Unpacking inequitable distribution of environmental hazards and amenities

Fiona Macleod CEng FIChemE

BHOPAL – A Case Study

The world’s worst industrial accident

What went wrong?

accident prevention, preparedness, response and follow up

Former UCIL Bhopal factory today Photo taken August 2023 – ©thechemicaldetective www.thechemicaldetective.blog

Bhopal UCIL Tragedy

When?	Just after midnight on the night of 2/3 December 1984
Where?	Union Carbide India Limited (UCIL) factory in Bhopal, India
What?	Toxic gas was released into the community
How?	Water mixed with chemicals leading to a runaway reaction
Who?	Thousands died and hundreds of thousands were injured The legacy continues to blight the lives of local people today

Why? – Contributing Causes

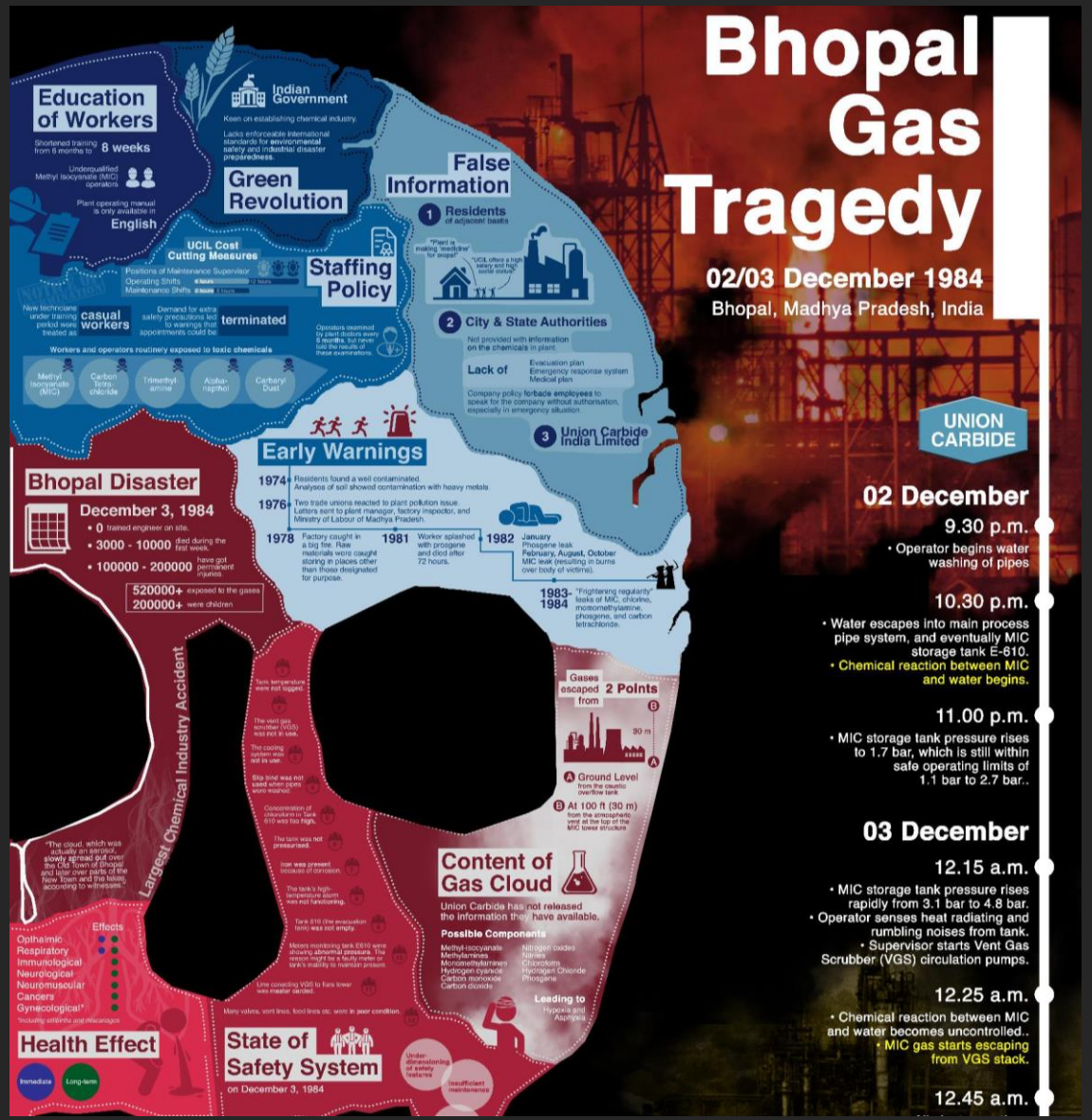
Operational decisions in the 1980s – running to closure

- Increased inventory
- Loss of experienced staff
- Operational workarounds
- Reduced maintenance
- Compromised safety systems

Why? – Root Cause

Design decisions made in the 1970s – Inherent Safety

- Process Hazard Analysis
- Materials of Construction
- Equipment Reliability


Bhopal Gas Tragedy
02/03 December 1984
Bhopal, Madhya Pradesh, India
Education of Workers
Shortened training from 6 months to 8 weeks
Undequalified 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
False Information
1 Residents of adjacent basts
"Plant is making 'weaklings' for export"
"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
UCIL Cost Cutting Measures
Positions of Maintenance Supervisor
Operating Shifts
Maintenance Shifts
Staffing Policy
New technicians under training period were treated as casual workers
Demand for extra safety precautions led to warnings 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
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, monomethylamine, phosgene, and carbon tetrachloride.
UNION CARBIDE
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
Largest Chemical Industry Accident
"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 fakes, according to witnesses."
Effects
Opthalmic
Respiratory
Immunological
Neurological
Neuromuscular
Cancers
Gynecological*
*including stillbirths and miscarriages
Health Effect
Immediate
Long-term
Tank temperature was not logged.
The vent gas scrubber (VGS) was not in use.
The cooling system was not in use.
Bita blind was not used when pipes were washed.
Concentration of chloroform in Tank 610 was too high.
The tank was not pressurised.
Iron was present because of corrosion.
The tank's high-temperature alarm was not functioning.
Tank 610 (the evacuation tank) was not empty.
Meters monitoring tank E610 were showing abnormal pressure. The reason might be a faulty meter or tank's inability to maintain pressure.
Line connecting VGS to flare tower was master carded.
Many valves, vent lines, feed lines etc. were in poor condition.
Gases escaped from 2 Points
B
30 m
A
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
Nitrites
Chloroform
Hydrogen Chloride
Phosgene
Leading to
Hypoxia and Asphyxia
State of Safety System
on December 3, 1984
Under-dimensioning of safety features
Insufficient maintenance
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.
• 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.
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• Chemical reaction between MIC and water becomes uncontrolled..
• MIC gas starts escaping from VGS stack.
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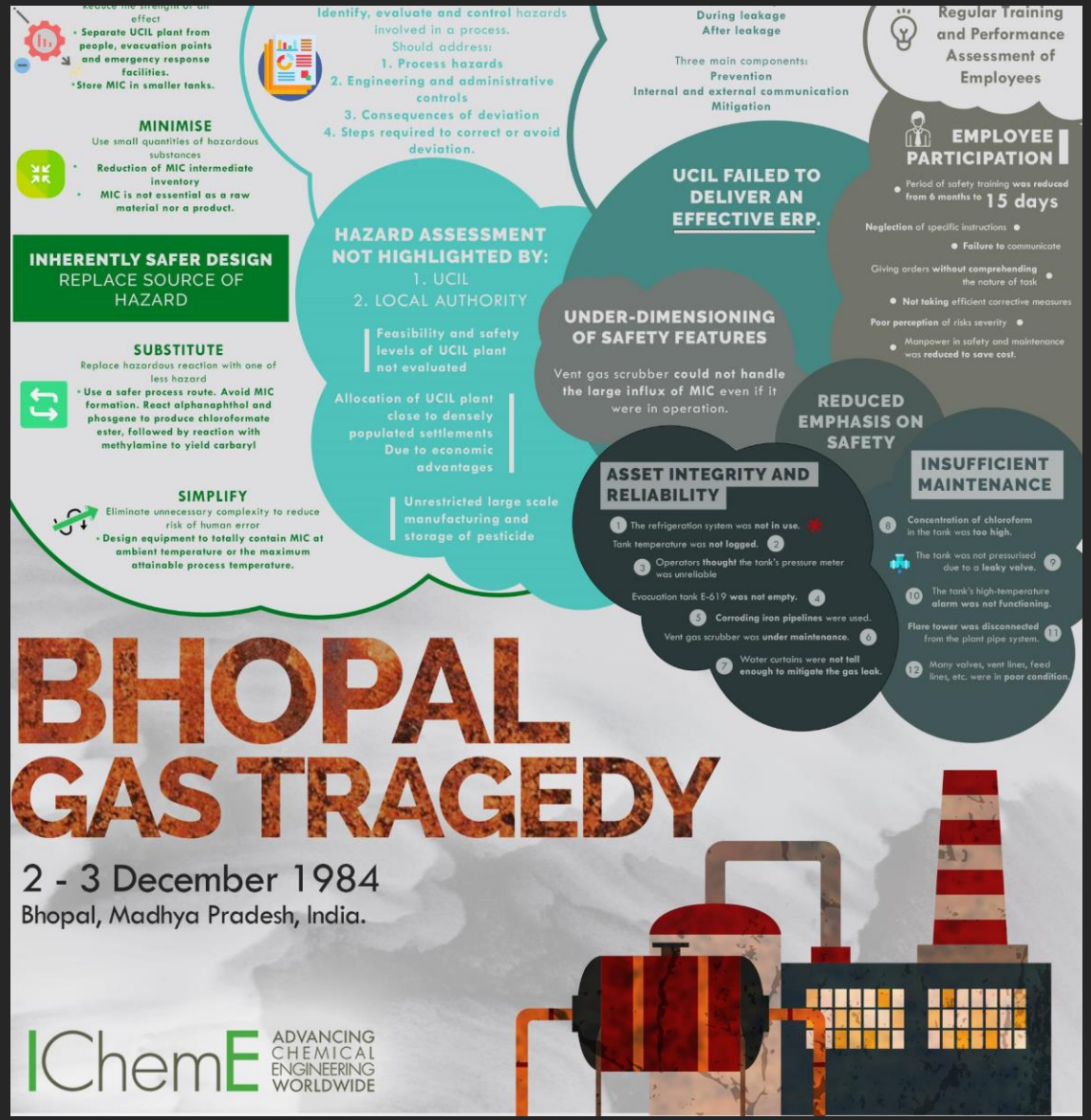
effect
• Separate UCIL plant from people, evacuation points and emergency response facilities.
•Store MIC in smaller tanks.
MINIMISE
Use small quantities of hazardous substances
• Reduction of MIC intermediate inventory
• MIC is not essential as a raw material nor a product.
INHERENTLY SAFER DESIGN
REPLACE SOURCE OF HAZARD
SUBSTITUTE
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.
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.
HAZARD ASSESSMENT NOT HIGHLIGHTED BY:
1. UCIL
2. LOCAL AUTHORITY
Feasibility and safety levels of UCIL plant not evaluated
Allocation of UCIL plant close to densely populated settlements Due to economic advantages
Unrestricted large scale manufacturing and storage of pesticide
During leakage
After leakage
Three main components:
Prevention
Internal and external communication
Mitigation
UCIL FAILED TO DELIVER AN EFFECTIVE ERP.
UNDER-DIMENSIONING OF SAFETY FEATURES
Vent gas scrubber could not handle the large influx of MIC even if it were in operation.
REDUCED EMPHASIS ON SAFETY
Regular Training and Performance Assessment of Employees
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.
ASSET INTEGRITY AND RELIABILITY
1 The refrigeration system was not in use.
Tank temperature was not logged. 2
3 Operators thought the tank's pressure meter was unreliable
Evacuation tank E-619 was not empty. 4
5 Corroding iron pipelines were used.
Vent gas scrubber was under maintenance. 6
7 Water curtains were not tall enough to mitigate the gas leak.
INSUFFICIENT MAINTENANCE
8 Concentration of chloroform in the tank was too high.
The tank was not pressurised due to a leaky valve. 9
10 The tank's high-temperature alarm was not functioning.
Flare tower was disconnected from the plant pipe system. 11
12 Many valves, vent lines, feed lines, etc. were in poor condition.
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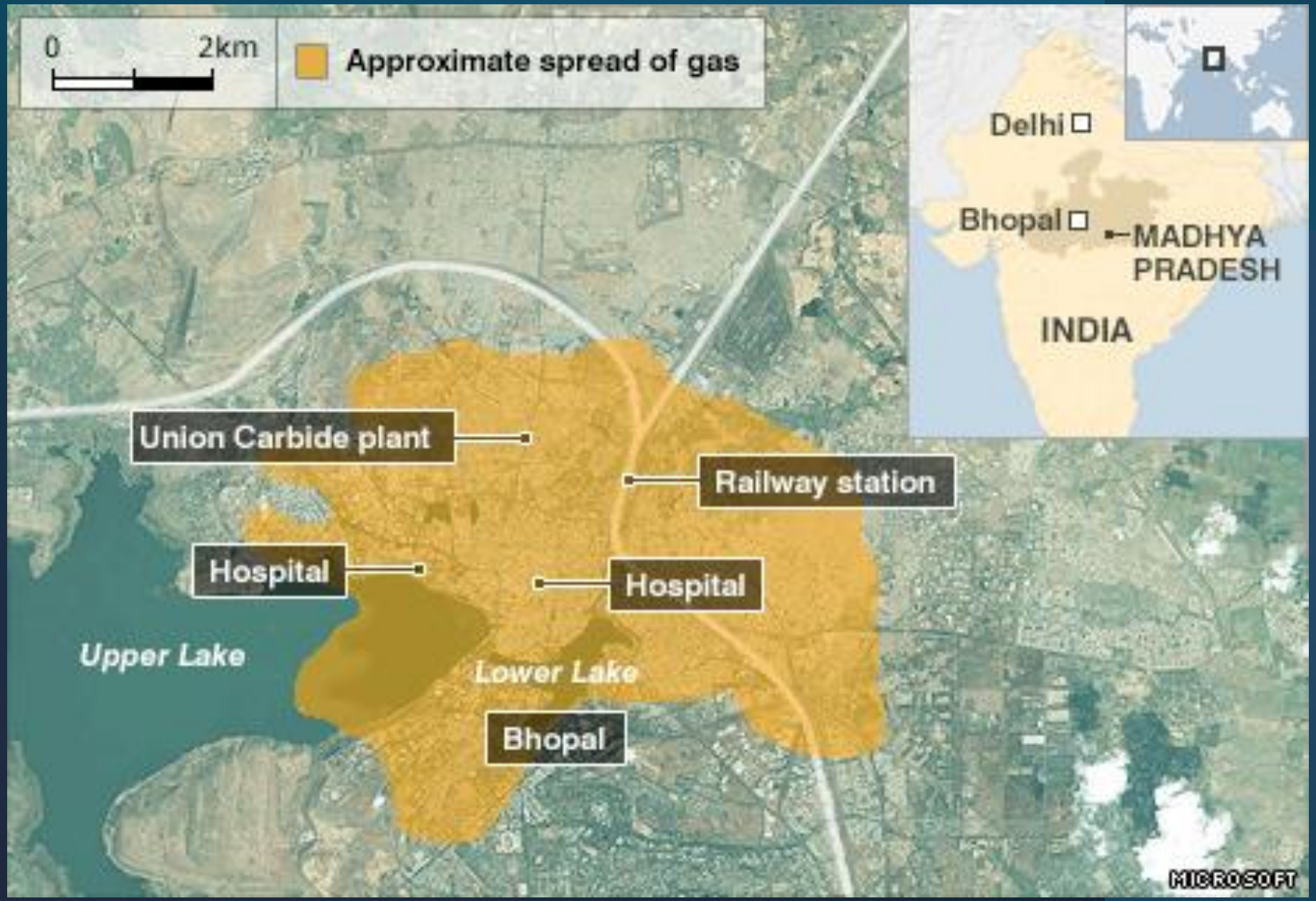

0
2km
Approximate spread of gas
Delhi
Bhopal
MADHYA PRADESH
INDIA
Union Carbide plant
Railway station
Hospital
Hospital
Upper Lake
Lower Lake
Bhopal
MICROSOFT

OECD Guiding Principles for Chemical Accident Prevention, Preparedness and Response

PREVENTING … LOSS OF CONTAINMENT OF HAZARDOUS SUBSTANCES

PREPARING …MITIGATING ADVERSE EFFECTS OF ACCIDENTS THROUGH EMERGENCY PLANNING, LAND-USE PLANNING, AND COMMUNICATION WITH THE PUBLIC

RESPONDING … MINIMISE THE ADVERSE CONSEQUENCES…

FOLLOW-UP …CLEAN-UP … ACCIDENT REPORTING AND INVESTIGATION

Managing change

- Change of ownership
- Closure

Preventing

- Inventory minimisation – what you don't have, can't leak
- Materials of construction – inherent safety
- Equipment specification - reliability
- Instrumented Safety Systems – Independent safeguards
- Management of Change
- Process Hazard Analysis and Risk Assessment

Preventing - Bhopal

Large Quantities of a Hazardous Intermediate (MIC) stored on a site in the middle of a town

Vent gas header constructed of Carbon Steel instead of Stainless Steel

MIC transfer and circulation pumps unreliable

Lack of instrumentation and Independent safeguards

Workarounds common No effective Management of Change

Loss of trained staff Lack of appreciation of hazards

Preparing

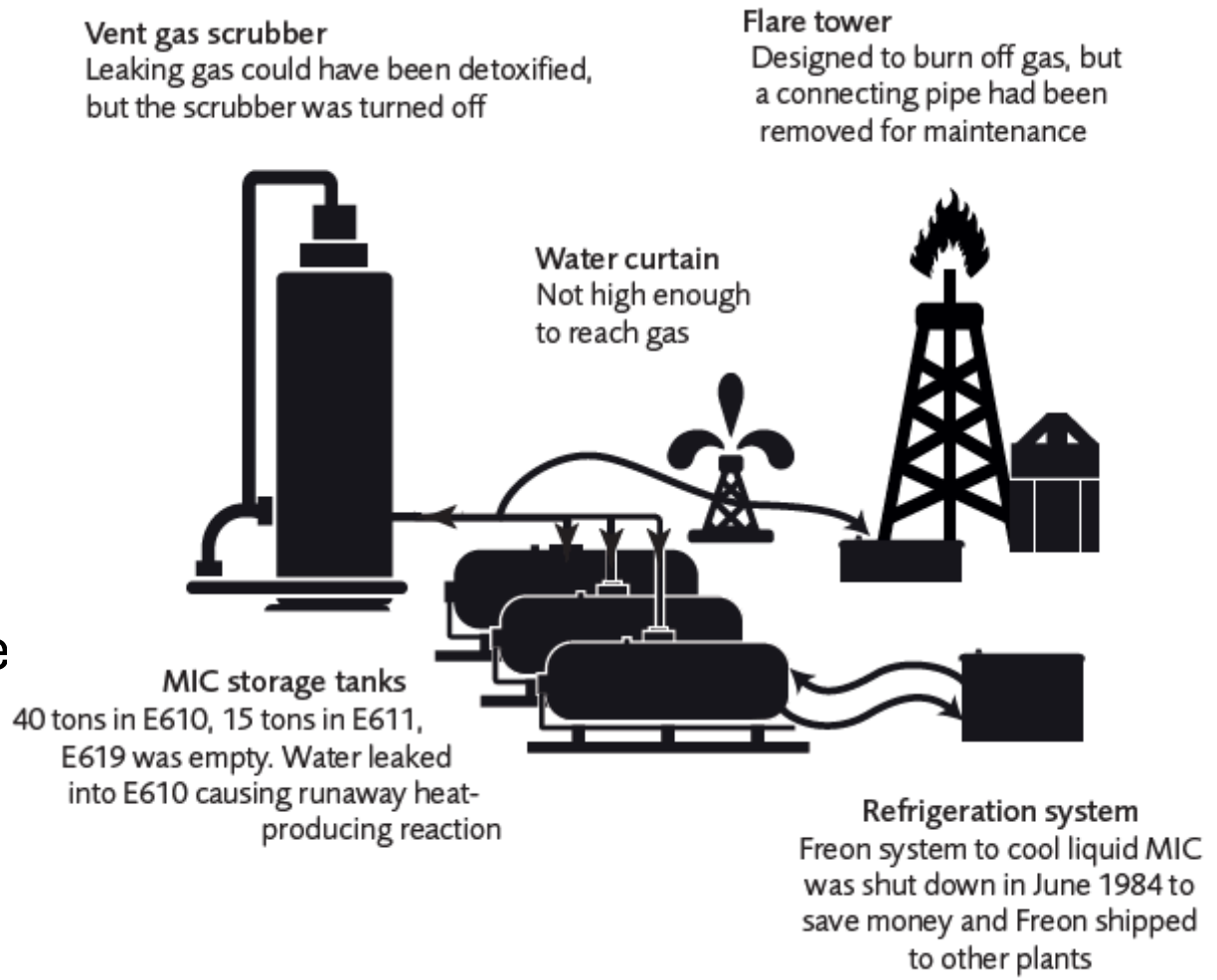
Emergency planning

Land use planning

Communication

Preparing - Bhopal

- Emergency planning
  - Flare disconnected
  - Vent gas scrubber not in operation
  - Refrigeration decommissioned
  - Water curtain pressure insufficient
  - Public alarm silenced
- Land use planning
  - Growth of communities around site
- Communication
  - Limited



Responding

- Alert response personnel
- Trigger the Emergency Plan
- Warn the public
- Limit adverse effects to health and environment
- Effective and open communication with the public

Responding – Bhopal – Too little, too late

- Instrument alarms overridden

- Public alarm system was silenced
- Panicking public left their homes and fled into gas cloud

- Hospitals had no idea how to treat victims

- Compensation was too little and too late
- Health care wholly inappropriate

- Lease terminated before clean up
- Groundwater contamination continues

Follow up

The application of the **Polluter Pays Principle** acts as a major incentive for management of hazardous installations to do everything in their power to avoid accidents

Areas affected by accidents involving hazardous substances should be monitored to determine if there are any **long-term or delayed consequences of acute exposures**

Appropriate epidemiological and **medical follow-up** procedures should be put into place for monitoring and observation of persons exposed to hazardous substances

An **investigation** should be a fact-finding activity to learn from experience, not an exercise designed to allocate blame or liability.

Follow up - Bhopal

- Chemical plant equipment, piping and structures have been left to corrode and are in an increasingly dangerous state.
- There is no meaningful security - access to the wasteland is open to all, including children and grazing domestic animals.
- There are ~350 tonnes of packaged hazardous waste that need to be contained, stabilised and safely destroyed.
- The soil inside the is contaminated, and ground water pollution continues to spread.
- There has been no effective clean-up of the former UCIL site or the external Solar Evaporation Ponds in Bhopal.
- The surrounding communities continue to suffer.

The second tragedy - Environmental

- Environmental problems at the factory predate the 1984 accident
- A failure to maintain the solar evaporation pond barriers or control hazardous waste has led to heavy contamination of the groundwater in and around the abandoned factory with
  - Heavy metals including mercury, chromium and lead
  - Organoclorides classed as persistent organic pollutants
- Many of the communities affected have still not been provided with a reliable source of clean drinking water
- Domestic animals continue to graze on contaminated land inside and outside of the factory
- The ground water pollution continues to spread.

Final Message

Before construction

- Substitute
- Minimise
- Simplify
- Moderate

Build in Error tolerance

Inherent safety by design

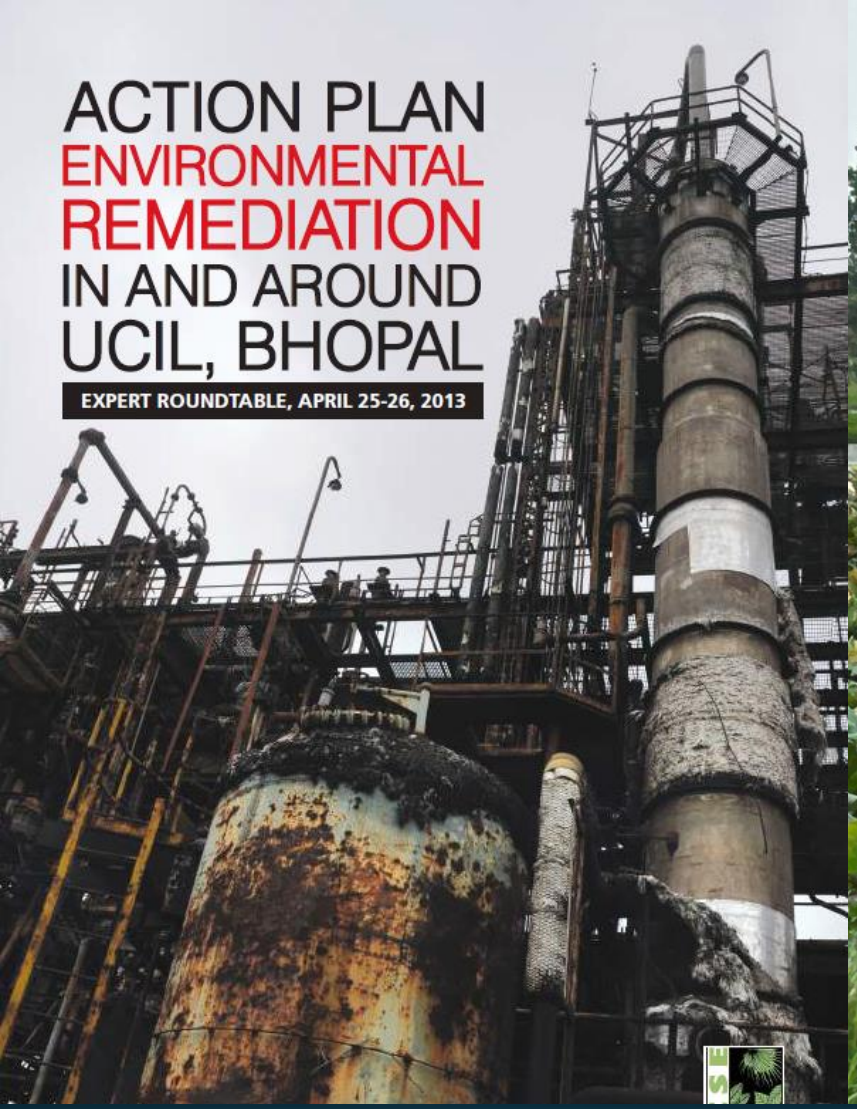
After closure

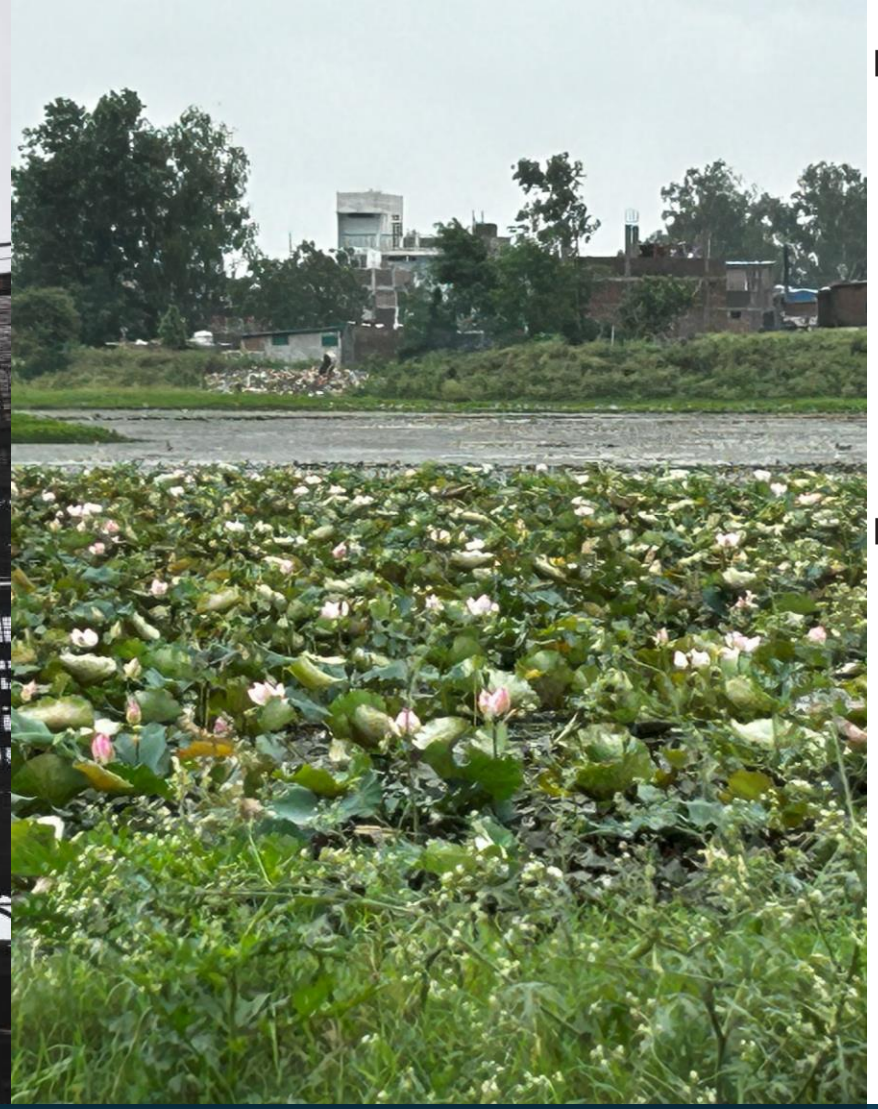
Timely and effective clean-up

How to break the impasse?

- 1989 US$470M settlement brokered by Government did not include funds for remediation
- 1994 US parent company sold its majority share in Indian Subsidiary to fund a hospital
- 1998 State Government cancelled the lease and resumed control of the site
- 2013 Indian NGO outlines steps before environmental remediation can proceed
- 2024 – No progress

- GOI – Government of India
- Parent - UCC – Union Carbide Corporation
- Subsidiary - UCIL – Union Carbide India Ltd
- Buyer - Eveready – Eveready Industries India Ltd
- MP – Madhya Pradesh State Government
- NGO - CSI – Centre for Science and Environment, Delhi, India

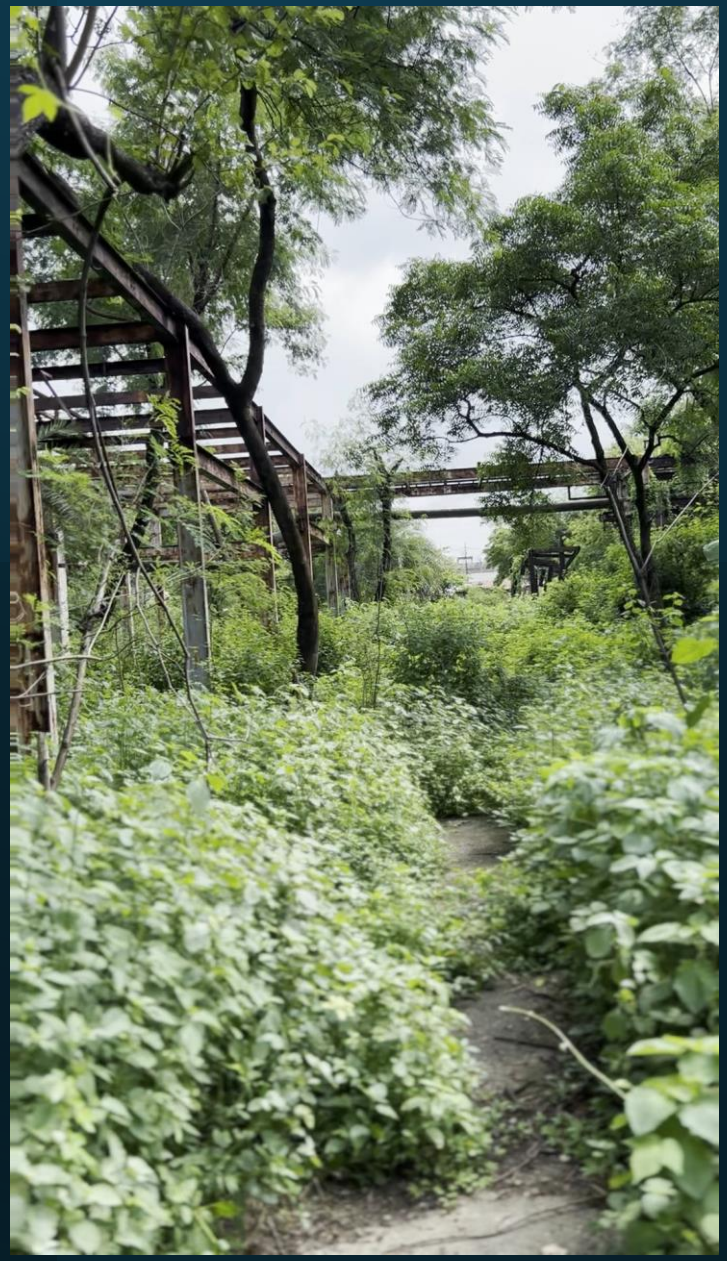




Summary of Action Plan

IMMEDIATE MEASURES	
SECURING THE SITE AND PREVENTING ANNUAL SURFACE WATER RUNOFF	**THREE MONTHS**
Fencing and guarding of the UCIL site and landfill area within the SEP	Immediate
Stopping construction at the SEP area	Immediate
Measures to be taken to protect annual surface water runoff from the site during monsoon	Three months
EXCAVATION, RECOVERY AND CHARACTERISATION OF WASTE DUMPED AT THE UCIL SITE	**SIX MONTHS**
Clearing vegetation and dewatering the site	One month
Identification and refurbishment of a temporary storage area for excavated waste	Three months
Excavation and recovery of dump materials from already identified and new sites	Three months
Recovery of mercury present in drains, pan filters and soil with the help of local community	Three months
Characterisation and inventorisation of the collected waste for proper treatment and/or disposal	Six months
CHARACTERISATION AND INCINERATION OF THE STORED WASTE AT THE UCIL SITE	**SIX MONTHS**
Trial at the Pithampur incinerator with ten tonnes of similar waste from HIL, Kerala	Three months
Characterisation results of the stored UCIL waste to be made public; if required, further characterisation and inventorisation to be done in parallel with the trials	Three months
Waste with high calorific value and hazardous in nature to be incinerated with continuous stack monitoring; remaining waste to be dealt with suitable decontamination/remediation measures	Six months
MEDIUM- AND LONG-TERM MEASURES	
GROUNDWATER CONTAMINATION ASSESSMENT AND REMEDIATION OUTSIDE THE UCIL SITE	**TWO TO THREE YEARS**
Field investigation and lab analysis of the groundwater	One year
Possibility of hydraulic containment to be explored as an interim measure	Six months to one year
Remediation/containment plan to be developed and implemented	Two to three years
CHARACTERISATION AND REMEDIATION OF WASTE DUMPED IN LANDFILL IN THE SEP AREA	**ONE TO TWO YEARS**
Characterisation of waste and development of a basket of disposal/decontamination/remediation options	One year
Disposal/remediation of the waste and decontamination of the landfill area	One to two years
REMEDIATION OF ENTIRE SEP AREA	**THREE TO FIVE YEARS**
Assessment of the need of geohydrological and contamination analysis based on previous reports	Three months
If required, SEP to be studied for waste characterisation and source of groundwater contamination	One year
Development and implementation of the remediation plan keeping residential purpose in mind	Three to five years
DETOXIFICATION, DISMANTLING AND DECOMMISSIONING OF UCIL PLANT, MACHINERY AND STRUCTURE	**TWO YEARS**
MIC plant including the vent, vent scrubber, storage tanks and control room to be strengthened and preserved	Two years
Remaining parts of the site to be decontaminated, dismantled and decommissioned as recommended by IICT	Two years
REMEDIATION AND FATE OF THE UCIL SITE	**THREE TO FIVE YEARS**
Geohydrological and contamination studies for the site based on stratified judgmental sampling	Two years
Development of a basket of decontamination/disposal methods accordingly	Two to three years
Remediation plan based on future use as a memorial and a centre of excellence	Two to three years
An international competition on master planning for conversion of the site	One year
Implementation of the remediation plan and conversion of the site to a memorial and a centre of excellence	Three to five years

No progress on 2013 plan



Videos taken August 2023

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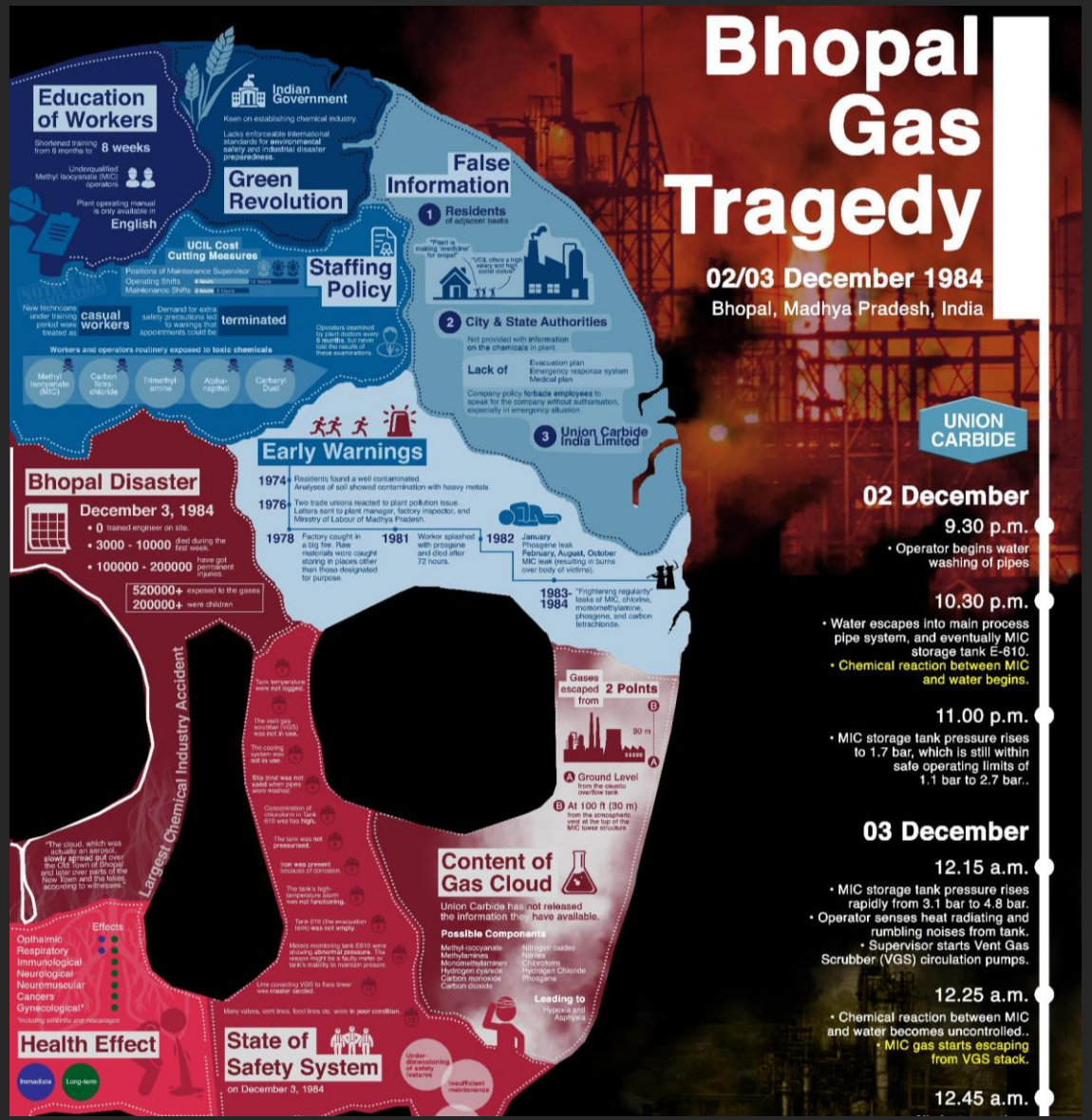
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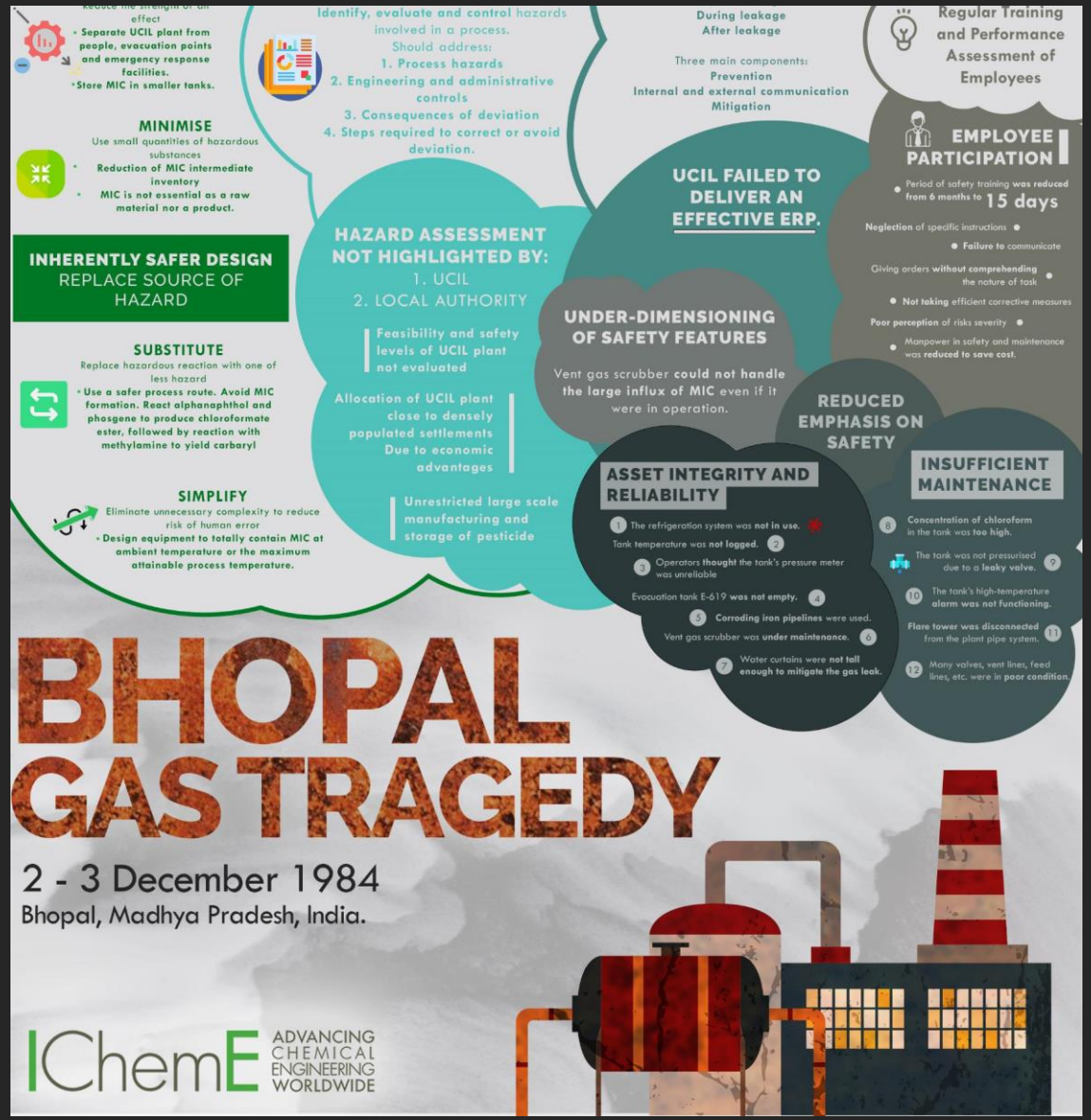
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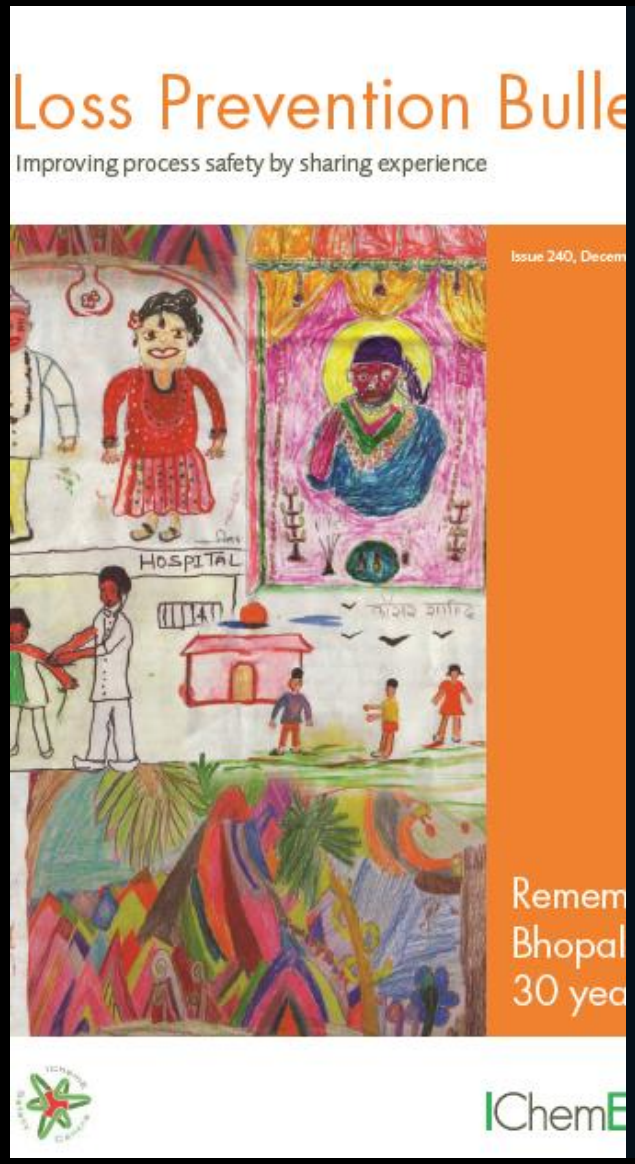


Loss Prevention Bulletin – 30 Years on

https://www.icheme.org/media/1277/lpb240_digimag.pdf

Plan Environmental Remediation in and around

Action Plan CSE India Environmental Remediation Environment*, India*
http://cseindia.org/userfiles/Action%20Plan_Environmental%20Remediation%20in%20and%20around%20UCIL,%20Bhopal.pdf

SEISO Medal – winning student entry
SEISO Medal winning student entry poster
https://www.icheme.org/media/12445/tzelin-sieso-medal-2019-graphic-art-1.jpg

https://www.icheme.org/media/12446/tzelin-sieso-medal-2019-graphic-art-2.jpg

Rethinking Bhopal by Kenneth Bloch

https://shop.elsevier.com/books/rethinking-bhopal/bloch/978-0-12-803778-2

Long-term health and human capital effects of in utero exposure to anindustrial disaster: a spatial difference-in-differences analysis of the Bhopal gas tragedy Gordon C McCord BMJ Open

https://bmjopen.bmj.com/content/13/6/e066733

Appendix

Root Cause Analysis

Equipment reliability

Transfer pumps unreliable

Operational change approved to bypass the MIC pumps

Pumped transfer was changed to pressure transfer

Nitrogen was diverted to pressurise the tank

Circulation pumps unreliable

In line quality sampling stopped

MIC Refrigeration stopped

High Temperature alarms overridden

High pressure ignored

Materials of Construction

Vent header constructed in carbon steel instead of stainless steel

Dry Nitrogen was required to prevent corrosion

However

Nitrogen diverted to provide MIC pressure transfer

Vent header began to corrode

Iron catalysed reactions formed solids (trimer) in the vent header

Backpressure affected the quality of distillate

The vent header was routinely washed with water to remove the solids

Process Hazard Analysis

Phosgene gas risks understood and controlled

Phosgene gas made in-situ and consumed

Original US process involved an intermediate that boiled at 296C

However

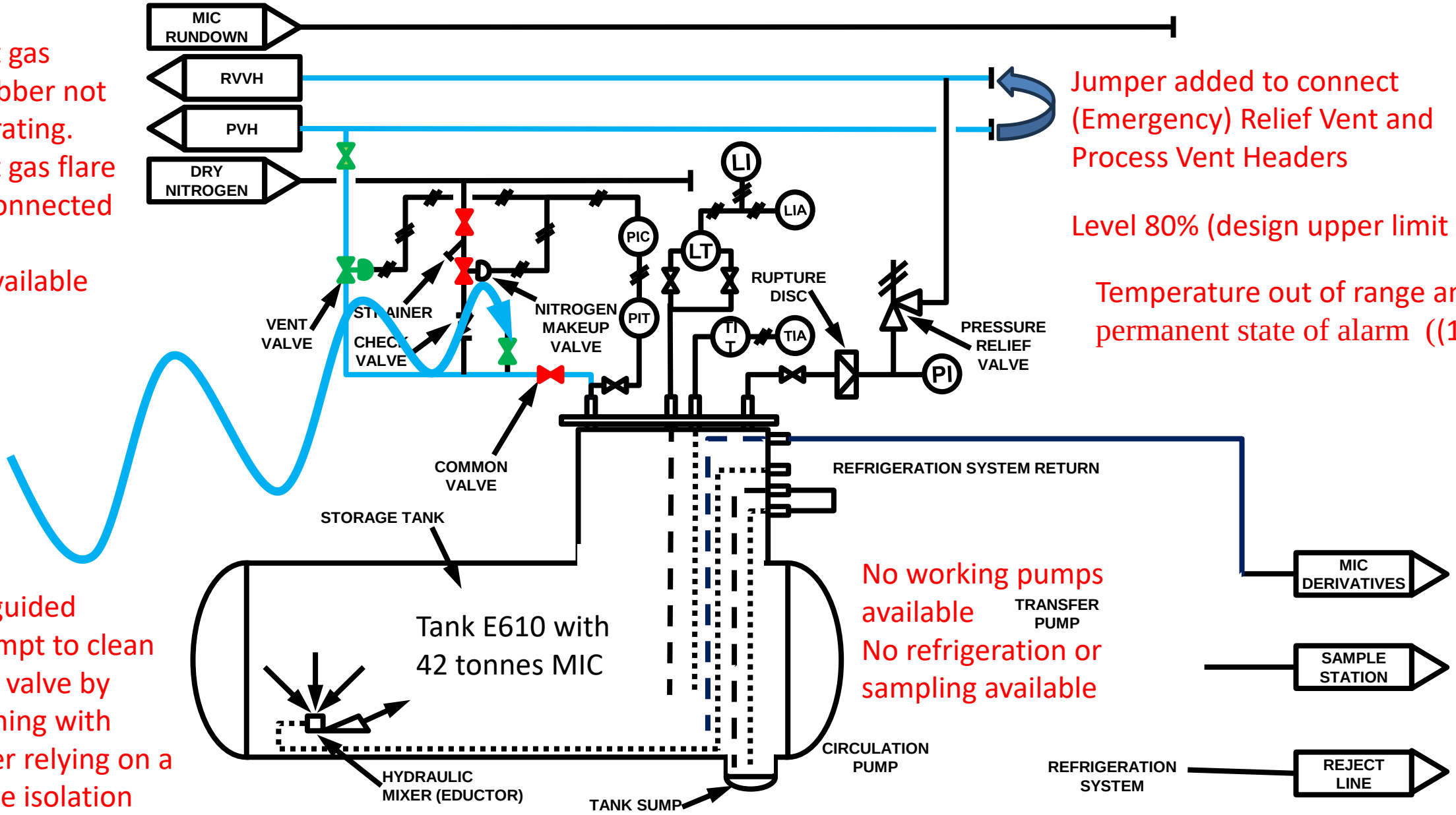
Revised US process used MIC with boiling point of 35C

MIC forms solid trimers with iron

MIC reacts violently with water

Dry Inert and Rust-free Conditions Essential

Vent gas scrubber not operating. Vent gas flare disconnected and unavailable



Jumper added to connect (Emergency) Relief Vent and Process Vent Headers

Level 80% (design upper limit 60%)

Temperature out of range and in permanent state of alarm ((11˚C)

No working pumps available

No refrigeration or sampling available

Misguided attempt to clean vent valve by washing with water relying on a single isolation (common valve)

Ref: Kenneth Bloch *Rethinking Bhopal* 2016 Elsevier IChemE