RISK ASSESMENT

CBE 9185 Project

BHOPAL DISASTER CASE STUDY

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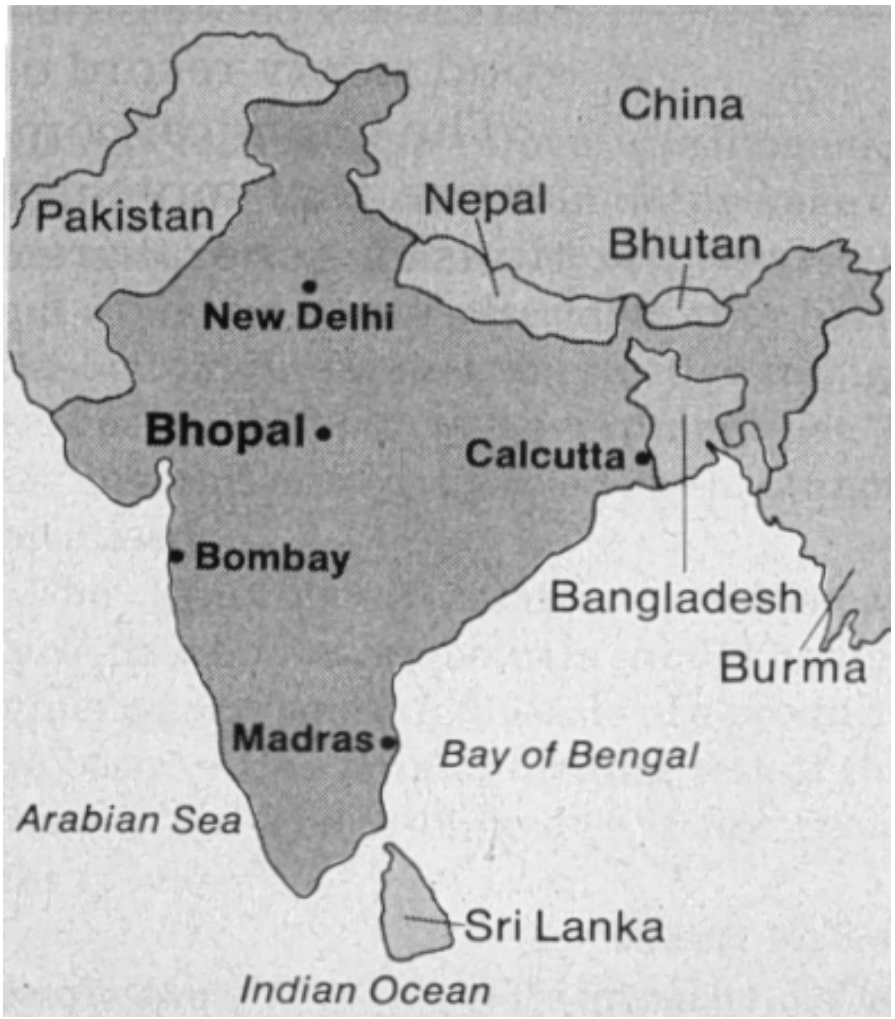
2-Difficulty of this case study

This case study is a trial to collect and analyse information from several resources to give an explanation of what happened 29 years ago in Bhopal- India. Due to the conflict between Indian government and Union Carbide Corporation about the responsibility of what happened. A lot of information still hidden. Investigators were prevented to meet Indian employees. These employees gave stories to Indian investigators and couldn't change them later. For several years after the disaster, no information was given about the composition of that deadly cloud. Moreover, both Indian government and Union Carbide lied to the public about the fatality of the gas which causes the disaster. They claim that it will act as a tear gas and couldn't harm human beings exposed.. Union Carbide and Indian government continued this claim till 1994. In the available references and official reports, there is a lot of variation about the number of victims and different theories about the reason of the initial event caused that disaster. In addition, a lot of stories are available about what happened exactly that night inside the plant. In summery there were a lot of gaps in the way of understanding of this case, but risk analysis studies enable as to extract the most probable scenario.

Figure(1) The difficulty of this case study

3- INTRODUCTION

Bhopal disaster, also known as Bhopal gas tragedy is a gas leak incident in India. This incident is considered the worst industrial disaster in the world. It occurred at the night of 2-3 December 1984 in the pesticide plant of Union carbide India limited (UCIL) in Bhopal, Madhya Pradesh, India. It happened when about 40-45 tons of extremely toxic MIC gas released to the atmosphere .More than 0.5 million Indian citizens exposed to Methyl isocyanate (MIC) and other gases in the small towns and villages around the plant. The affected area was about 40 sq km.[**[**2**],[4]**



Figure(2) Location of Bhopal in India

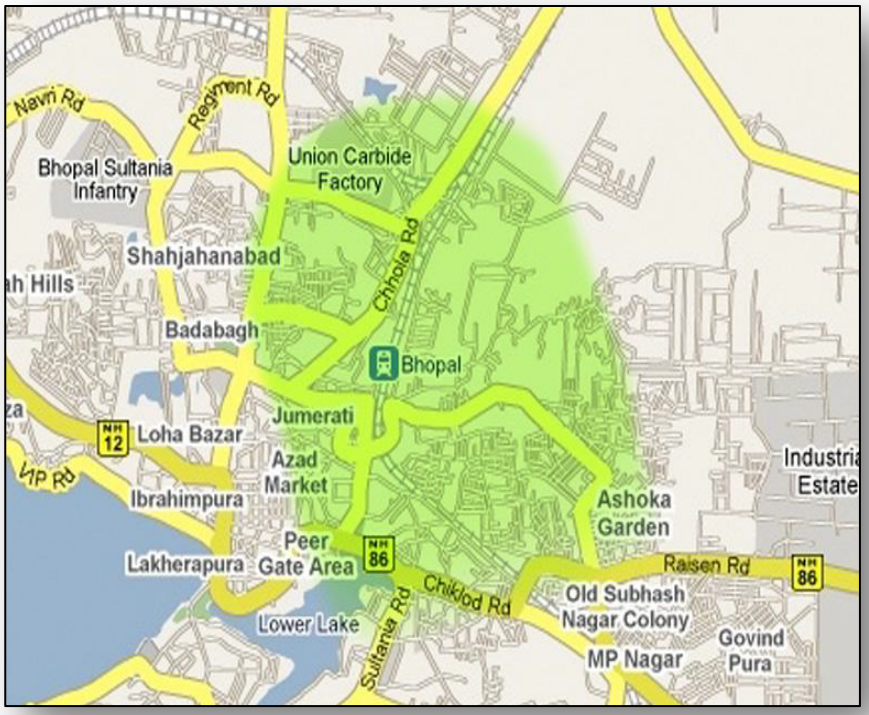


Figure (3)The area affected by gas

There were different estimates about the number of victims. The official number of immediate deaths was 2259. There were estimates about other 8000 died after two weeks, and other 8000 died as a result of diseases related to the exposure to the gas. Governmental estimates in 2006 talk about 558125 injuries include 38478 of temporary partial injuries and 3900 severely disabling injuries. Other references stated that among the people, who were exposed to gas, 25000 people died, 558125injured, 120000 continue to suffer of bad health effects.

(UCIL) is the Indian branch of Union Carbide Corporation (UCC). At the time of disaster, Indian government al banks and Indian public were holding 49.1% stake. UCIL produced pesticides and agricultural product s to cover the huge demand of Indian market.

Criminal cases were pending in Indian courts. At June 2010, it was found that 7 of previous employees including the previous UCIL chairman were convicted in Bhopal for causing deaths of negligence and got the maximum punishment stated in the Indian law (two years in jail plus 2000$ fine). Other eighth employee died in jail before the judgment.

4-The pre-event condition [3]

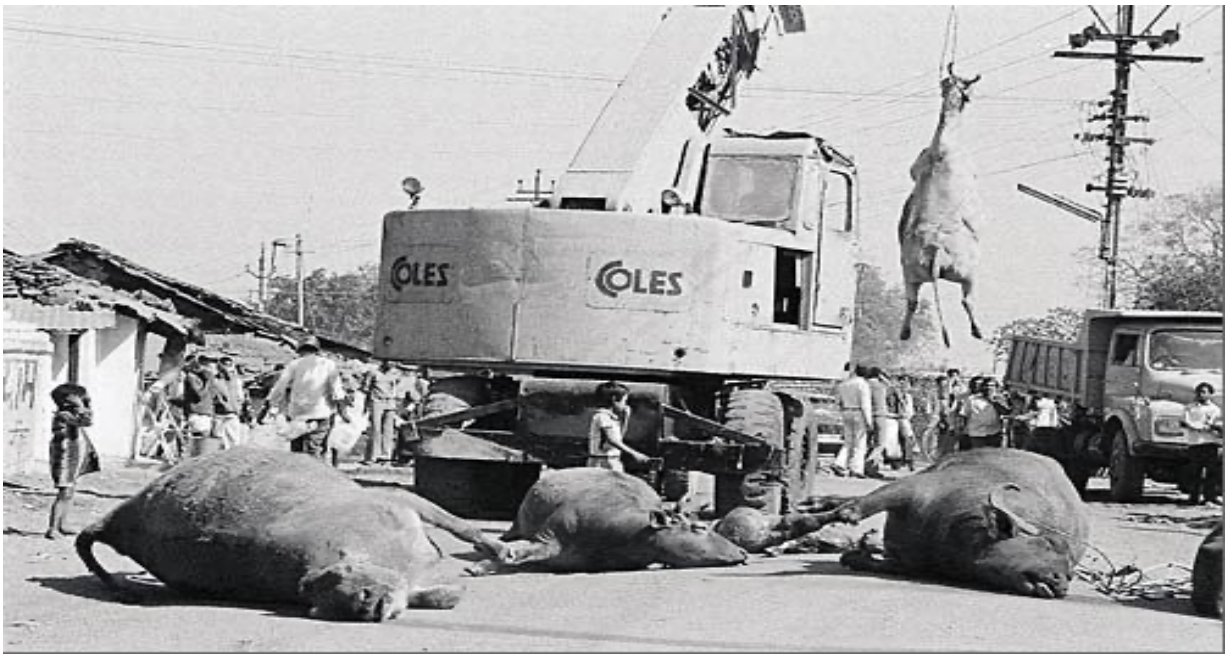
After the independence, the Indian policy was depending on attracting foreign companies to invest in India by getting the benefits of cheap labor and low taxes. UCC built the UCIL factory in Bhopal to produce the pesticide sevin using the MIC as an intermediate material. MIC production unit was added at 1979 to produce it on side rather than importing it. At that time the plant was considered as a part of green revolution in India,as it clear in the poster below.

The plant had a capacity of 5,250 metric tons per year of MIC. After the MIC unit was added, Bayer Company produced sevin without using the MIC. The new method was safer, but more expensive. UCIL continue using the cheaper but dangerous MIC method.

In the year 1980 the demand for pesticide dropped but the company continues producing MIC. This resulted in accumulation of unused MIC in the tanks

Figure(4) Victims

Figure(5)Poster about the green revolution inhanced by Union carbide corporation in India



Figure(6) Victims and dead animals

5-What is Methyl Isocyanate?[3]

In order to understand what happened in the disaster, we should know about the lethal gas whose leakage caused that disaster. Methyl Isocyanate is a Clear, **colorless**, sharp smelling liquid, **Extremely toxic, and** Highly flammable, Its **boiling point** is ~**40**^{o}c.

MOLECULAR STRUCTURE CH3-N=C=O

LC_{50} is 5 ppm (for rats) (LC the lethal concentration which cause 50% death of population after 4 hours of exposure).

TLV-TWA OF 0.02 PPm (ONE OF THE LOWEST!)

(For comparison TLV-TWA of Phosgene is 0.1 ppm) (Phosgene is a famous war gas used in the First World War)

TLV-TWA is the time weighted average for normal 8 hours' work day to which all workers can be exposed without adverse effect.

It has a highly active volatile reaction with water. If water comes in contact with MIC a run-away reaction starts which increases the reaction temperature, as a result the reaction rate increases more and more. At a certain temperature the MIC molecules start to combine with their selves with generating more heat.[2]

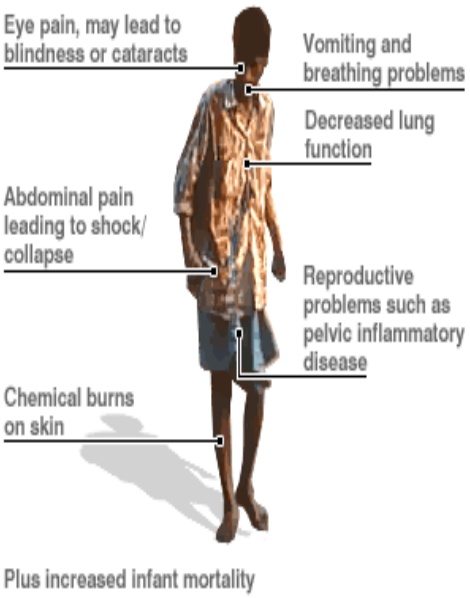
6-Effects of exposing to the gas

6.1 Side effects of inhaling Metyl Isocyanate

Figure(7)effects of Inhaling MIC

Side Effects of Inhaling Methyl Isocyanate

- Effects at 0.4ppm
  - Breathlessness
  - Choking
  - Asthma
  - Throat Irritation
  - Eye Irritation
  - Skin Damage
  - Vomiting
  - Muscular Weakness
  - Altered Consciousness
- Effects at 21ppm
  - Pulmonary Edema
  - Emphysema
  - Hemorrhages
  - Bronchial Pneumonia
  - Death



6.2-Societal Effects[2]

- No or little earnings reduced self esteem
- Heavy loans to pay for medicines
- Children future destroyed
- Children could be affected for life
- Forgotten by media

7-Exothermic Reactions with Water and itself [7]

MIC + H2O ----------> 1,3,5 TRIMETHYLBIURET + CO2

MIC + H2O ---------> 1,3 DIMETHYLUREA + CO2

3 MIC ----------> Trimer

All of these reaction all exothermic. In closed system these reactions could increase the pressure in great manner. For this reason proper cooling should be available in MIC storage tanks and water should be prevented from entering any vessel containing MIC. These reactions will be catalyzed and be faster in case of existence of Iron oxides as happened in the day of disaster.

If water for any reason enters the tank, it will react with MIC. The reaction products are not toxic as the MIC. The main problem is that the temperature could increase quickly to about 200C. The boiling point of the MIC is around 39. This will result in the boiling of unreacted MIC.

8-Safety features

Safety features could be divided into to

1- Storage tank safety features
2- After tank (leak mitigation process).

8.1-Tank safety features

Nitrogen was supplied to the storage tanks for the following reason.. First, since MIC is a flammable and can burn – so contact with oxygen is avoided. Then bone dry, high purity nitrogen was used at the Bhopal plant to reduce the risk of contamination, especially from trace amounts of water.. MIC's flash

point is -18_C, and its LFL (lower flammability limit) is 6% in air. Thus nitrogen “padded” the flammable contents of the tank. This is also called nitrogen blanketing or nitrogen purging. Nitrogen or inert padding is commonly used in tanks holding volatile fuels or reactive chemicals. Thirdly, the nitrogen pad provided a positive head of 15 to 20 psig within the tank so that material could be forced through the feed pipe to the transfer pumps. According to the regulations, MIC level in the tank shouldn’t exceed the 50% mark. Then in case of dangerous chemical reactions occurring, solvents could be pumped to quench the reactions. Moreover the storage tanks are put under a concrete cover to protect them from hot Indian sun.[1]

In case that water for any reason enters the tank, there was external coiled jacket with (Freon/chloroform) coolant capable to keep the vessel contents close to 0C. This can prevent the propagation of run-away reactions.

Pipes that transfer MIC from the production unit to the storage tanks has a special valves of flanges with sliding plates. These sliding plates are efficient to prevent any quantity of water from entering the tank when cleaning the (MIC transferring pipe) by flushing with water.

8.2-After tank safety process (leak mitigation process)

In case that water enters the storage tank and run-away reaction occurs, and in case that refrigeration system fails to keep low temperature inside the vessel, then in order to prevent the explosion of the tank a safety valve will be opened. This valve is a rapture disc type allows the gas to go to the next mitigation step. The second mitigation step is a vent gas scrubber. In this scrubber the gas entering from its lower part is sprayed by caustic soda solution which can neutralize the MIC and convert it to harmless material. Any residual MIC gas should be taken to a flare. Inside this flare there is a burner which burns any MIC and convert it to harmless CO2 gas.

Other safety feature is added to treat any gas leakage inside the plant. This feature is the water curtain spray. It is wall of sprayed water droplets which can react with the MIC gas in the plant atmosphere and convert it to less harmful water soluble materials.

The following diagram is for the tank and after tank safety features [3].

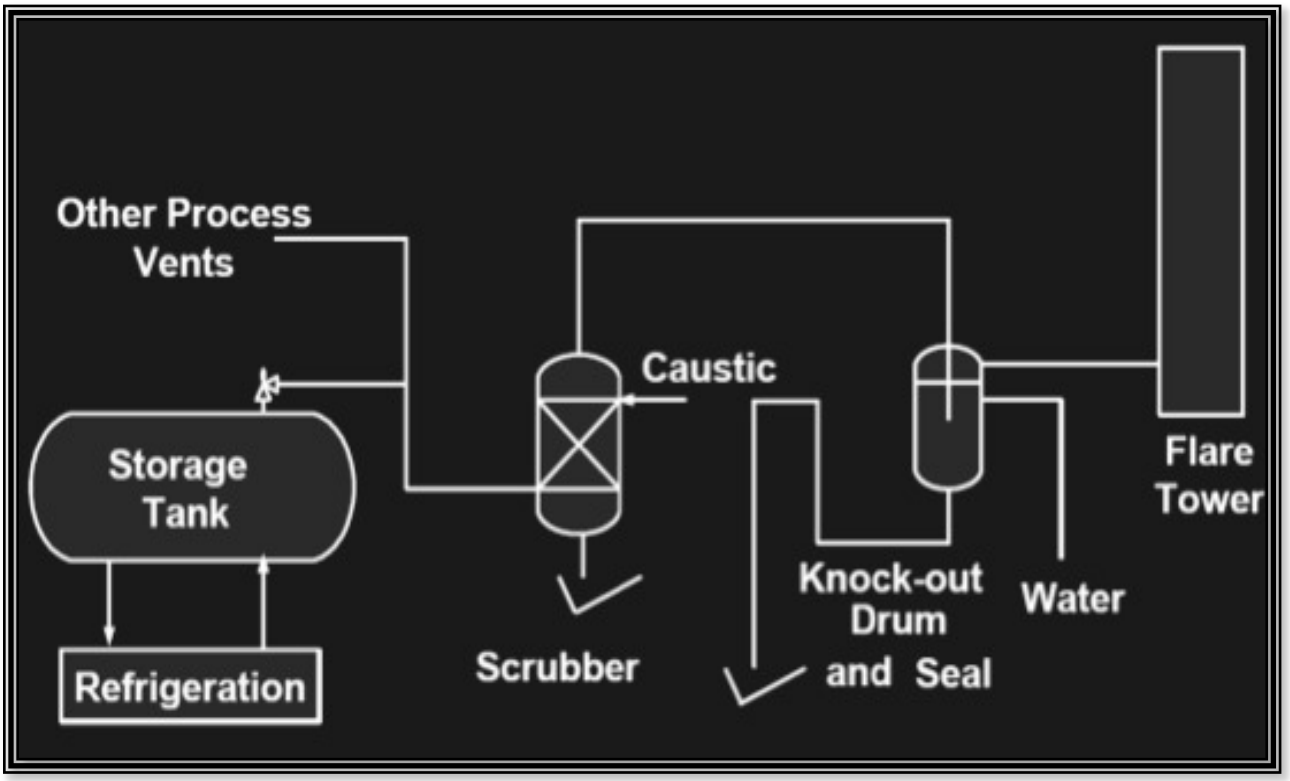


Figure (8)Flow sheet of the mitigation process

For me as a chemical engineer the above mitigation process is a wonderful one. It is a good combination of Thermodynamics, chemical kinetics, plant design and control, but two very important features were

absent which caused the disaster. These were management and ethics. At 1972 an internal report of UCC had recommended[5] that if another MIC plants to be built, they should be of the same materials as good as those used in the West Virginia UCC plant. It was clear later that although the UCC engineers supervised the design, installation and operation till 1982, the Indian staff made a lot of cuts in design and construction which make the finished plant different than that in western countries.

9-Early warnings

A lot of accidents happened during the operation of the plant before the disaster. All of them gave warnings about bad management, poor maintenance, poor training and careless about safety regulations. In 1976, two trade unions complained about pollution in the plant[4]. In 1981 a worker died after inhaling a large amount of phosgene [1]. In 1981 the plant was visited by a group of American experts; they warned UCC about the possibility of ran-away reaction in the MIC storage tanks. In 1979, a warning given by Indian authorities to UCIC about the same problem, but no real action was taken by UCIC[1]. In January 1982, 24 workers were exposed to phosgene and entered the hospital. None of them were asked to wear gas masks. One month later, 18 workers exposed to MIC leakage [1]. In August 1982, a chemical engineer exposed to MIC which cause to burn 30% of his body. Another MIC leakage happened in the same year causes severe burns to MIC supervisor who tried to stop the leakage. Other leaks happened 1983 and 1984 .They were of MIC, Chlorine, phosgene, carbon tetrachloride, mono methyl amine.

In summary, the event was preceded by warning events since 1976, but neither the UCIC took a step to treat the events noted nor do anything to mitigate the consequences of an event could happen later. Additionally, no one was punished for this irresponsibility

10-Contributing factors

UCC continue using the most dangerous process while safer process was available.

Several factors contribute to cause such a huge disaster, such as:

Storing the MIC in large tanks more than the advised level.

Poor maintenance after the plant stops MIC production in 1984.

Safety systems were in a stand by mood to save money. This includes the MIC storage tank refrigeration system which could prevent this disaster. Actually there was no Freon in the system.

Growing of mushrooming slums around the plant increase the effect of gas release (nearest one was 1.5 mile away from the plant when it was installed).

The weather at the time of the disaster helped to increase its magnitude. There was no strong wind to disperse the gas, no rain to react with the gas. The gas was pushed by a gentle wind as a compact front towards Bhopal city. Moreover , the disaster happened at night when there was convection current to push the gas to upper atmospheric layers

No emergency plans for evacuation of people or medical treatment for any catastrophic gas release.

11-Working conditions

Reduction of expenses affected the plant employees and plant maintenance. Dan Kruzman[6](famous American writer and author of “A KILLING WIND”) argues ” cuts...meant less stringent quality control and thus looser safety rules. A pipe leaked? Don't replace it; employees said they were told ... MIC workers

needed more training? They could do with less. Promotions were halted, seriously affecting employee morale and driving some of the most skilled ... elsewhere".[6].

Reductions of employee's promotions affecting them in a bad manner and push the best of them to leave the work. In addition workers were asked to use manuals written in English although few of them know it effectively.

At the time of the disaster only six of the twelve operators were still working and the number of the supervisors was reduced to the half. Even 70 % of the employees were fined due to refuse the orders of neglecting safety regulations. Moreover a study group from American university **(American University (AU or American) is a private liberal arts[4] and research university in Washington, D.C., United States, affiliated with the United Methodist Church)** this group pointed series communication problems between The UCC and its Indian branch.

12-Equipment and safety regulations

MIC storage tank alarms didn't work for 4 years ,and there was only one feedback system while there were 4 in a similar plant in the united states[4].

There was no storage tank between the large storage container and the MIC production unit to check its purity.

The reserve tank was full of MIC. This should be empty to allow evacuation of some of the MIC from the other tank to reduce the pressure.

To minimize operating cost, the refrigeration unit was shut down by setting the temperature set point to 20 C instead of the 4.5 C recommended in the operating manual. Moreover, since June 1984. The Freon

was drained and used somewhere else within the plant. Thus, MIC was stored without cooling, and, if a run-away reaction event should occur, no cooling was available.

There should be slip blind plates that could prevent cleaning water in the pipes from entering the MIC tank (in case the valves were faulty). These plates were not installed and their installation was omitted from the maintenance checklist.

Several gas scrubbers were out of service. Only one gas scrubber was operating, during the disaster it was in standby mode. Then couldn't treat the MIC gas by neutralizing it with caustic soda. Even if it worked, it couldn't treat such a huge amount of MIC gas released. In contrast, similar plants in the USA had 4 times the number of vent gas scrubbers in the Bhopal plant.

Flare tower was out of service for five months before the disaster because a length of piping was corroded and was not replaced. In contrast similar plant in USA has two flares.

The water curtain which was supposed to reduce the amount of MIC escaping out of the plant was not efficient. Its pressure was enough to spray water to height of 11 meter only. This wasn't high enough to reach the height of vent gas scrubber stack (33meter).

Carbon steel valves and pipes were used in the factory. Carbon steel is corrodible when exposed to acid. This was the reason of malfunctioning of a lot of safety devices; need to sequence dangerous water flushing of pipes. Moreover, the existence of Iron oxides with water which entered the MIC tank acts as a catalyst accelerates its chemical reaction with water.

Manual safety devices were installed instead of the automatic ones in the West Virginia plant.

According to the operators, the pressure gage of the MIC tank had been malfunctioning for a week.

Readings were taken each two hours, nor each hour as in the operating manual.

Following the Indian government guide lines, the design of the MIC plant was “Indianized” by the UCIL engineers to maximize using Indian products. This includes replacing imported stainless steel parts with Indian carbon steel parts.

A $3-6 million saving was done with the number and quality of safety devices compared with the West Virginia plant.

Early warning systems sensed leaks, monitored their concentrations, linked to a telephone system to automatically dial out alerts in similar western plants while in Bhopal there weren’t even any emergency planning measures[**5**].

No information was given to the local authorities about the huge quantities of dangerous chemicals used and manufactured in the plant.

Both UCC and Indian government lied to the public by telling them that the MIC gas acts as a tear gas, and couldn’t harm human beings exposed. UCC and Indian government continued this claim till 1994.

In summary, the accident was waiting to happen, and was given a chance to happen The company and the operators were careless about safety of the society and workers.

13-The accident [1]

On December 2, 1984, and in the absence of blocking device water found its way to tank 610(various theories are existed to explain that will be explained later). Investigations done later indicate that about 1000-2000 lb of water entered the tank. This was enough to start a run –away violent reaction, its rate increased by the existence of Iron Oxide impurities coming from corroded carbon steel components. This increased the temperature gradually to 200 C. The MIC with a boiling temperature of~ 39C, started to

boil and rise the pressure inside the tank. At 11 p.m. one of the operators noticed that the pressure in the tank was rising. But the gages were not trustful due to bad maintenance for a long period of time. The right action was to open the valve connecting the tanks 610 and 619. This was enough to halve the pressure till adding agents to neutralize as much MIC as possible, and warn the people outside the plant to run away. At midnight the MIC started to leak from the safety valves of the tank. The workers didn't care and went to the canteen for a tea. When they returned after two hours, it was too late. In the original manual, the measures should be done each one hour not two. The concrete around the tanks started to crack. Safety valve (rupture disk type) opened and the gas found its way to the vent gas scrubber, and exit out of its stack. The operator switched on the the vent gas scrubber and the water curtain sprinkler to neutralize the released gas. The scrubber failed, and the water curtain was not high enough. The flare system was out of service. When the plant superintendent reached after a short time, he activated the toxic gas alarm. This alarm was switched off after 5 minutes. Many workers run away out of the plant escaping from the gas. They warn some of the people outside the plant to escape.

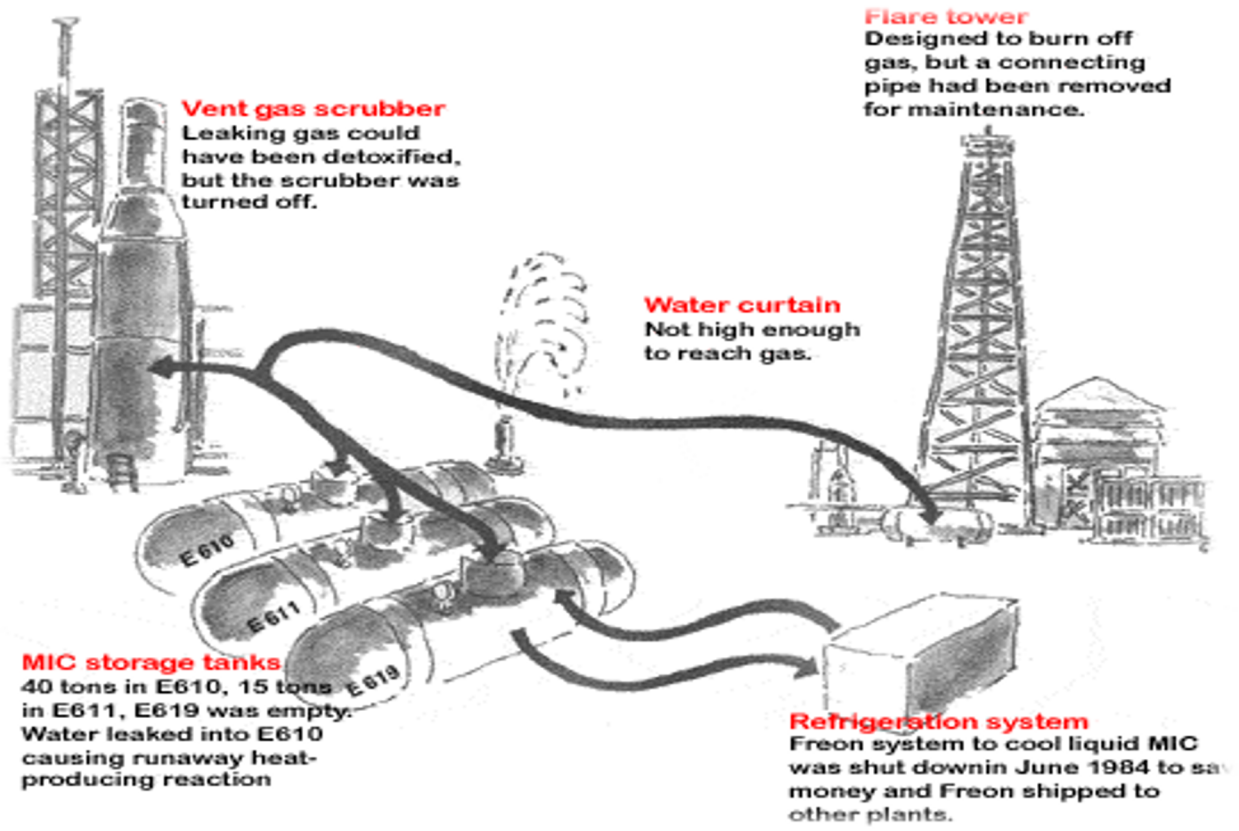


Figure (9) Mitigation process [2]

In the early hours of December3,1984, 40-45 tons of MIC released out of the vent gas scrubber. Because the gas is heavier than the air it settled down and pushed by a gentle wind towards Bhopal city. The people started to wake up when the gas started to suffocate them. There was no warning or any emergency plan to evacuate the people as soon as possible. When victims arrived to the hospitals, the doctors didn't know what to do for them. The only thing done for most of those poor people was drops in their eye. On December 5, total died people were more than 2,000 and the UC plant had been locked. The parent company's chairman, Warren Anderson was arrested by Indian authorities when he visited India shortly after the incident. Later in 1985 the Indian Government cancelled UC's operating license.

14-Direct reasons caused the failure of system precautions:

1- Shutting down the refrigeration system in June 1984 and draining the refrigerant and use it somewhere else in the plant.
2- Several weeks before the disaster, a corroded portion of the line leading to the flare system was removed for maintenance. Due to that the vent gases could no longer be moved to be burned in the flare.
3- The vent gas scrubber was put in a standby mode because the MIC production was stopped.

It is clear that all of the above were operations management decisions, these decisions are made by line supervisors, and managers at the plant level.

15-HOW DID WATER ENTER THE TANK?

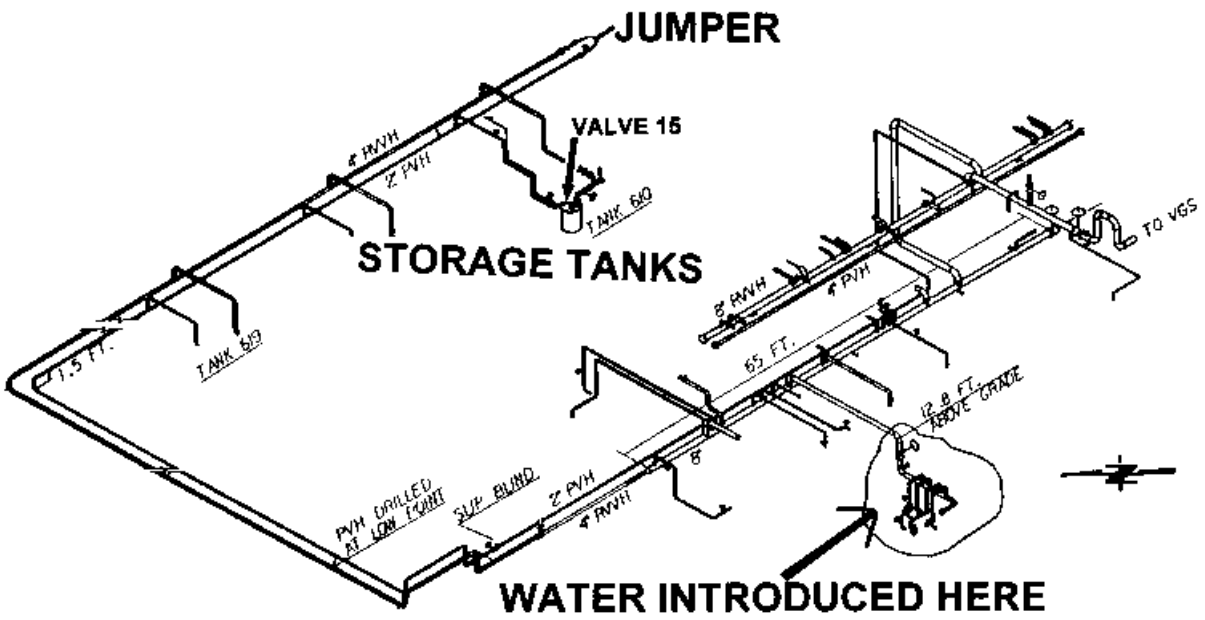
There are two theories explaining how water entered the tank

15.1-Human error

Water accidently entered the tank through water a water flushing operation (theory taken by the Indian government).[7],[2]

. At the time, workers were cleaning out a clogged pipe with water about 400 feet from the tank. They claimed that they were not told to isolate the tank with a pipe slip-blind plate. The operators assumed that owing to bad maintenance and leaking valves, it was possible for the water to leak into the tank. The water was supposed to be drained through drainage nozzles.

Due to the existence of large quantities of rust in the pipe, these nozzles were plugged with dirt. Then the water started to accumulate in the pipe till finding its way inside the tank 610 because the slip blind plate wasn't in its place also because the tank 610 wasn't pressurized enough {Nitrogen pad} due to the leakage of many valves connected to the tank. It was found that if water accumulated to a height of 6 meters above the cleaning area, it could drain by gravity flow into the tank.



Figure(10) description of the human error theory

15.2-Sabotage theory taken by UCC. [7],[2]

Union Carbide depended on investigation done by the engineering consulting firm "Arthur D. Little", which concluded that an angry employee (laid-off that day) secretly introduced a large amount of water into the MIC tank by removing a meter{Meter 10 in figure 11} and connecting a water hose directly to the tank through the metering port.[2,][7] Carbide claimed that such a large

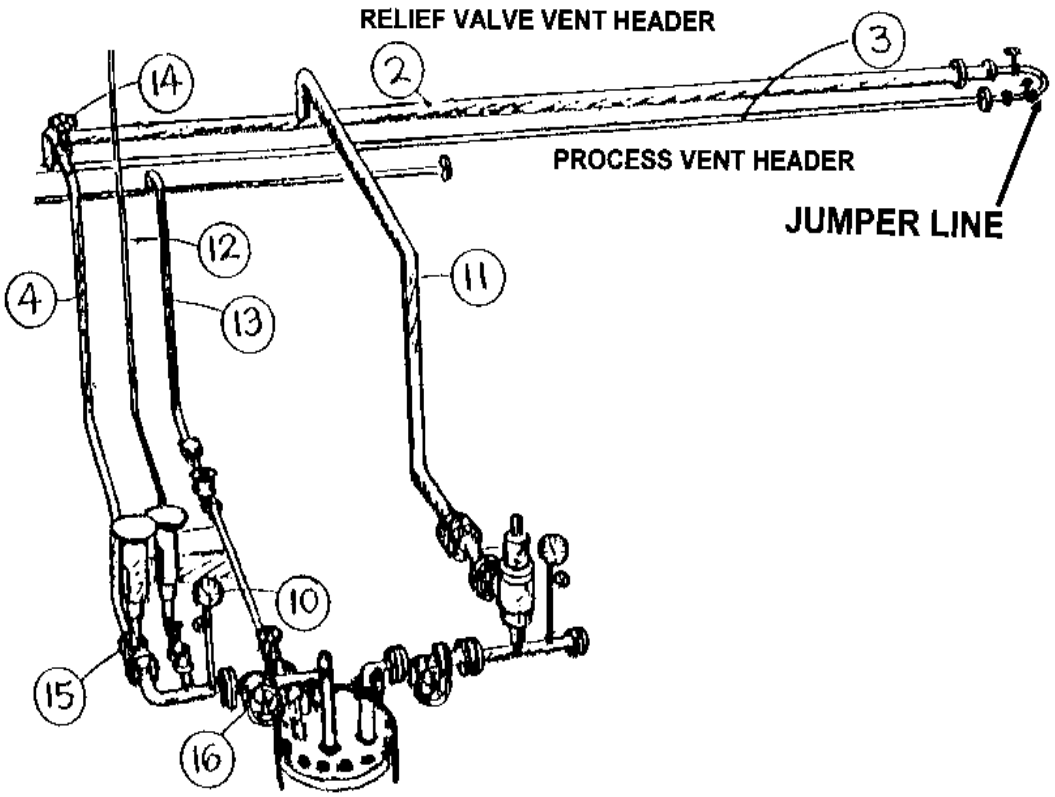
quanitity of water could not enter the tank by accident, available safety systems couldn't deal with intentional sabotage.

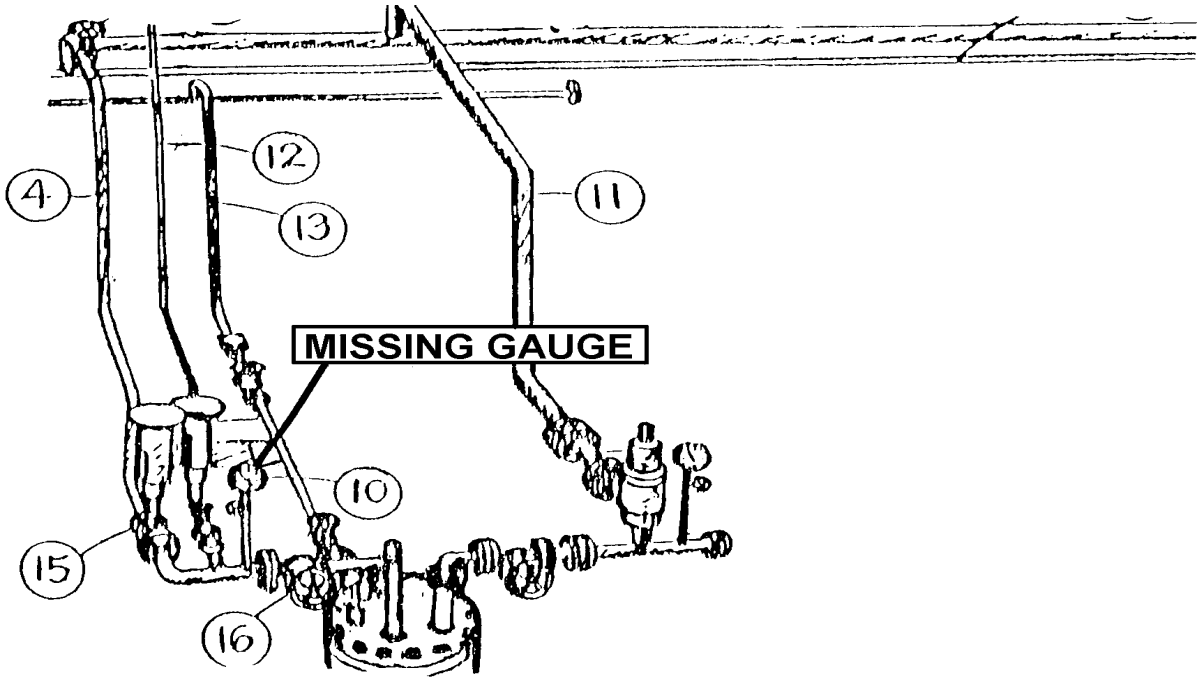
UCC and the investigation firm tried to reproduce the water flushing theory by they failed. UCC found 3 main weak points in the water flushing theory.

1- Water head was not enough to push such a large quantity of water to the MIC tank

2- An intermediate valve found closed after the accident.

3- The intermediate line found dry.





Figure(11) description of sabotage theory

ACCORDING TO SABOTAG THEORY WATER INTRODUCED TESTIMONY INDICATED THAT THE PRESSURE GAUGE (PRESSURE INDICATOR) WAS MISSING ON T-610

Again

What really happened?

Figure(12) Lost information between scientific investigations and politicians

16-Event tree analysis

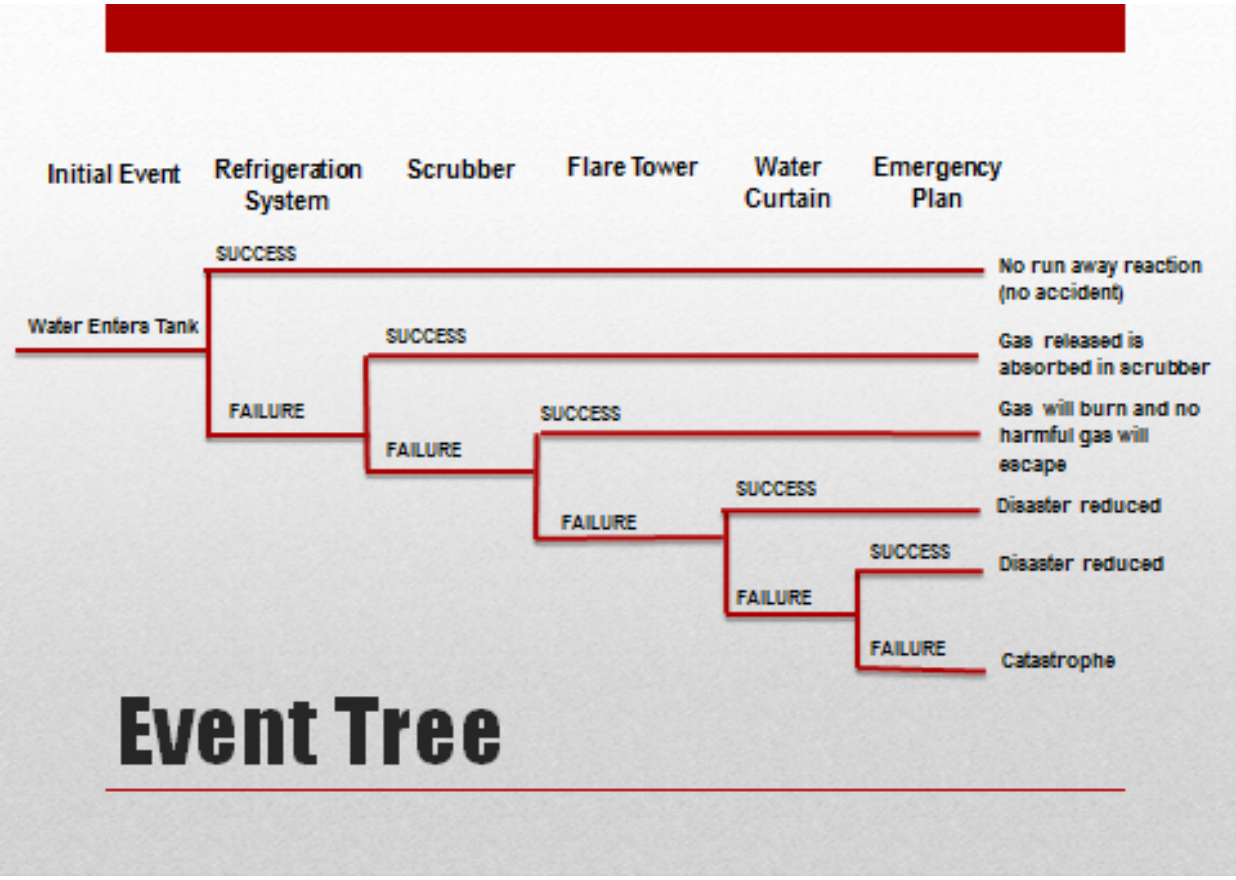


Figure (13) Event tree analysis of Bhopal disaster

First event is considered the entrance of water inside the tank. This because there is uncertainty about how water entered the tank 610.

17- Risk analysis

	Severity	Probability	Outcomes

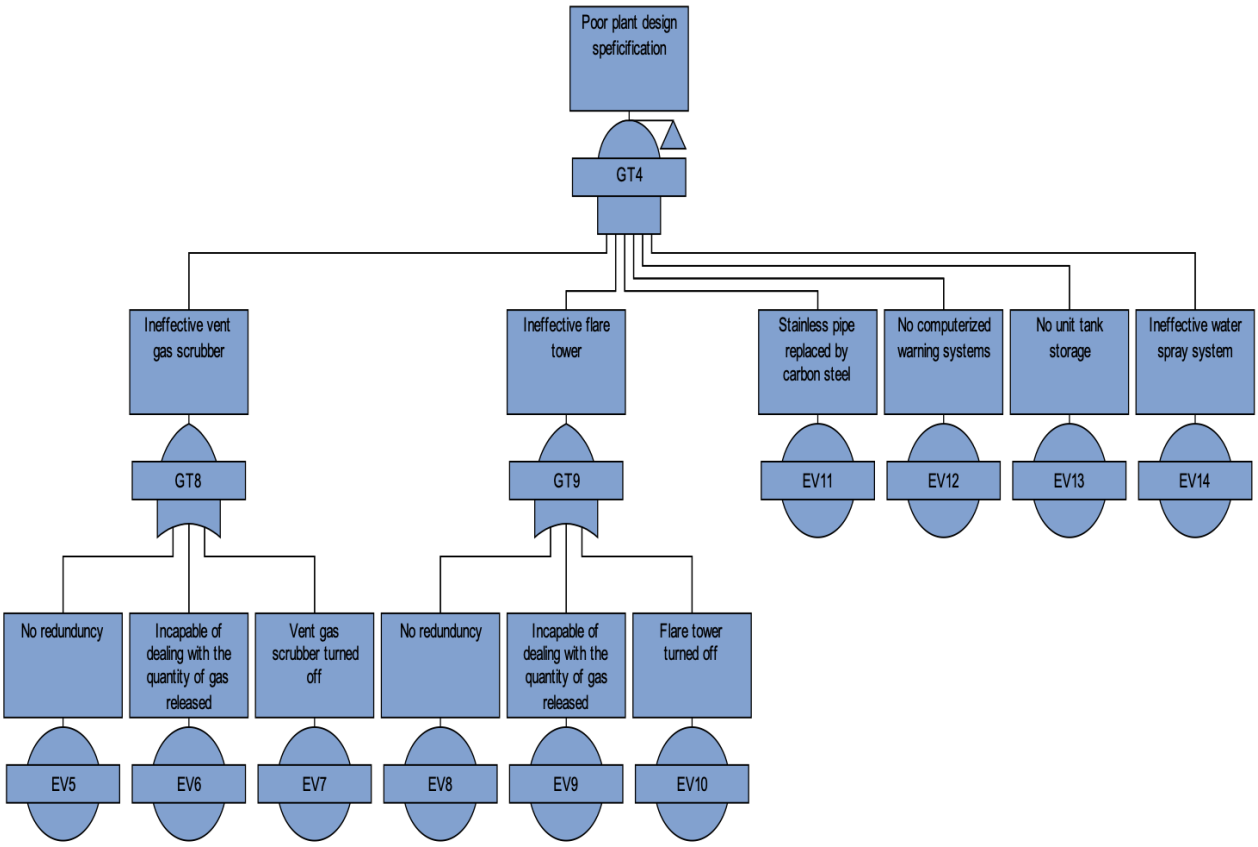
Water Enters the tank	**High**	**Low**	**No run away reaction (no accident)**
Failure of refrigeration system	**High**	**Moderate**	**MIC gas released**
Failure of vent gas scrubber	**High**	**Low**	**Gas cannot be contained**
Failure of Flare tower	**High**	**Low**	**Gas released to atmosphere**
Failure of plant sprinkler system	**High**	**Low**	**Gas could not be removed "disaster "**
Lack of Emergency Plan	**High**	**Moderate**	**Severity of disaster increased**
Gentle wind moved it over the occupied area	**High**	**Moderate**	**Severity of disaster increased**

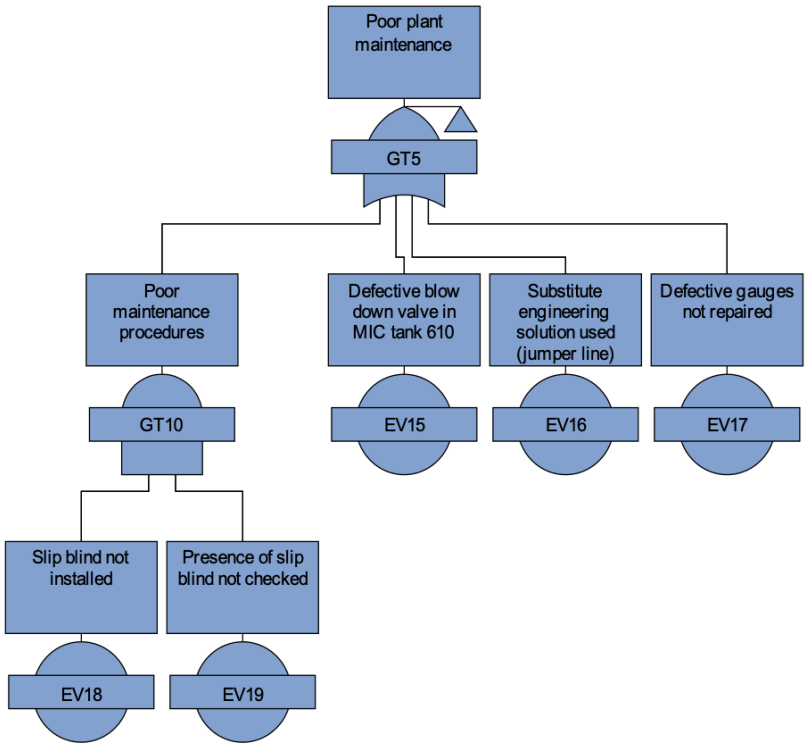
Figure (14) Risk Analysis

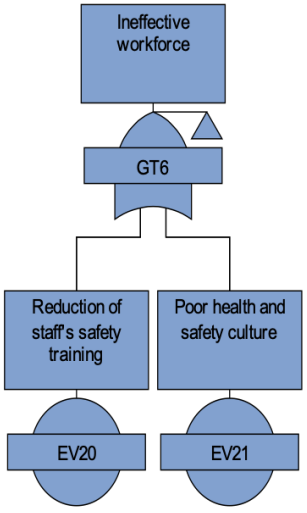
This analysis is considered at time of designing the plant.

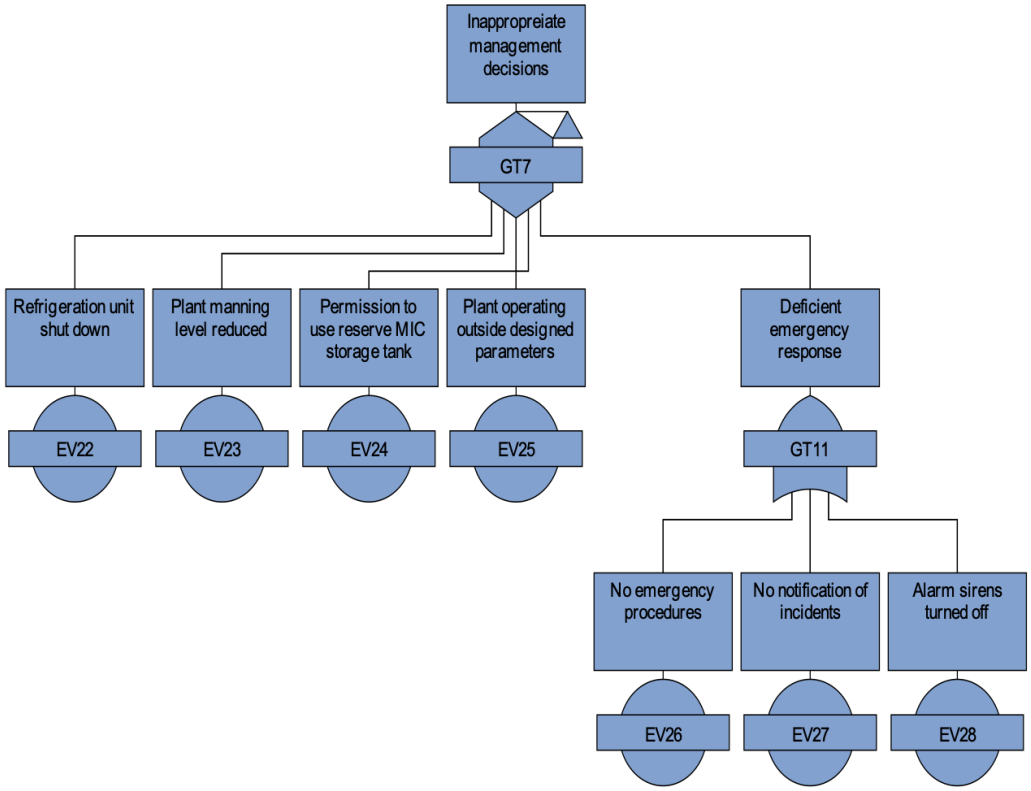
18- Fault tree analysis

Figure (15) Fault tree diagram (due to large size of the diagram, it is separated into parts to make it easy to understand it)




Poor plant maintenance
GT5
Poor maintenance procedures
Defective blow down valve in MIC tank 610
Substitute engineering solution used (jumper line)
Defective gauges not repaired
GT10
EV15
EV16
EV17
Slip blind not installed
Presence of slip blind not checked
EV18
EV19


Ineffective workforce
GT6
Reduction of staff's safety training
Poor health and safety culture
EV20
EV21



19-conclusions

- Bhopal Gas Tragedy occurred due to:

    1. Poor management systems

    2. Bad copying of safety process design (materials, instruments and piping…etc. weren't as good as those used in the West Virginia UCC plant).

    3. Ignoring process and personnel safety regulations

    4. There is a need for the improvements in safety equipment (manual to automatic). Stricter enforcement and personnel training must be followed.

5. Government not ensuring compliance with regulations

6. Both Indian government and Union Carbide Corporation gave the priority to the profit. They didn't wary a lot about the life of Indian citizens.

- Result: Death and injury of hundreds of thousands of people

20-Lessons Learned

- Improve effectiveness of public and private policies related to chemical releases
- Provide expanded programs of toxicity testing that examine effects of chemicals on humans and environment
- All safety related equipment should be kept in order
- Provide national and international incident surveillance programs
- Residential areas should be kept away from plant
- Find ways to prevent the use of toxic chemicals and reduce its inventory.
- Strengthen management systems
- Enhance worker and community rights to know about chemical hazards
- Ensure separation of facilities from residential and public areas
- Educate of health care providers about environmental health and toxicology
- If the claim of Union Carbide about sabotage is accepted as a lesson then an important lesson is extracted which is" don't let laid off employee to stay in the work site".

21-Bhopal's Impact on the Chemical Industry

The accident in Bhopal had great impact within Europe and North America. It resulted in great changes in the US regulations, .After the disaster, the AICHE Center for Chemical Process Safety was established, and the Safety and Chemical Engineering (SACHE) program was formed. These first steps led to a change in the practice and education of chemical engineers in the US and Europe. For sure lives have been saved. In addition, practicing and graduating chemical engineers became closer to the process safety and environmental issues through the educational development and scientific research.[8]

22-References

1-. Peterson.M.J, "Bhopal Plant Disaster – Situation Summary," Science, Technology & Society Initiative,. University of Massachusetts Amherst, 2009. 14

2- Basha.O, Alajmy.J , Newaz.T.The Bhopal gas Tragedy: A safety case study http://repository.qatar.tamu.edu/bitstream/handle/1969.2/256/CHEN 455 Bhopal 2009 presentation.pdf?sequence=1

3-Lectures of the (Chemical Process safety course) in UWO CBE 9173L 001 GS13

4- https://en.wikipedia.org/wiki/Bhopal_disaster

5-. Labib.A and R. Champaneri, "The Bhopal Disaster - learning from failures and evaluating risk" **http://www.maintenanceonline.org/maintenanceonline/content_images/Pages%2041,%2042,%2043,%2044,%2045,%2046,%2047.pdf**

6- Kurzman,D, A Killing Wind: Inside Union Carbide and the Bhopal Catastrophe (New York: McGraw-Hill, 1987).

7- Willey, R.J., 1998, Slide Package: The Bhopal Disaster, prepared for SACHE. (Safety and Chemical Engineering Education) as a product of the AIChE-CCPS,

8- A. S West, Hendershot.D, Murphy. J. F., and Willey. R, "Bhopal's Impact on the Chemical Industry," *Process Safety Progress*, (Dec. 2004), 23(4): 229–230.