolted joint technology and practice, criticality assessment, training and competence, records, data management and tagging, in-service inspection, management of leaks, analysis and review and integrity testing.

A route to competency

There is a marked difference between being 'trained' and becoming 'competent'.

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[1] *Information from IMechE article: https://www.imeche.org/news/news-article/what-do-engineers-earn-small-drop-in-average-salaries-for-uk-engineers#:~:text=The%20average%20age%20of%20engineers,than%2060%25%20are%20over%2050.*
And a survey from The Engineer magazine: https://www.theengineer.co.uk/content/news/how-much-is-a-uk-graduate-engineer-s-salary-in-2018

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Competency can be defined as *"the ability to undertake responsibilities and perform activities to a recognised standard on a regular basis"*. It is a combination of knowledge, skills and experience. Making one bolted joint every six months will not make you competent. Nor will attending a single joint integrity training course and never using the skills.

Ensuring competency should apply to *anyone* who works with bolted flange joints; process operators have been asked to remove and install blank flanges for decades but rarely are they given any form of training. ECITB and Step Change in Safety provide guidance for identifying competency. While this is the benchmark for proving competency in the UK offshore industry, it is widely ignored in the downstream industries.

Where do we go from here?

It is encouraging to hear of incoming UK projects associated with net zero — carbon capture, hydrogen networks, clean energy etc, but the one thing that always makes me nervous is the question 'who will install all the pipework and associated plant/equipment?' If we already struggle to service existing industries, shouldn't we be concentrating on future proofing our skills now?

New nuclear build projects are underway in the UK and Hinkley Point C seems to be already sucking the life out of our more traditional process industries. Over the coming months, the number of skilled people needed to install tanks, vessels and pipework will increase and this is already affecting the current labour pool and the competencies required by industry.

It is my belief, shared by many others, that we need a focused and collaborative approach to the UK skills shortage. An increase in meaningful engineering apprenticeships is a long-term investment and requires a massive focus and commitment from industry.

Asset owners, contractor companies, institutions, regulatory bodies, training providers, OEM's and recruitment agencies should be working together for the greater good. IChemE and IMechE should have far closer collaboration to call attention to loss of containment through bad practice.

Conclusion

On this very poignant 40th anniversary of the Bhopal disaster, shouldn't we reflect on history's dark moments and wrong-doings to prevent re-occurrence?

It is easy for us to look at disasters in foreign countries and point to shoddy work standards and question competencies. However, if we look at the UK process industries, it becomes evident that a reduction in craft skill, training and experience can be seen closer to home.

I can hear my apprentice training manager saying to us; "we don't pump jam and chocolate around these plants" and "it's not a pillow factory!". He was right. Sometimes we need to step back, review and analyse the current situation so we can move forward with a clear, structured plan.

There is no quick fix for the UK skill shortage but recognising that it exists is the first step.

It is the job of the operating company to put processes in place to ensure that mechanical joint integrity best practice is understood and followed and that anyone working with bolted flange joints in pressurised systems in hazardous industries are suitably trained, skilled and competent.

A final thought

In 2019 I carried out a plant inspection and audit that resulted in a rather damning report with several immediate recommendations. Sadly, these recommendations were ignored by senior management and because of this blatant ignorance, a catastrophic loss of primary containment from pipework recorded in the audit resulted in multiple fatalities and injuries the following year. This sad and avoidable loss of life affected me personally but allowed me to be as focused as ever on my quest for compliance.

Nothing would make me happier than for 'industry' (that includes everyone!) to start treating this subject with the seriousness it deserves so that we see a marked step change in attitude, skills and competence. But in the meantime, we will continue to beat the drum of compliance while no doubt continuing to witness poor standards.

Editorial note

In a 1988 paper[1], on the Bhopal accident there is a short sentence that caught my attention.

'an MIC operator was told to wash a section of ... (piping) ... in the MIC manufacturing unit. Because he failed to insert a slip-blind, as called for by plant standard operating procedures, the water supposedly backed up...'

The 'standard operating procedure' also called for a written plan and skilled craft involvement, but the maintenance crew had been taken off shift as the factory ran down to closure.

Process operators are key to making physical isolations in preparation for maintenance or before operational activities like washing. They close and lock valves, open vents and drains. How often do we also expect them to undertake tasks like the insertion or removal of a blank? Without being fully trained? And how often does that lead to error? Or in the case above — omission?

When I started work back in 1983, UK demarcation of craft responsibilities was seen as an old-fashioned restrictive practice. But sometimes I wonder if we've gone too far the other way. When does multi skilling lead to dilution of skill?

Who should be allowed to make or break a bolted joint in a high hazard service and what training is required to ensure they follow best practice?

Fiona Macleod

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[1] *Investigation of large-magnitude incidents: Bhopal as a case study, Ashok S. Kalelkar, Arthur D. Little, Inc. for Union Carbide Corp.*

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Information for authors and readers

Loss Prevention Bulletin

Helping us to help others

- The *Loss Prevention Bulletin* (*LPB*) aims to improve safety through the sharing of information. In this respect, it shares many of the same objectives as the Responsible Care programme particularly in its openness to communication on safety issues
- To achieve our aims, we rely on contributions providing details of safety incidents. This information can be published without naming an affiliated author, and details of the plant and location can be anonymised if wished, since we believe it is important that lessons can be learned and shared without embarrassment or recrimination.
- Articles published in LPB are essentially practical relating to all aspects of safety and loss prevention. We particularly encourage case studies that describe incidents and the lessons that can be drawn from them.
- Articles are usually up to 2500 words in length. However we are also interested in accepting accident reports to be written up into articles by members of the Editorial Panel. Drawing and photographs are welcome. Drawings should be clear, but are usually re-drawn before printing. Any material provided can be returned if requested.
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- Correspondence on issues raised by LPB articles is particularly welcome, and should be addressed to the editor at:

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- Energy

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