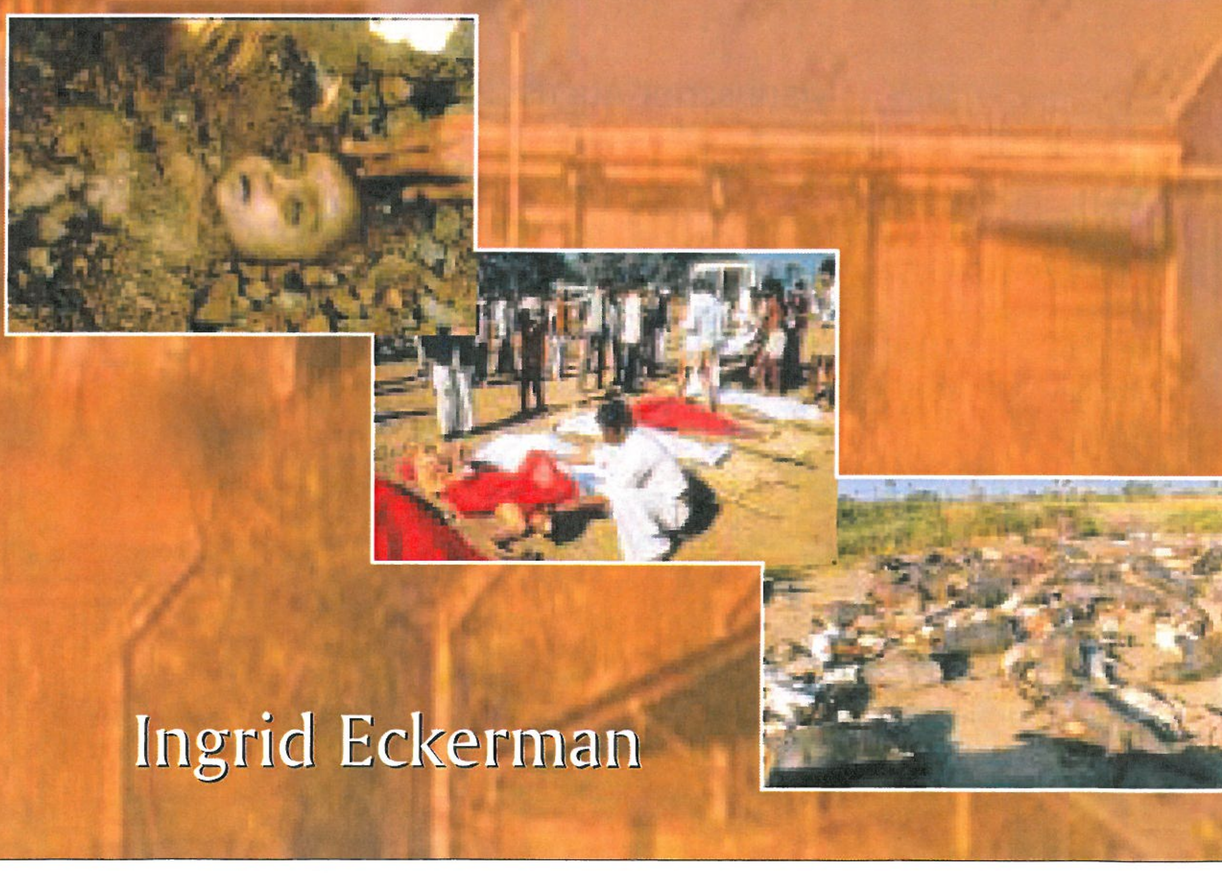
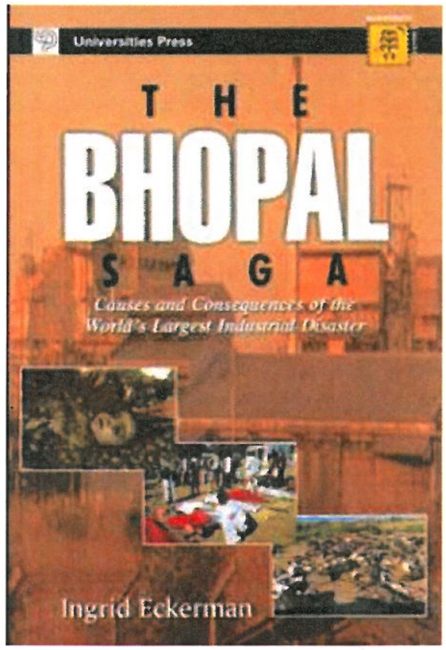
Universities Press

THE BHOPAL SAGA

Causes and Consequences of the World's Largest Industrial Disaster



Ingrid Eckerman



Ingrid Eckerman: The Bhopal Saga – Causes and Consequences of the World's Largest Industrial Disaster.

Manuscript August 2004

Published by Universities Press (India) Private Limited 2005.
ISBN 81 7371 515 7.

The book is available from the author ingrid@eckerman.nu and from Sambhavna Trust, Bhopal, India.

Further reading: www.eckerman.nu.

2. ABBREVIATIONS AND INDIAN TERMS

2.1 Abbreviations

BGIA	Bhopal Group for Information and Action
BGPMUS	Bhopal Gas Peedit Mahila Udyog Sangathan, a survivors' organisation
BMHRC	Bhopal Memorial Hospital and Research Centre
BMHT	Bhopal Memorial Hospital Trust
CBI	Central Bureau of Investigation
CSIR	Council for Scientific and Industrial Research
ICMR	Indian Council of Medical Research
IMCB	International Medical Commission on Bhopal
MIC	Methyl Isocyanate
MP	Madhya Pradesh, an Indian state
NGO	Non-governmental organisation, voluntary association
Rs	Rupees, the Indian currency. 40 rupees is about 1 US$ (2003)
UCC	Union Carbide Corporation
UCIL	Union Carbide India Limited

2.2 Indian terms

Crore	10 millions
Lakh	100,000
Dharna	Sit-in
Basti	Settlement
Kuccha	Simple (house, toilet etc)
Pucca	Better (house, toilet etc)
Coolie	Bearer
Bhurka	Chaperone, the body-covering coat of muslim women

2.3 Technical terms

Psi	Pounds per square inch (pressure)
Psig	Pounds per square inch gauge
Ppm	Parts per million (concentration)

THE BHOPAL SAGA
CAUSES AND CONSEQUENCES OF THE WORLD'S LARGEST INDUSTRIAL DISASTER

Summary

INTRODUCTION

The Bhopal Gas Leak, India 1984 is the largest chemical industrial accident ever. 520,000 persons were exposed to the gases, and up to 8,000 died during the first weeks. 100,000 persons or more have got permanent injuries. The catastrophe has become the symbol of negligence to human beings from transnational corporations. It has thus served as an alarm clock. All the same, industrial disasters still happen, in India as well as in the industrialised part of the world. Although they are far from the size of Bhopal, they are so numerous so that chemical hazards could well be considered as a public health problem. The companies usually dispute their own roll to the accidents, and deny the health effects of the accidents. The companies have also been reluctant to compensate the victims economically.

In injury analysis, the conception "the process of the accident", including pre-event, event and post event phases, is used. Many models for injury analysis are developed. Usually, they are used for events like traffic accidents and child burns.

METHODS

The book is based on thorough review on already published material from India and outside India, and the author's experiences from visiting the city of Bhopal. The Logical Framework Approach (LFA), a tool for project planning and management, is tested on this mega accident, in order to analyse the causes and its consequences.

RESULTS

The Logical Framework Approach (LFA) provides one main message: That irrespectively of the direct cause to the leakage, it is only two parties that are responsible for the magnitude of the disaster: Union Carbide Corporation and the Governments of India and Madhya Pradesh.

LFA appears to be a complete and useful model for analysing a complex situation like the Bhopal gas leak. The problem and objectives trees look like a chain of event from where there are branches and roots. Despite of thorough knowledge of the Bhopal gas leak, developing this problem tree gave the author some new views on the connection between causes and effects. However, the tree looks more like a "problem net". Also when drawing the tree of objectives, the author got some new ideas on measures necessary to prevent an accident or mitigate the effects of it. The matrix makes it possible to clarify what processes/changes from other instances that are needed if the project should succeed.

CONCLUSIONS

Models developed for analysis of injuries can be used for analysing a complicated mega accident like the Bhopal gas leak, although different models might stress different aspects. Visualising causes and consequences in tree models might provide a new understanding. When visualising causes and consequences to this kind of accident, it is obvious that "chain" or "tree" are not the right words. "Net" is more appropriate.

Analysis according to the LFA problem tree demonstrates that to create the mega-gas leak, it was not enough that water entered the tank. The most important factors were the plant design and cutting down the expenses because of economic pressure.

The same analysis shows that the most important factor for the outcome of the leakage is the negligence of the Union Carbide Corporation and the Governments of India and Madhya Pradesh.

To reduce the influence on public health of chemical industries, there is great need of actions from many actors. The governments have a responsibility to protect their inhabitants from the negative effects of "development". As a result of globalisation, co-ordination between governments and national organisations is necessary.

4. INTRODUCTION TO THE BHOPAL SAGA

4.1 The chemical industry and public health

During the last century, the chemical industry, including the pharmaceutical industry, has grown and developed enormously. It is estimated that several hundred new chemical compounds are being synthesised every day. We know very little about the effects of these compounds on human beings, animals and eco-systems, in either the short or the long term. The trial and error method seems to be the most common method used for risk assessment.

A number of these compounds, as well as many intermediates and waste products, are toxic to nature and to human beings. The health of workers and residents in proximity to mines, transportation routes and plants will be affected, as well as coming generations.

When we talk about "pesticides and developing countries", we should not only consider the use of pesticides, but also their production. Production of pesticides is a part of the chemical industry, which is growing rapidly in developing countries. The history of the chemical industry is lined with chemical accidents and the exposure of workers and people around the plants. The chemical industry is an important factor from a public health point of view.

Pesticides and the chemical industry in developing countries are a public health problem also for those of us who live in high-income countries. Hazardous products and processes exported to the third world are already returning to the developed countries in a "circle of poison". The physical consequences of a chemical accident might spread to other countries through water, wind and food. The political and economic consequences might also spread all over the world.

Cassels [1] points out that the internationalisation of both business and environmental degradation is increasingly teaching the developed world that the provision of aid to poorer countries – in order to better manage the risks and effects of industrial development – may no longer be a matter of charity, but an imperative motivated by self-interest.

The gas leakage from Union Carbide's plant in Bhopal, India, in 1984 is the largest industrial hazard ever experienced in the world. Over 500,000 persons were exposed to the gases, between 3,000 and 10,000 people died within the first weeks, and between 100,000 and 200,000 may have permanent injuries.

Because of its magnitude, this catastrophe has not been forgotten. Hundreds and hundreds of articles have been published as well as several books. Different kinds of research has been done. The process that led to the leakage, the effects of the gases, and the actions of the company, the government and the medical and scientific establishments are documented in hundreds or thousands of articles and several reports and books.

There is no evidence that the processes and actions would have been different with other chemical accidents. On the contrary, the knowledge about Bhopal can be used when we study other accidents or discuss what measures should be taken to prevent exposure to toxic chemical substances.

The Bhopal Gas Leakage has become a symbol of transnational corporate negligence towards human beings. It has thus served as a wake-up call. All the same, industrial disasters still happen, in India as well as in the industrialised parts of the world. Although they are far from the size of Bhopal, they are so numerous that chemical accidents could well be considered to be a public health problem. The companies usually dispute their own role in the accidents and deny the effects of the accidents on health. The companies have also been reluctant to compensate the victims economically.

In 1984, 40 workers had to be hospitalized because of a chlorine leakage from a textile mill in Kerala. In Gujarat in 1987, 5,000 persons were injured because of a gas leakage. In an explosion in a ship in Maharashtra in 1991, 100 persons were killed. During 1994, around 50 chemical and/or fire accidents were voluntarily reported from within Madhya Pradesh to the Disaster Management Institute in Bhopal (personal correspondence).

Industrial disasters also happen in the industrialised part of the world. In the USA, during 1985 more than 16,000 persons were evacuated, 31 were injured and 30 killed in 9 chemical accidents. In Union Carbide's factories in USA and Europe, more than 700 have died, several hundred have been injured and 17,000 have been evacuated because of accidents. After installing a new safety system at the MIC-plant at Institute, West Virginia, 135 people were injured by toxic gases in 1985. Wells and vegetables have been contaminated and ruined by Union Carbide pesticides.

The pharmaceutical industries are no better. In Seveso, in Italy in 1976, 1,000 persons were evacuated and 100,000 cattle died. During 1986, massive amounts of toxic chemicals, including 66,000 pounds of pesticides, were accidentally released into the river Rhine by Sandoz, Hoechst, Bayer and Ciba-Geigy. In 1997 during the building of railway tunnels in Sweden and Norway, the use of the tightening compound Rhoca-Gil, manufactured by Rhône-Poulenc, led to the leakage of acrylic amid into the groundwater.

There are some similarities between the accidents:

- The catastrophes affect countries outside those where the transnational companies are seated. Production is often established in countries where regulations are less stringent.
- Trade unions and occupational health care seem to have been poorly developed, having little influence on the work environment.
- It seems as though the catastrophes could have been predicted and prevented.
- The companies have disputed their own role in the accidents and denied the health effects of the accidents.
- The companies have been reluctant to compensate the victims economically.

"Syndrome" from a medical point of view is a combination of several symptoms and findings. So far, we have used "the Bhopal syndrome" for the combinations of symptoms and affected organs for the gas affected. But maybe, one could talk also about the "Bhopal syndrome" as a matter of occurrence. We know that small Bhopals happen every day – the mechanisms and the affected organs seem to be the same as for the original Bhopal catastrophe.

4.2 Human rights

After the Bhopal tragedy, the Permanent Peoples' Tribunal in Bhopal in 1992 concluded that fundamental human rights had been grossly violated in terms of a series of articles in the various international declarations concerned with human rights [2].

National governments have signed those declarations and many try seriously to follow them. Thus, it is possible to sue with the International Tribunal for Human Rights in the Hague.

However, sometimes transnational companies have more power than national governments. In 1993, the fifteen largest corporations in the world had gross incomes greater than the gross domestic products of over 120 countries [3]. So far, these corporations have not signed any declarations on human rights.

One might expect that human rights included the right to life and health as well as the right to a healthy environment.

However, in the *International Bill of Human Rights*, nothing is said directly about human rights to life and health, or human rights to a healthy environment [4].

In the *Universal Declaration of Human Rights*, the following text was found, which to some extent supports the idea of rights to health and a healthy environment:

> "Everyone, as a member of society, has the right to social security and is entitled to realisation, through national effort and international co-operation and in accordance with the organisation and resources of each State, of the economic, social and cultural rights indispensable for his dignity and the free development of his personality" (Article 22).
>
> "Everyone has the right to a standard of living adequate for the health and well-being of himself and of his family, including food, clothing, housing and medical care and necessary social services, and the right to security in the event of unemployment, sickness, disability, widowhood, old age or other lack of livelihood in circumstances beyond his control" (Article 25:1).

The *International Covenant on Civil and Political Rights* in Article 6:1 states that "every human being has the inherent right to life. This right shall be protected by law. No one shall be arbitrarily deprived of his life."

The *International Covenant on Economic, Social and Cultural Rights*, however, is clearer on rights, health and environment. Article 8 talks about the right to form and join trade unions. In Article 12, the "right of everyone to the enjoyment of the highest attainable standard of physical and mental health" is recognised. It includes child health, improvement of environmental and industrial hygiene, prevention and treatment of occupational diseases, and assurance of medical service and medical attention.

4.3 Bhopal: History, geography and demography

Bhopal is an old town with a Mogul past. In the 1950s it had only around 60,000 inhabitants. When it became the capital of Madhya Pradesh, it started to grow rapidly. It is the centre of administration, education and political and economic power as well as culture. It is also the centre of communication and a railway junction.

Bhopal is situated in the centre of India, 500 metres above sea level. It is surrounded by hills, forests and fields. There are two large lakes, the Upper Lake and the Lower Lake, which are actually two dams, built one thousand years ago. The area of the Bhopal municipality covers 285 sq.km.

North of the dams lies the Old Town, with narrow streets, 2–4 storey houses, markets, mosques and the railway station. It is crowded with people. This is where the poor population lives. They are labourers, loaders, handcart pullers, carpenters, domestic servants, and many keep cattle. South of the dams is the New Town, with some parks, broad avenues, modern building complexes here and there and widespread villa quarters. Both areas are partially mixed with and surrounded by squatter slum areas, but by and large fairly rich people live here.

Bhopal is surrounded by hills. The plant of Union Carbide Indian Limited (UCIL) is situated in the north, adjacent to densely populated slum wards and the railway station. As early as 1975, it was pointed out that 12 colonies thickly surrounded the factory and thus posed serious environmental hazards [5]. Further south is the Old Town, which slopes upwards toward the Lakes and the New Town. New slum areas have grown up around the factory, even on ground that is most probably still polluted by different chemicals from the factory [6].

In 1984, Bhopal had around 800,000 inhabitants. In 1981, 38 % of the population were in the age group 0–14 years [7]. The 36 wards that were classified as affected had around 520,000 inhabitants [8]. This means that around 200,000 children between 0–14 years were affected by the gases.

In 1985, of the total affected, 80 % earned below Rs 145 per month (around US$ 5). 1,2 % earned more than Rs 465 per month. 47% lived in a kuccha (non-permanent) house. 50 % were Hindus and 49 % Muslims [8]. Muslims are generally considered to be poorer than Hindus are and it is less common for Muslim women to work outside the home.

The total population of Bhopal in 1994 was 1,062,800. The number of houseless households was 5,331. With a mean household size of 5 people, it means around 29,000 people do not have a house [9].

The density of the population is 3,746 per sq.km. For the city, the birth rate is 29 per 1,000, the crude death rate 9 per 1,000 and the infant mortality rate 78 per 1,000 live births [10].

After the gas disaster, it was found that 55 % of the population in the Old City was Hindu and 43 % Muslim [11].

The per capita expenditure on family welfare services by the government of Madhya Pradesh was Rs 7.08 during 1985–1986 [10].

The inflation rate has been high. In 1994, 1 rupee was worth one-third (or 30 paysa) of the 1984 rate. Bhopal is said to have become one of the most expensive towns in India since the interim relief began to be paid out.

4.4 References

1. Cassels, J., *The Uncertain Promise of Law: Lessons from Bhopal*. 1993, Toronto: University of Toronto Press Inc.
2. *Asia '92. Permanent Peoples' Tribunal. Findings and judgements*. in *Third session on industrial and environmental hazards and human rights*. 1992, Oct 19-24. Bhopal-Bombay.
3. Morehouse, W., *The ethics of industrial disaster in a transnational world: The elusive quest for justice and accountability in Bhopal*.
4. *The International Bill of Human Rights*. 1993, United Nations: New York.
5. *Socio economic impact of disbursement of interim relief to gas affected families of Bhopal*. 1991, Academy of Administration, Government of Madhya Pradesh: Bhopal. p. 154.
6. *Union Carbide in Bhopal, India. The lingering legacy. Analyses of carbide related toxins at the former UCIL site*. 1990, National Toxics Campaign Fund: Boston.
7. *Census 1981*. 1982, Government of Madhya Pradesh, The Census Department: Bhopal.
8. *Annual report 1990*. 1990, Indian Council of Medical Research, Bhopal Gas Disaster Research Centre, Gandhi Medical College: Bhopal.
9. *Census 1991*. 1991, Government of Madhya Pradesh, The Census Department: Bhopal.
10. *Report on family welfare/primary health care needs of slumdwellers of Bhopal town and formulation of proposal for strengthening of existing family welfare services and creation of new health facilities*. 1992, Department of Preventive and Social Medicine, Gandhi Medical College: Bhopal.
11. *Compensation Disbursement. Problems and possibilities*. 1992, Bhopal Group for Information and Action: Bhopal.

5. OBJECTIVES AND METHODS

5.1 OBJECTIVES

The general objective of this report is to produce a reliable overview of the Gas Leakage in Bhopal in 1984.

The specific objectives are to analyse available material to find answers to the following issues:

- If and how the accident could have been prevented;
- What the probable components of the gases were;
- Whether these components could explain the deaths, the permanent injuries and the distribution of symptoms and injuries from grave to light;
- If and how the immediate treatment of the survivors could have been more efficient;
- If and how the long term effects on health could have been mitigated;
- If and how the long term socio-economic effects could have been mitigated;
- If the accident had any influence on the safety policies of the chemical industry in India.

To use the knowledge gained in a discussion on:

- How chemical disasters can be prevented;
- How outbreak epidemiology should be designed;
- The demands to make of authorities, medical establishment and the WHO in the prevention and management of industrial disasters.

5.2 METHODS

The book is based on material already published in India and other countries, and on the author's experiences from repeated visits to the city of Bhopal, totalling eight months during 10 years.

The collected material can be classified as follows.

Scientific papers and reports

- By members of IMCB
- By other (medical) authors
- Research on MIC

Material from ICMR

- Manuals and the like
- Annual reports
- Other reports

Material from official Indian authorities

- Government of Madhya Pradesh
- Central Bureau of Investigation
- Disaster Management Institute

- Gandhi Medical College
- Council for Scientific and Industrial Research

Material from Union Carbide
- Manuals, published before 1984
- Pamphlets, video and other material, published after 1984

Material published by NGOs
- BGIA: pamphlets
- Sambhavna: newsletters, annual reports, papers
- Other NGOs

Books
- *Bhopal: Industrial Genocide?* (Arena Press) A collection of 30 articles published in different newspapers in 1984.
- *Bhopal Gas Tragedy* (Delhi Science Forum). A thorough examination of the causes and the management of the accident, written in 1984 and 1985.
- *Nothing to Lose but Our Lives* (Dembo et al). A series of articles by different authors, dealing with industrial hazards.
- *Corporate Killings. Bhopals Will Happen* (Jones) is a thorough examination of what was known in 1987.
- *The Bhopal Syndrome. Pesticides, Environment and Health* (Weir).
- *The Uncertain Promise of Law: Lessons from Bhopal* (Cassels) is a thorough examination of the relations between multinational corporations, governments and the people.
- *Bhopal: The Inside Story* (Chouhan). The main section was written by a former MIC plant operator in the UCIL factory in Bhopal. One appendix has testimonies from 16 plant personnel. Another describes the legal issues.
- *The Ophidian and the Orphans of Bhopal* (Pandey) is mainly about legal issues.
- *Bhopal Tragedy. Socio-Legal Implications* (Chauhan) deals with the economic compensation and the social rehabilitation.
- *It was five past midnight in Bhopal* (Lapierre, Moro) is a novel based on interviews and studied material.
- *Silent Invaders* (Jacobs et al) is a series of articles on pesticides and women's health.
- *Asphyxiating Asia* (Mac Sheoin) is a thourogh examination of what the development of chemical industry in Asia means to people and environment.

Articles from non-scientific papers

Reports

Background material
- Toxicology and pathology
- Pathology
- Injuries
- Post traumatic stress disorder
- Night work
- Socio-economic conditions and health
- Environmental risk management
- Human rights

Web sites

Submissions (in addition to the material above)
- from survivors to IMCB
- from activists and doctors to IMCB

Interviews
- Ms Rashida Bee, the president of Bhopal Gas Affected Women's Stationery Workers' Union
- Ms Champa Devi Shukla, the secretary of Bhopal Gas Affected Women's Stationery Workers' Union
- Mr Abdul Jabbar Khan, the convenor of the Bhopal Gas Peedit Mahila Udyog Sangathan
- Mr T R Chouhan, a former operator at UCIL plant in Bhopal
- Mr N D Jayaprakash, Bhopal Gas Peedit Sangharsh Sahayog Samiti and Delhi Science Forum
- Mr Satinath Sarangi, the convenor of BGIA and the managing director of Sambhavna clinic
- The late Dr Dwivedi, MD, former director of ICMR in Bhopal
- Mr Deena Deenadayalan, the Other Media, Delhi
- Drs Desphande, Qaiser and Kaur, Sambhavna Clinic

Many statements and submissions are repeated in different articles and books. For practical reasons, some books and articles are chosen as major references. When the statements in other sources are congruent with the major references, they will not be indicated in the text.

The full list of reference material and other studied material is found at the end of this report.

The conceptual models for accident and injury analysis by Haddon and Berger were originally used to analyse the causes of the disaster and its consequences. As a complement, the Logical Framework Approach was tested on this mega-accident. As this model seems more complete and useful for this complex situation, it is included in this book. However, the Haddon structure pre-event, event and post-event phases, is used for the structure of the book.

5.3 COMMENTS

The quality of the collected material can be discussed. This is especially true with regard to the submissions from survivors and workers.
- Submissions by survivors may have been biased because of hopes of economic gain.
- Submissions by workers may have been biased due to the intention of avoiding responsibility.
- Even when survivors' home language is Urdu, the interviews are likely to have been held in Hindi.
- Submissions have been translated into English; qualities may have been lost.
- Foreign journalists generally do not know Urdu or Hindi. Many interviews must have gone through an interpreter or were conducted in bad English.
- Many of the original statements or submissions have been repeated in different articles and papers in a way that makes it seem as if they were new.

Quite a few times, data about the material is missing – author, publisher and/or year of publishing. Referring to research is done, without references being given. This creates an uncertainty about the relevance and adequacy of the material.

Some material is missing, because it is not released.

- It is very probable that UC knows much more about the composition of the cloud compared to the information they have released.
- It is likely that there still exists information from governmental institutions which has not been released, for instance, why the Government of India suddenly accepted the sum of compensation offered by UC.
- ICMR's annual reports were kept secret for many years.
- The surveys undertaken by the Tata Institute immediately after the disaster are still not released.

The quality of the epidemiological and clinical research material will be discussed in chapter 8.2.

Although the list of studied material is extensive, I am fully aware of that I have missed information. More interviews should have been done with doctors and officials in Bhopal. I hope those who have something more to add will contact me.

6 THE PRE-EVENT PHASE: THE PROCESS THAT LED TO THE LEAKAGE

6.1 BACKGROUND

6.1.1 The Green Revolution

In the 1960s, the market for pesticides in Europe began to be saturated and, because of new knowledge and protests from environmental activists, became restricted. The multinational corporations then turned to the Third World, which offered cheap labour, low maintenance costs and relative indifference to occupational health.

During the 1950s and 60s, failure of the crops and famines were common occurrences in Asia. The "Green Revolution" was considered to be the solution, not only by the chemical industry, but also by farmers, governments and NGOs [1]. In India, the Green Revolution displaced traditional growing methods with high yielding seed varieties that required large amounts of fertilisers and pesticides. The government encouraged the production of pesticides locally, but it was insufficient. In 1966, Indian leaders decided to turn to foreign manufacturers. UCC immediately imported American Sevin, and undertook to build a Sevin-producing factory within five years.

The effects of pesticides on health soon became obvious. Illiterate peasants, labourers and their families were exposed to massive doses of the toxins when handling the pesticides, without receiving instructions or safety precautions [1]. Accidents were regularly reported in the newspapers. In some areas, cancer rates rose quickly. Psychological disorders were common. Pesticides became the most used method for committing suicide. Peasants who doubled or tripled the recommended dosage were ruined.

India had isolated itself from the global economy [2]. At the time of the Green Revolution India had greater autonomy in relation to multinational capital than had Latin America countries. The Green Revolution was a co-production of state and capital. At the time of the Bhopal massacre, the balance of power between state and capital had shifted, with the collapse of the command economies and India's desire for economic modernisation and liberalisation.

The Indian Government was very keen on establishing chemical industries. Indian authorities stated in 1998 that one of the competitive advantages that India had was that companies are comparatively free to pollute there [3].

6.1.2 Union Carbide Corporation

The creation in 1917 and the development of Union Carbide Corporation (UCC) are described by Mac Sheoin [2]. UCC has innumerable times violated the environment and the health of workers and residents [1, 2, 4-6]. For example, during the years 1980-1984, sixty-seven leakages of MIC occurred at the Institute's factory. The management of the factory took care not to bring these leaks to the attention of the people living in the valley, claiming that none had posed a real threat to health, nor exceeded the legally accepted standards for toxic emissions in the atmosphere [1].

As part of its internationalisation, Union Carbide became India's first petrochemical producer. For nearly a century, UCC's lamps and batteries brought light to remote farms and villages [1]. In India, UCC manufactured chemical products, plastic goods, photographic plates, films, industrial electrodes, polyester resin, laminated glass and machine tools.

Union Carbide Corporation (UCC) is the parent company and Union Carbide India Limited (UCIL) the Indian subsidiary. 50.9 % of the stock was held by UCC and 49.1 % by various Indian investors, including public sector financial institutions.

UCC was allowed majority ownership, despite government limitations on foreign investment, because of the technological sophistication of its operations. UCC chose all production processes, supplied all plant designs and designated operational procedures. UCC also conducted the safety audits.

Managerial control of UCIL was exercised by Union Carbide through its Eastern Division headquarters in Hong Kong [7]. There is evidence that even minor production and maintenance decisions were made there [6-8].

This picture was added to the pdf-version of The Bhopal Saga in September 2014.

6.1.3 The UCIL plant in Bhopal

The process of creating the UCIL plant in Bhopal is described by Lapierre and Moro [1]. It was welcomed not only by the authorities, but also by the residents, who saw opportunities to get jobs. To work for UCIL meant a high salary as well as high social status. UCIL developed social activities like sport and entertainment that involved the whole community.

The Union Carbide plant in Bhopal opened in 1969 to manufacture pesticides [6, 7]. At first, UCIL in Bhopal only formulated carbamate pesticides from concentrates imported from the US.

The pesticide plant at Bhopal was a facility set up in 1977 for the manufacture of Sevin (carbaryl) and its formulations. Initially, the primary raw materials were imported from the USA. The highly reactive MIC was transported on lorries, with police escort, from Bombay to Bhopal. Only from 1980, did the Bhopal plant start manufacturing methyl isocyanate (MIC), using the know-how and designs supplied by the parent company in the USA. The plant also produced carbon monoxide and phosgene, both of which are required for the production of MIC [9-11].

The Government of India granted UCIL a license to manufacture 5,000 tons of Sevin a year. The UCC man in Bombay realised that annual sales would not exceed 2,000 tons. He tried in vain to persuade the management committee in New York to plan a smaller plant. The president, the directors and the engineers were obsessed by the idea of creating the most beautiful pesticide plant in India and ignored advice from the man on the ground [1].

The production of pesticides at the UCIL plant in Bhopal was not a great success. Repeated droughts in combination with an unsatisfactory effect of the pesticides, led to a decline in pesticide sales. In 1982, sales equalled less than half the production capacity – in 1984, less than a fifth. In 1982, the alpha-napthol plant was closed down – it had never been able to supply a product that was pure enough [1, 12]. The MIC unit was over-dimensioned from the beginning and always ran at a loss. Because of this, the work force was reduced. Immediately prior to the accident, UCC had been considering ways in which it might divest itself of the Bhopal operation or dispose of the plant. One suggestion was to dismantle the plant and ship it to Brazil or Indonesia, but objections to this were raised "because of the high corrosion at several points" [1, 12].

The Bhopal plant included a research centre, the biggest in Asia, with five insect-rearing laboratories and a two-hectare experimental farm for testing chemical agents [1, 13, 14].

From 1977 to 1982, the pesticide plant was managed by an American engineer, who had one essential principal: "Always keep only a strict minimum of dangerous materials on site." He was also keen on safety precautions. He worked hard at being a good leader. In 1982, he was replaced by an Indian-born engineer, educated in the USA. The directors of UCIL made him subject to a financial controller whose purpose was to reduce the factory's losses. These two men had a more hierarchical sense. As wages constituted the primary expense, they started to dismiss first *coolies*, and later skilled workers and technicians [1, 8].

6.2 DESIGNS IMPORTANT FOR SAFETY

Between 1958 and 1973, Union Carbide used an alternative way of producing carbamate pesticides, without using MIC. For economic reasons this was changed to a more hazardous method [10].

MIC is produced by a reaction of phosgene and monomethylamine (MMA) into methylcarbamyl chloride (MCC) and hydrogen chloride (HCl). MCC is then pyrolysed to yield MIC and HCl [15]. Chloroform is used as a solvent in the MIC process, and caustic lye for the neutralisation of any toxic material that needs to be disposed of.

Chouhan [10], Delhi Science Forum [9], CSIR [15] and the Disaster Management Institute [11] describe the design of the MIC plant in Bhopal:

Instead of using a "closed loop" process, where MIC was converted as soon as it was manufactured, UCC applied for large-scale storage of MIC, consisting of three horizontally mounted stainless steel tanks. Normally two of the tanks (no. 610 and 611) were used to store the product when it was of acceptable quality. The third tank (no. 619) was used for temporary storage of off-specification material until it was reprocessed. The two tanks could hold around 90 tonnes of MIC, sufficient for about 30 days' production of Sevin. Any off-specification material not reprocessed was sent to the vent gas scrubber for neutralisation with caustic solution.

The UC manual [16] states that one tank should always be kept empty, that the tanks should not be filled to more than 60 percent, that the tanks should be kept under an atmosphere of nitrogen with a pressure 1,0 kg/cm^2, and that the temperature should be kept below +5° C. Only stainless steel tanks should be used and it was prohibited to use iron, carbon steel, aluminium, zinc, galvanised iron, tin, copper and their alloys.

The relieve valve vent header (RVVH) provided a relief line for toxic gases to be routed to the vent gas scrubber (VGS), in the event that a pressure build-up in any one of the tanks caused a large volume of gas to escape [8]. If the pressure within the tank were to exceed 40 psig[1], it would cause a rupture disc fitted to the end of the RVVH line to give. The gas so released would force the relief valve to open, which allowed the gas to flow down the RVVH directly to the VGS.

A second line, called the process vent header (PVH) led from the tanks to the VGS. The nitrogen pressurisation system was connected to this line. To ensure that MIC did not come into contact with moisture in the air, the chemical was stored under pressure and protected by a blanket of dry nitrogen. If the pressure in a tank fell below the operating pressure of 2 psig, nitrogen was fed into the tank [8].

The vent gas scrubber (VGS) consisted of columns packed with ceramic balls. The bottom portion of the scrubber held about 21,000 gallons (95 m^3) of 10 percent caustic solution, which was pumped to the top of the scrubber. The waste gases were scrubbed by a counter-

[1] Pounds per square inch above atmospheric pressure

current flow. After scrubbing, the gas was flared or released through a 33.5 m high stack. While the flare tower primarily burnt vent gases from the carbon monoxide unit, it also burnt vent gases from the MIC storage tanks.

The written instructions which the workers were to follow in washing out the lines at the MIC unit omitted the procedure that a slip-bind be inserted, according to a report 1985 by the Union Research Group of Bombay, "The role of management practices in the Bhopal Gas Leak Disaster" [8].

Until May 1984, the lines to the RVVH and the PVH had been unconnected and each performed a separate function [8]. The management wanted a standby line in the event that either the PVH or the RVVH needed to be shut down for repair. A jumper line between the two lines provided an easy solution.

When the plant was first designed, the managing director of UCIL recommended that the preliminary design of the Bhopal MIC facility be altered to involve only token storage in small individual containers. However, UCIL was overruled by the parent corporation, which insisted on a design similar to the West Virginia plant [1, 6, 17].

But for reasons of economy, Bhopal's "beautiful plant" would not be provided with all the safety equipment and security systems the engineers in South Charleston had envisaged. The precise reasons for these economies would remain obscure [1].

In 1975, the state government prepared a master plan for the city of Bhopal. A sparsely populated site outside Bhopal was designated as an industrial area for hazardous facilities. In spite of warnings, Union Carbide insisted on building the MIC production and storage unit at an existing Union Carbide facility upwind from the city, mainly because it was cheaper to draw on the infrastructure of the existing facility [1, 18].

The chief engineer was worried about the squatters just outside the wall around the factory area. He asked the municipal authorities to force people to move, and he proposed drawing up an evacuation plan. However, the Chief Minister considered this would reduce his chances of re-election [1].

The policy of UCC was to maintain "centralised integrated corporate strategic planning, directing and control" [17]. The Indian subsidiary had to send detailed monthly operating reports to UCC [8]. All accidents involving fatal or serious injuries "will be reviewed by the UCC executive officer". In 1982 over 30 percent of UCIL's raw materials, spare parts and components were imported [13]. Training for Bhopal management was also provided in the USA. UCIL was one of the few firms in India in which the parent company was allowed to maintain a majority interest, because it possessed all "know-how".

After the leakage, UCC's first line of defence was that the equipment installed in Bhopal was made in the USA to US specifications, with safety equipment and standards virtually identical in both Bhopal and the Institute, Virginia [13]. Because of the reactions in Virginia, UCC was forced to admit that this was not the case.

Survivors and NGOs have accused UCC of using double standards for safety when planning factories in developing countries. In Table 1, we can compare the design used for the Bhopal plant as well as available alternative techniques.

Table 1. Technique used in Bhopal, and alternative methods

Ref.	*Bhopal plant*	*Available alternative*
6, 9	Using MIC in the production of pesticides	Two-step process without MIC (patented by UCC)
6, 9	Storing large amounts of MIC for long periods	Storing small quantities for short periods (as in Virginia)
6, 9	Storing MIC in large tanks	Storing in small vessels (as in Texas, France, West Germany, Japan and Britain)
9, 12	Manual monitoring of important instruments	A fully computerised 4-stage alarm system (as in Virginia)
9	No chemical inventory monitoring	A chemical inventory monitoring (as in Virginia)
9	No "knock down" tank	A "knock down" tank to take out MIC discharge to the flare tower (as in Virginia)
8, 9	Vent Gas Scrubber with limited capacity	An extra Emergency Gas Scrubber with extra capacity (as in Virginia)
8, 9	Flare tower with limited capacity	Flare tower designed for "worst possible" scenario
15	Possible to shut down VGS and flare when MIC production stopped	Continuous operation of VGS and flare
9	Keeping MIC tank at 0° C	Keeping MIC tank at –10° C (as in Virginia)
9	Possible to move or switch off refrigeration system	An extra emergency refrigeration system
6, 12	Water spray was designed to reach 15 m (the flare tower was 33 m high)	A larger water spray system (as recommended after the 1982 UCC inspection)
8, 15	Carbon steel in adjacent lines	Only stainless steel (as recommended in the UC manual on MIC)
6, 9	Location close to a large densely populated area	Location downwind, outside town (as called for in the Bhopal Development Plan)
1	Alarm system directed only at the workers at the factory site	Alarm and loudspeakers pointed outwards, in the direction of the *bastis*
1, 6, 8	The alarm siren automatically stopped after ten minutes. A less noisy alarm that could not be heard outside the factory area took over. Loudspeakers were used to instruct workers	An alarm system, including loudspeakers, that reached the residents

6.3 MANAGEMENT IMPORTANT FOR SAFETY

6.3.1 Education of workers

The education of the operators is described by Chouhan [10] and others [6, 19].

To be an operator in the MIC plant at the beginning, one had to be either a graduate in science or hold a diploma in mechanical or chemical engineering. The training of the operators at the MIC plant was later shortened from 6 months to 8 weeks. As a rule, workers and operators were given more responsibility than they had the training and competence to cope with. Vacancies at the MIC plant were filled by unskilled personnel from the closed-down parts of the plant.

In 1982, most of the original MIC operators had resigned from UCIL, because of the staffing policy of the company (see 6.3.2). After the shutdown of the napthol plant, these workers were asked to take MIC plant training without any official letter. The operators' opinion on the two months of classroom training was that it was just a formality. After only 14 days of training in the MIC unit, they were asked independently to take charge of a regular plant operator's position.

The secrecy issue hampers the acquisition of knowledge by the workers [9]. Employees were never permitted, even during training, to take the company's specialised literature and safety manuals outside its premises. The manuals themselves were kept in the safe custody of the manager. Furthermore, the plant-operating manual was available only in English [7].

6.3.2 Staffing policy

Chouhan describes how in 1975, a group of new technicians were employed for an 18 month training period [10]. During this period, they were treated as casual workers. After the training, they were only placed on an hourly rate. Among the workers, it was known that the MIC plant was the most dangerous. When Chouhan accepted a job there, he got a paper about receiving six months training. After five weeks, he was asked to stop the training and to take charge as a full-fledged plant operator. After opposing this, he got another three weeks training.

In the matter of promotions, individuals with little experience but with unquestioning loyalty to the bosses were invariably selected before others [10]. A demand for extra safety precautions led to warnings that appointments could be terminated [10, 19].

Contract workers without safety equipment did dangerous work that should have been done by machines. Workers and operators were routinely exposed to toxic chemicals like MIC, carbon tetrachloride, trimethylamine, alpha-napthol and carbaryl dust. They seldom had the equipment recommended in the manuals [16, 20].

In 1983 and 1984 there were personnel reductions in order to cut costs. A number of workers were encouraged to take early retirement, some 300 temporary workers were laid off, and another 150 permanent workers were put in a pool to be assigned to jobs as needed [8]. The operating shifts were cut from twelve to six and the maintenance shifts from six to two [6, 8, 10]. The positions of second- and third-shift maintenance supervisor had been eliminated just a few days before the disaster [8, 21]. Employees were often assigned to jobs for which they were not qualified. If they refused, their salaries were reduced [6]. On the night of the disaster, there were no trained engineers on the site [10]. The production supervisor who was on duty had been transferred from a Carbide battery plant only a month earlier [8].

Operators were examined by the plant doctor every six months, which included an examination of blood and urine. The employees were never told the results of these examinations [10]. The UCIL management advised the workers to develop resistance against toxic substances by drinking six or seven glasses of milk a day and eating a high-protein diet of fish and eggs [13].

The personnel management policy led to an exodus of skilled personnel to better and safer jobs. The degradation of the "beautiful plant" contributed to this.

6.3.3 Information

Most of the workers at the UCIL Bhopal plant had not received training or information about the hazards of the toxic chemicals in the plant. Residents of the adjacent *bastis* thought the plant was making "medicine" for crops. City and state authorities were not provided with information on the chemicals in the plant [6]. Although UCIL had provided Hamidia Hospital with modern resuscitation equipment, the medical staff engaged by Carbide did not get any specific training in the pathology of gas related accidents [1].

Neither UCIL nor government had prepared an evacuation plan, an emergency response system or a medical plan [17].

Company policy forbade employees to speak for the company without authorisation, especially in emergency situations [17].

6.3.4 Management of the plant

Chouhan [10] and other workers [6, 19] describe how operational problems in different parts of the Bhopal plant were solved through design modifications. Most of the modifications of the original design consisted of changes from automatic and continuous to manual and batch processes. This led to more hazardous working conditions, poor recovery of solvents, and leakage of chemicals, leading in turn to atmospheric pollution and inadequate control over the whole process of production.

In 1978, there was only one fire truck at the factory. When this was out of order, there was no fire truck [10].

In 1983, there was great pressure from the Danbury head office in the USA to cut expenses. Decisions were made to prolong the time between certain checks from six to twelve months, and to replace damaged stainless steel pipes with ordinary steel pipes [1]. Items that should have been replaced every six months had been over-used for more than two years [9, 12]. Faulty instruments were not replaced. In late 1983, the principal safety systems were shut down, as the plant was not operating [1].

The plant had been shut down for a maintenance overhaul and to reduce inventories for over a month prior to the accident. The maintenance operation was almost complete and the plant ready to resume operations by early December [8].

As the parent company held sole responsibility for all design decisions relating to the Bhopal plant, the Indian subsidiary must have secured the parent company's approval for the process modification. The former safety officer of the plant said in an interview that any design change or change in the material of construction had to be approved by the US. According to the CBI inquiry, approval to install a jumper line was given in May 1984 [8].

In Table 2, the management of the different safety systems of the MIC plant is described. This can be compared to the recommendations in the UC manuals on MIC [16, 20, 22].

Table 2. Safety systems and management.

Safety system	*Ref.*	*Comments*
Filling of tanks	1, 6, 23 1, 6, 23	• Tank 610 was filled well above the recommended level (75–87 % instead of 60 %). • Tank 619 was not kept empty for emergency needs.
Pressure	6 1, 8, 23, 24 8	• Tank 619 was not kept under pressure. • Tank 610 could not be pressurised on October 21, November 26 or 30 and December 1. • The level indicator (LI) was faulty.
Temperature	21, 23 8, 10 10 1, 8 6, 8, 23	• No tank temperatures were logged for a long time. There was no column for it in the log book. • The rule on temperature was rewritten so as to shut down the MIC refrigeration unit when production was not in process. • The temperature of MIC was not recorded on the log sheet. • The alarm that should have gone off in case of any abnormal rise in temperature (15° C) in the tanks had been disconnected years earlier. • The refrigeration unit had been shut down one year earlier and moved and/or the freon been drain off.
Vent Gas Scrubber	8, 10 10 6, 10, 23	• Safety specifications were rewritten to allow the VGS to be shut off when the plant was not in operation. • The caustic soda feed to the VGS was modified into a batch process, from the continuous process originally designed. • The VGS had been moved from an operating mode to a standby mode on October 23, 1984, after the MIC unit was shut down with a total MIC inventory of 83 tonnes in tanks 610 and 611. The return to an operating mode was dependent upon the operator being alerted to any problem and taking prompt action to activate the circulating pump.
Lines	8 8	• As a section of the PVH was under repair, the jumper line had been left open. • Components of the PVH and RVVH pipelines were made of carbon steel.
Flare	6 6, 10, 23	• The backup, set to ensure that the pilot light stayed on, was discontinued to save money. • On November 25th, a section of corroded pipe had been removed for maintenance work. A replacement pipe could have been prepared in the plant, and should have taken only four hours to install.

	10	• The pilot flame in the flare tower was lighted only when the carbon monoxide plant was running.
Analyses	10 23 23	• The rules on parameter reading were rewritten to do a reading every eight hours, compared to every hour during 1979-80. • No analysis of caustic concentration had been made since October 23. • There was no record of analyses of MIC in tank 610 after October 19.
Alarm	8, 10, 19, 24 1	• The siren had been delinked from the alarm so that the operators could warn just their workmen, without "unnecessarily" alarming the people outside the plant. • The windsock, that showed the wind direction, could be seen only within the factory area. There was no windsock for the residents.
Meters	6, 10, 23 6, 10 10	• The temperature indicator alarm was malfunctioning from just after the time the plant began operation, and recording of temperatures could not be done. • The level indicator and alarm of the storage tank were often out of order. This created the possibility of overflow in filling the tank, and made it impossible to see if the level was reduced because of leakage. • Air supply to critical monitoring instruments and gauges was cut off during plant shutdowns.
Design	10 8, 10, 13	• Faulty plant design was worsened by on-site management decisions to bypass approved operating procedures to save time and money. • A design modification in 1983 and/or 1984 (a jumper line between the lines to RVVH and PVH) provided a route for the water to enter the MIC tank 610.
Maintenance	10, 23 6, 10 6, 10 10 1 10	• Lines were corroded • Malfunctioning valves were not replaced. • Faulty gauges were not repaired. • Key instruments were absent. • The stopcocks controlling access to the decontamination tower were turned off because the factory was not in service. • Since one month, the pressure control valve on tank 610 was malfunctioning, thus allowing water to enter the tank when the connecting lines of the RVVH downstream were being washed.
Personnel	10 6, 8 6, 8 6 6, 10 6, 10 13	• Reduction of the work force and a high turnover of trained workers led to the workers not having the proper education. • The post of maintenance supervisor was eliminated. • The production supervisor in charge had only recently been transferred here. • All signs and operating procedures were written in English, although many workers only spoke Hindi. • Not all operators were provided with safety equipment. • Maintenance work was done at night-time. • The workers were advised to "develop resistance against toxic substances by drinking six or seven glasses of milk a day and eating a high protein diet of fish and eggs".

In the weeks prior to the incident, the MIC manufacturing unit had been shut down [25]. The Sevin unit was operating, using the MIC that had been stored in Tank 611.

The production of MIC was stopped on October 22. At that time tank 610 contained approximately 42 tonnes of MIC. Tank 622 also contained MIC in quantities of the same order [15]. During the period October 22 to November 30, MIC was being transferred from tank 611 to the Sevin unit, whenever required.

6.3.5 Previous warnings

Already in 1974, residents found a well was contaminated. Cattle belonging to residents of Chola strayed into the area of a pool fed by a rubber pipe issuing from the factory. They drank the water and died soon after. Analyses of soil showed contamination with heavy metals. In water from wells outside the plant area, toxic chemical substances were found. UCIL did not divulge these findings [1].

In 1976, the two trade unions reacted because of the pollution within the plant. Letters were sent to the managers of the plant and the factory inspector as well as to the Ministry of Labour of Madhya Pradesh [10]. They never received any answer.

In 1978, there was a big fire in the factory [10]. It showed that raw materials were being stored in places other than those designated for the purpose. It was suspected that management deliberately started the fire, in order to circumvent the import restrictions of alpha-napthol laid down by the government. A report on the incident was never filed.

In 1981, a worker was splashed with phosgene. In panic he ripped off his mask, thus inhaling a large amount of phosgene gas, and died after 72 hours. The managers blamed the worker for removing his mask. The workers' union pointed out that it was the malfunctioning valve that led to the accident and that the worker was not provided with a PVC overall [10]. Two others were seriously injured on this occasion [17].

In January 1982, there was another phosgene leak, when 24 workers were exposed and had to be admitted to hospital. None of the workers had been ordered to wear protective masks. After this accident, the workers agitated for safer working conditions [1, 10, 17].

In February 1982, a MIC leak affected 18 workers [6].

In August 1982, a chemical engineer came into contact with liquid MIC resulting in burns over 30 percent of his body [6].

In October 1982, there was a leak of MIC, methylcarbaryl chloride, chloroform and hydrochloric acid [1, 6, 12]. As an operator was opening a valve in an MIC pipeline, the joint linking it to several other pipes unexpectedly broke. Evacuation of the plant was ordered. The gas plume moved toward the nearby settlement and people ran away in panic. In attempting to stop the leak, the MIC supervisor suffered intensive chemical burns and two other workers were severely exposed to the gases.

During 1983 and 1984, "with frightening regularity", leaks of the following substances took place in the MIC plant [10]: MIC, chlorine, monomethylamine, phosgene, and carbon tetrachloride, sometimes in combination.

After the leak in 1982, the trade union printed 6,000 posters with warning texts that were distributed throughout the community [1, 6]. The Hindu union leader went on a hunger strike at the entrance to the factory. The result was that all political and trade union meetings inside the factory were banned. One UC staff member burnt the principal union's tent. In the ensuing scuffle, several people were injured. The trade union leaders were laid off. Meetings and processions were held throughout the city. As the UC staff regarded the plant as "one of the safest ships in the modern industrial fleet", the demonstrations were considered to be a campaign by agitators wanting higher salaries and shorter working hours [1].

A journalist was a neighbour of the worker who died in 1981. He had listened to the workers' discussions about the dangers at the factory – toxic gases, deadly leaks and the likelihood of explosions. After having done some research, he started to write articles in the local press warning of the hazards associated with the plant [1, 17]. His final article, which appeared just five months before the disaster, was titled "Bhopal on the Brink of a Disaster". No one took any notice. He also sent letters where he summarised the findings of his investigations to the Chief Minister and to the Chief Justice of the Supreme Court, whom he requested to close the factory. He got no answer.

One engineer was anxious that the pipelines might crack, allowing MIC to escape and hit passing trains and their passengers. He collected information about the meteorological conditions for Bhopal from the national meteorological observatory in Nagpur, and sent it to UC in South Charleston. After computer simulation he got the answer that such a cloud would pass over the train – which meant it would hit the *bastis* [1].

On October 21, 1984, nitrogen pressure in tank 610 dropped to one-fifth of its normal level and none of the excess MIC could be extracted. To continue Sevin production, managers switched on to tank 611. They never investigated the cause of the pressure loss in tank 610 [1, 21]. On November 30 (or 26th [8]3]), nitrogen pressure failed in tank 611 as well, prompting attempts to repressurise tank 610. A defective valve attached to tank 611 was repaired and tank 610 was again abandoned. Operators later told journalists that every time nitrogen was pumped in, it leaked out again through an unknown route.

6.3.6 Safety audits

Safety audits were done every year in US and European UCC plants, but only every two years in other parts of the world [13].

Before a "Business Confidential" safety audit by UCC in May 1982, the senior officials of the corporation were well aware of "a total of 61 hazards, 30 of them major and 11 minor in the dangerous phosgene/methyl isocyanate units" [24].

In this audit, it is indicated that worker performance was below American standards [6]. Ten major concerns were listed, many of those are found in Table 2. It expressed alarm at the poor state and inappropriate placement of safety equipment, and at the lack of periodic checks to see that the instruments and alarm systems were functioning correctly. It also expressed concern at an alarming turn over of inadequately trained staff, unsatisfactory instruction methods and a lack of rigour in maintenance reports. Installation of an automatic sprinkler system in the MIC production zone was recommended. Three lines in the 52 pages pointed to a particularly serious mistake: a section of pipe work had been cleaned without the person in charge of the process taking the precaution of blocking off the two extremities of the pipe with special discs designed to prevent the rinsing water from seeping into other parts of the installation [1].

However, the report ended "No situations involving imminent danger or requiring immediate correction were noted during the course of the survey". UCIL prepared an action plan, but UCC never sent a follow-up team to Bhopal. Many of the items cited in the 1982 report were temporarily fixed, but by 1984, conditions had again deteriorated [6].

In mid-1984, one of the engineers, who had built up the Bhopal plant, visited Bhopal again. What he saw at the plant worried him, and he tried to relay this to his superiors. They did not listen [1].

In September 1984, an internal UCC report on the Virginia plant in the USA revealed a number of defects and malfunctions. It warned that "a runaway reaction could occur in the MIC unit storage tanks, and that the planned response would not be timely or effective enough to prevent catastrophic failure of the tanks". This report was never forwarded to the Bhopal plant, although the main design was the same [1].

6.4 THE STATE OF THE SAFETY SYSTEMS ON 3RD DECEMBER, 1984

UCC admitted in their own investigation report [23] that most of the safety systems were not functioning on the night of the 3rd December 1984:

- Tank temperatures were not logged;
- The vent gas scrubber (VGS) was not in use;
- The cooling system was not in use;
- A slip bind was not used when the pipes were washed;
- The 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 619 (the evacuation tank) was not empty.

In addition, other faults are recorded:

- The meters monitoring tank E610 were showing abnormally low pressure. The reason might be either a faulty meter or an inability of the tank to maintain pressure [9].
- The line connecting the VGS to the flare tower was master carded [9, 10].
- Many valves, vent lines, feed lines etc. were in poor condition [9, 10].

After the leakage, there were findings that give rise to several questions concerning the maintenance of the plant [9, 19].

- Water was discovered by the workers after the accident when they drained the vent lines connecting the tank E610 and the relief valve vent header (RVVH).
- Caustic soda was found in the RVVH when it was opened on December 10th.

Night work has been shown to be a risk factor in accidents [26, 27]. This might have contributed to the mistakes made by the staff during the course of the leakage.

6.5 COMMENTS

Kumar [28] points out how the culture from the British time was alive after freedom. The elite in the small kingdoms has used the modern state organisation to retain power. Every small progress was looked upon as a heroic achievement, whereas every failure was a shame, something that had to be buried and forgotten. The elite in Bhopal tried to do the same – to bury and forget.

The deficiencies in the Bhopal plant design can be summarised as:

- Choosing a dangerous method of manufacturing pesticides;
- Large-scale storage of MIC prior to selling;
- Location close to a densely populated area;
- Under-dimensioning of the safety features;
- Dependence on manual operations.

Deficiencies in the management of UCIL can be summarised:

- Lack of skilled operators because of the staffing policy;
- Reduction of safety management because of reducing the staff;
- Insufficient maintenance of the plant;
- Lack of emergency response plans.

It was UCC that chose the design. On the UCIL board, UCC was well represented. Thus, UCC can hardly avoid responsibility for the safety status of the plant.

It seems as though the management's views on safety differed from those of the workers. The chief medical officer at Bhopal said, "The safety precautions we took were the best possible. We did everything the Americans advised. In fact we used to think that we were overdoing the safety" [13].

6.6 REFERENCES

1. Lapierre, D. and J. Moro, *It was five ast midnight in Bhopal*. 1st Indian ed. 2001, New Delhi: Full Circle Publishing.
2. Mac Sheoin, T., *Report on Union Carbide Corporation*. 2002, The Other Media: New Delhi.
3. MacSheoin, T., *Asphyxiating Asia*. 2003, Mapusa, Goa: Other India Press.
4. *Contempt of People. Ramifications of the Bhopal Gas Leak Disaster Case*. 1992, Delhi Science Forum: New Delhi.
5. Weir, D., *The Bhopal Syndrome. Pesticides, Environment and Health*. 1988, London: Earthscan publications Limited.
6. *The Trade Union report on Bhopal*. 1985, ICFTU-ICEF: Geneva, Switzerland.
7. Morehouse, W., *The ethics of industrial disaster in a transnational world: The elusive quest for justice and accountability in Bhopal*.
8. Morehouse, W. and A. Subramaniam, *The Bhopal Tragedy. What really happened and what it means for American workers and communities at risk*. 1986, New York: The Council on International and Public Affairs.
9. *Bhopal gas tragedy*. 1985, Delhi Science Forum: New Delhi.
10. Chouhan, T.R., *Bhopal: The inside story. Carbide workers speak out on the world's worst industrial disaster*. 1994, New York: The Apex Press.

11. Ramachandran, C.R., *Immediate post industrial disaster management*, in *Refresher course for top executives. Management of chemical accidents*. 1994, Disaster Management Institute: Bhopal.
12. Chauhan, P., S., *Bhopal Tragedy. Socio-legal Implications*. 1996, Rawat Publications: Jaipur.
13. Jones, T., *Corporate killing. Bhopals will happen*. 1988, London: Free Association Books.
14. *Carbide's war gas tests right under DST's nose!*, in *Bhopal: Industrial genocide?* 1985, Arena Press: Hong Kong.
15. Varadarajan, S.e.a., *Report on scientific studies on the factors related to Bhopal Toxic Gas Leakage*. 1985, Indian Council for Scientific and Industrial Research: New Delhi.
16. *Carbon monoxide, phosgene and methyl isocyanate. Unit safety procedures manual*. 1978, Union Carbide India Limited, Agricultural Products Division: Bhopal.
17. Cassels, J., *The Uncertain Promise of Law: Lessons from Bhopal*. 1993, Toronto: University of Toronto Press Inc.
18. Morehouse, W., *Unfinished business. Bhopal ten years after*. The Ecologist, 1994. **24(5)**.
19. *Other workers speak out: testimonies from Union Carbide Bhopal Plant personnel*, in *Bhopal et al. The inside story*, T.R. Chouhan, Editor. 1994, The Apex Press: New York.
20. *Methyl Isocyanate. Union Carbide F-41443A - 7/76*. 1976, Union Carbide Corporation: New York.
21. *The Machine Stops: Runaway Reaction*. 2000, Jan 5, http://home.earthlink.net/~wroush/disasters/bhopal3.html.
22. Behl, V.K., et al., *Operating Manual Part-II. Methyl Isocyanate Unit*. 1979, Union Carbide India Limited, Agricultural Products Division: Bhopal.
23. *Bhopal Methyl Isocyanate Incident. Investigation Team Report*. 1985, Union Carbide Corporation: Danbury, CT.
24. *The Bhopal Gas Tragedy 1984 - ? A report from the Sambhavna Trust, Bhopal, India*. 1998, Bhopal People's Health and Documentation Clinic: Bhopal.
25. Kalelkar, A.S. and A.D. Little. *Investigation of large-magnitude incidents: Bhopal as a case study*. in *The Institution of Chemical Engineers Conference on Preventing Major Chemical Accidents*. 1988. London.
26. Mitler, M.M., et al., *Catastrophes, sleep and public policy: Consensus report*. Sleep, 1988. **11**: p. 100-9.
27. Akerstedt, T., *Increased risk for accidents at night work*. Lakartidningen, 1995. **92**: p. 2103-4 [In Swedish].
28. Kumar, K., *Princes and pesticides*. South Asia - Political and cultural magazine, Sweden, 1985. **3**(7-8) [In Swedish].

7. THE EVENT PHASE: THE LEAKAGE AND ITS IMMEDIATE EFFECTS

7.1 THE LEAKAGE

7.1.1 The course of the leakage

The first UC team report [1] was published in March 1985. In Kalelkar's report [2], written four years after the leakage, the log records have been carefully examined and interviews with management and workers analysed. One chapter deals with the contradictions in the statements.

The CSIR report [3] was formally released around 15 years after the leakage.

Other reports on the course of the leakage have been written by ICFTU-ICEF [4], Delhi Science Forum [5], Kulling and Lorin [6], and Chouhan [7, 8]. Sometimes these reports are contradictory. Table 3 is a compilation of statements from the seven reports and other material.

Table 3. The course of the leakage.

Time	*Ref.*	*Event*
20.30	7 9	• Water washing of lines began. A slip bind was not used. • Water washing of lines began. Slip-binds were not used. When the water did not come out through the drain-cocks, the water was cut off and the filters cleaned. Then the water was released again.
21.15	10	• An operator was asked to flush the lines. He opened a nozzle on one of the pipes and inserted a water hose.
21.30	4 11 10	• Water washing of lines began. A slip bind was not used. When the operator noticed that no water was coming out of the bleeder lines, he shut off the flow, but the MIC Plant supervisor ordered him to resume. • An operator started pumping water under high pressure into four lines downstream of the MIC storage area, all of which were connected to the RVVH. According to standard operating procedures, the maintenance crew had prepared the job (i.e. closed the isolation valve between these branches and the RVVH). The outflows of bleeder valves were not releasing water at the same rate at which it was being pumped in. Two valves were completely clogged and the others partly clear. He stopped washing and reported the problem to the supervisor. • The operator turned on the water. As no water was coming out the overflow line, he turned off the hose. The supervisor ordered him to resume.
21.45	11	• The operator resumed washing the lines. But the bleeders remained obstructed and soon water accumulated in the pipes.
22.00	7	• Approximate time water entered Tank 610. Reaction begins.
22.15	2	• Final transfer of MIC from Tank 611 to the SEVIN unit according to one log, that seems to have been changed.

22.20	1, 6, 7 6	• Pressure of tank 610 noted as 2 psi. • An operator was told to use water to clean lines close to the MIC tank.
22.30	9 10	• The operator was told to keep the water running, and that the night shift would turn the tap off. • The new operators came on duty. They noted and logged in the pressure of tank 610 as 2 psi. Temperature was not recorded.
22.45	2, 4	• Shift change. The unit was shut down for around half an hour. • The third shift began to suffer throat and eye irritation from a MIC leak close to the area where the lines were being washed.
23.00	9 7 1, 6 1 9	• Shift change. • MIC leak first reported by field operator in area near vent gas scrubber. • Pressure of Tank 610 noted as 10 psi. • Operator said later that pressure was 2 psi. • Operator noticed that the recorded pressure 2 psi was three hours old.
23.30	2 2 7, 8 3 2, 8	• Last transfer of MIC to the SEVIN unit. It seems to have come from tank 610 instead of tank 611. • The gases came out of the VGS. • Operators notice water leaking along with MIC in the MIC process area. • Operators on ground level noticed dirty water spilling from higher level in MIC structure and MIC in the atmosphere. MIC and dirty water were coming out of a branch of RVVH. The pressure safety valve had been removed and the open end of RVVH branch line was not blinded. • Operators reported the leak to the MIC supervisor and began to search for it in the MIC structure. The leak was considered "normal".
24.00	9 7, 8 3	• Operators found brownish water and steam coming out from a drain-cock eight yards off the ground. The supervisor recommended turning off the water taps after tea break. The team left for the staff cafeteria. • Operators found a section of open piping located on the second level of the structure near the VGS. They fixed a fire hose so that it would spray in that direction and returned to the MIC control room believing that they had successfully contained the MIC leak. • The operators went to the control room and informed the plant superintendent and the supervisor that there was a MIC leak. They were advised to spray water around the point of leakage.
00.15	2 2 2 2	• Tea break began. According to some, the alarm signalling the major release went off for only several minutes. Others stated that the tea period in the control room was normal. When a tea boy entered the MIC control room, he noticed that the atmosphere was tense and quiet. The operators refused the tea. • The two supervisors and the superintendent were, against the rules, taking a break together in the plant's main canteen for 45 minutes prior to the release. Here they received word of the incident. • Transfer from tank 611 to SEVIN unit. The UC investigation team concluded that this was an attempt by the MIC operators to remove water from the tank. • It is clear that the MIC operators knew at least 30–45 minutes before the release that something was seriously wrong, and that several had taken action in an attempt to forestall the problem.

	1, 6, 7	• Field operator reports the continued release of both water and MIC in the MIC process area. Water was sprayed on the leaking point. The tank pressure reading is noted as 30 psi and rapidly rising. Within moments, the pressure reading exceeded 55 psi, the top of the scale.
	3, 9	• The control room operator observed on the Pressure Indicator (PI) that the pressure was shooting up and was in the range 25–30 psi/g.
	3, 9	• Between 00.15 and 00.30 hours, PIN showed a reading beyond the maximum of the scale, i.e. higher than 55 psi/g.
	6	• Values up to 100° C and 100 psi have been mentioned.
	3	• The control room operator went to the storage area and heard a hissing sound from the safety relief valve (SRV), indicating that the SRV had popped off. He noticed that the local temperature and pressure transmitters were indicating values beyond their ranges (i.e. +25° C and 55 psi/g).
	9	• Two operators went to the tank 610. The pressure gauge indicated 55 psi. Movements were felt inside the tank. The smell of MIC, phosgene and MMA was noticed. A geyser burst from the spot where the gas leak was detected. The operator set off the general alarm siren. The supervisor left his tea and rushed to the tank. The tank and the concrete were trembling, cracking and creaking.
	1, 3, 6	• The control room operator called his supervisor and ran outside to the tank. He heard rumbling sounds from tank 610, a screeching noise from the safety valve and felt heat radiating. As he ran back to the control room, he heard the cracking of the concrete over the tank. As soon as he returned to the control room, he turned the switch to activate the VGS. The flow meter did not indicate that caustic circulation had been started. The operator did not go into the unit to check the pump and verify whether there was a flow.
	3	• A gaseous cloud was seen to be coming out from the stack by the field operator.
	7, 8	• Water washing of lines was stopped. All the water from the lines came out through the open bleeders. Near these open bleeders, MIC was detected. The alarm glass was broken to start the loud factory siren. After a few minutes, the loud siren was turned into a muted siren.
00.20	1, 6	• The MIC Production Supervisor notified the Plant Superintendent, who was in the formulation area, of the release.
00.25	1, 6	• The Plant Superintendent arrived in the MIC unit and found much MIC in the atmosphere.
?	9	• All communication between tank 610 and tank 611 was shut off by the supervisor and the operator. Tank 610 stood vertically, fell and stood up again, but did not burst. A second geyser erupted from a ruptured pipe at ground level.
00.30	7	• Tank 610 showed a noticeable heat increase and began to make a rumbling sound. The concrete casing of the tank then split due to expansion of the tank walls caused by the increase in pressure. The rupture disk broke, safety valves for tank 610 popped and the bulk of the tank contents was released through the vent gas scrubber.
	11	• The estimated time of the leak.
	9	• The water was cut off.
	3	• The siren was sounded and the plant was alerted to the leakage.

?	9 11	• The siren was turned off and the workers alerted through the loudspeakers. • The workmen were instructed to evacuate the plant. As the windsock indicated that the wind was blowing westward, they were instructed to move east.
00.45	1	• The Supervisors' Log records that Derivatives Unit operations were suspended because of the high concentration of MIC in the area.
00.50	8 11	• The alarm began inside factory, alerting workers to a hazardous leak. The emergency squad tried to control the leak by massive water spraying, but the water did not reach the site for the leak/not high enough. • A workman sounded the toxic gas alarm. In accordance with the plant's emergency procedures, the control room operator immediately switched off the siren and made an announcement over the plant's system informing the workmen. He then restarted only the internal alarm.
01.00	12 6, 8 1 1, 3, 6 3, 6, 9 6 2	• A worker broke the alarm glass and started the factory siren. • When the plant superintendent came back from smoking, he ordered that the loud siren be stopped. • A derivative unit operator turned on the Toxic Gas Alarm. • The Plant Superintendent and the MIC operator verified that MIC from tank 610 was being emitted from the VGS stack to the atmosphere. They turned on the fixed firewater monitors and directed them to the stack. Water streams were also directed on the MIC tank mound and on the relief valve line to the VGS for cooling. Steam came from the cracks in the concrete indicating the MIC tank was hot. • The water pressure was not high enough for the water to reach the point of emission. • One of the workers tried to climb up the construction to close the leakage. He was so exposed to the gases that he fell down and fractured several bones. • Within 15 minutes of the major release, the MIC supervisor called the MIC production manager at home and told him that water had got into an MIC tank.
01.30	8 1, 6	• Workers began to flee the factory premises to save their lives. • Sometime between 1.30 and 2.30, the safety valve restated, indicating a tank pressure below 40 psi/g, and the emission of MIC stopped.
02.00	8 11	• The workers realised that the toxic release was affecting the communities outside the plant. They insisted that the plant superintendent should restart the loud siren, which he finally did. • Most of the contents of tank E610 had escaped.
02.15	7	• The gas leak stopped.
03.00	3 8	• The SRV of tank 610 is reported to have sat back and the gas also stopped coming out from the stack. • People from outside came to the factory dispensary for treatment.
05.30	1, 6	• Tank 610 was hot to the touch (45-60^{o} C).
06.00	1, 6	• The thermometer on the VGS caustic accumulator read 60^{o} C, indicating that an MIC reaction had taken place.

07.00	8	• Both pressure gauges on the tank were twisted out of range. The tank manhole was very hot.
Morn-ing	3	• One witness noticed that a pressure indicator on tank no. 610 was missing and that no plug had been inserted in the opening. A water hose was lying nearby. Other witnesses contradicted these statements.
After leakage	5, 8	• Water was discovered by the workers after the accident when they drained the vent lines connecting the tank E610 and the relief valve vent header (RVVH).
Dec 10th	5, 8	• Caustic soda was found in the RVVH when it was opened.

7.1.2 The chemical reaction

In the CSIR report [3] the reaction in the tank is discussed. Phosgene is always present in MIC, as an inhibitor of polymerisation. When water entered tank 610, it would have reacted with phosgene and methylcarbamyl chloride (MCC) to produce hydrochloric acid (HCl). For this, relatively small amounts of water, a few litres, would be enough to reduce the phosgene to very low levels. HCl would react with metal particles to produce ionisable metal chlorides. HCl and the metal chlorides would, in the absence of phosgene, catalyse into a violent and explosive polymerisation. The heat would promote a chain reaction, leading to a very rapid increase in temperature, vaporisation, increase in pressure and leakage of gas.

The UC team [13] stresses that the corrosion rate would have increased markedly when the temperature increased, because of the presence of an abnormally high level of chloroform. Thus more iron would be produced and catalysed an exothermic trimerisation of MIC. The violence of the reaction would increase further.

The amount of water entering the tank is disputed. One estimate is that at least 200 litres (kg) of water entered the tank. The CSIR says that the chemical analysis of the tank residue clearly shows the evidence of the entry of approximately 500 kg of water. The UC team talks about 120 to 250 gallons of water (480–1,000 kg) [13].

The temperature in the tank is a very important question, as MIC decomposes to hydrogen cyanide at higher temperatures (see 7.2.3). UCC has maintained that the temperature would have been 0–250° C, while others claim it would have been 400 or even 540° C [11, 13]. The CSIR report [3] points out that information from the mechanical examination of the tank indicates that the pressures may have reached 11 to 13 kg/cm^2 with the corresponding temperatures in the range of 200 to 350 ° C. From the products found in the residue, the calculated amount of heat of chemical reactions and the extent bulging of the exhumed tank, it is surmised that the temperature in the tank rose above 250 ° C.

In the UC report [1] the tank temperatures are not described and hydrogen cyanide is not discussed.

The CSIR team found that the reactions of MIC with small quantities of water and chloroform at 250 ° C give all the products found in the solid residues in tank 610, except tetramethyl biuret [3].

Various Indian investigative journalists argue that there were in fact two runaway reactions in tank 610 [11]. The first was the reaction of MIC with itself, catalysed by iron contaminants washed into the tank. The second reaction was of MIC with water. The UC manual indicates that a runaway reaction of MIC with water by itself occurs only after 23 hours at 20 °C. But such a reaction is greatly accelerated and can take place in just a few hours when MIC is reacting with itself, catalysed by iron.

7.1.3 The direct cause – four theories

7.1.3.1 The Water Washing Theory

This is the workers' theory, supported in the Government's official report [3] and by the chief lawyer of UCIL in the Bhopal court [7]. It is described in detail in the Trade Union Report [4], by Morehouse and Subramaniam [11], and by Chouhan [7, 8]. It is discussed by Cassels [14], Jones [13] and in the UC team report [1]. Lapierre and Moro [9] have interviewed operators and workers.

Those in charge of the MIC plant on the evening December 2nd were not familiar with the factory's complex maintenance procedures, and they knew nothing about MIC or phosgene. The supervisor was convinced that there could not be a leak when production had been stopped.

The supervisor from the day shift had left instructions on flushing the pipes leading from the MIC tanks to the vent gas scrubber with water. He forgot to mention the slip-binds that should have been placed at each end of the pipes. When the worker placed the stopcocks, he was not sure that they tightened completely, because of corrosion and rust. The water did not come out of the drain-cocks, and he found that the filters were blocked with metal debris. He cut off the water. The supervisor told him to clean the filters. When he turned on the water, it came out through three of the four drain-cocks. He was told to keep the water running, and that the night shift would turn it off.

The workers maintain that entry of water through the plant's piping system during the washing of lines was possible because a slipbind was not used, the downstream bleeder lines were partially clogged, many valves were leaking, and the tank was not pressurised. Carried with the water were iron rust filings from corroding pipe walls, residue of the salt compounds that had blocked the lines being washed, and other contaminants.

The water, which was not draining properly through the bleeder valves, may have built up in the pipe, rising high enough to pour back down through another series of lines into the MIC storage tank. Once water had accumulated to a height of 20 feet (6.1 m), it could drain by gravity flow back into the system. Alternatively, the water may have been routed through another stand-by "jumper line" that had only recently been connected to the system. Indian scientists suggested that additional water might have been introduced as a "back-flow" from the defectively designed vent-gas scrubber.

The UC team says this was impossible. In order for the water to reach the MIC tank during washing, it would have had to travel through dozens of metres of piping, pass through several valves, and finally climb 3.5 metres to reach the tank opening. The UC team also says that "entry of water into tank 610 from this washing would have required simultaneous leaks through several reportedly closed valves, which is highly improbable". Chouhan points out that "grossly inadequate maintenance would permit water to pass even through closed valves because of malfunctioning".

The CBI's officials, who disconnected the pipeline from the storage tank on the morning after the leak, drained out as much as 27 litres of water from the structures on 14 February [13]. Water was found in almost all the connecting pipelines tracing the entire route from the point of washing to the Relief Valve Vent Header. This supports the water washing theory.

UCC's team spent 24 days in India, and continued its work for months thereafter [11]. However, they were not permitted to interview UCIL employees, and they were not allowed to examine the pipelines to determine how water got into the tank. UCC's only investigative work consisted of chemical investigations, and the results are still not released [13].

7.1.3.2 The Direct Entry Theory

UCC hypothesis was that the runaway reaction in the tank occurred "when a substantial amount of water was introduced". The theory is that somebody deliberately connected a hose to a pressure gauge [2, 4]. In a press conference in March 15th, 1985, it was hypothesised that "water could have been introduced inadvertently or deliberately directly into the tank through the process vent line, nitrogen line or other type of line". It is also said that someone might have connected a tube to the water line instead of the nitrogen line.

After objections from the workers, it was admitted that the company's investigation team did not find any evidence for such a connection [4]. Some journalists pointed out that the reaction would have occurred 23 hours later, and that there are no valves, vents or bleeders to which a hose could be put [11]. A senior UC official should have told a Congressional committee "that the IC tank line fittings are colour-coded and that the water line couplings are incompatible with the gas line couplings that go into the tank".

All the same, UCC blamed first a Sikh terrorist, then "a disgruntled worker". From Kalelkar's report [2], it is obvious that this worker has been identified by UCIL, but he was never reported. The worker has identified himself [8, 9], and says that the workers knew that putting water directly into the MIC tank would be extremely dangerous for the person himself. So any worker would avoid sabotage. He also says that if there was sabotage, the culprit is the management, which was responsible for supervising the safety precautions at the MIC plant.

One UCC spokesperson could not think of a motive, as there were "no radicals or groups like that". Some US financial analysts dismissed UCC's theory. Anderson himself admitted to a US Congressional panel that he had "no evidence whatsoever that sabotage was behind the disaster" [13].

The CSIR report in December 1985 notes: "The scientific analysis shows that any addition of water alone, even deliberately, could not lead to such an accident. Anyone wishing to cause an accident of this nature would have to be presumed to have very substantial knowledge and information that metal contaminants would already be present and that the alarms and safety systems installed for containment were grossly inadequate" [3].

UCIL has later admitted that the sabotage theory was false, arguing instead that three employees caused the disaster through negligent behaviour [15].

7.1.3.3 The Economy Theory

The UCIL factory was running at a loss and it was decided that the factory should be closed down and sold. However, to close a plant in India at that time needed the permission of the Government. It was suggested that Mr Warren Anderson wanted a minor accident, so that the Government of India would allow him to close the plant. In this scenario, the leakage was put on the stage on purpose, but ran out of control.

7.1.3.4 The Warfare Test Theory

Jones [13] describes this theory as mainly proposed by pro-Soviet elements in India: that it was a deliberate chemical warfare experiment on the part of the USA.

A Research and Development unit was set up in Bhopal in 1976. The centre, the biggest in Asia, had five insect-rearing laboratories and a two-hectare experimental farm for testing chemical agents. Here, new molecules were synthesised and tested. It appeared that the UCIL had been conducting field studies using new chemical agents without getting the projects cleared by the top-level committee from 1975, where all collaborative research efforts should be screened from a "security" angle [5].

The closeness of chemicals for peace to chemicals for war was highlighted by Indian charges that the centre was involved in chemical warfare experimentation [13]. The Delhi Science Forum said that "much of the results of the findings in these areas are also quite likely to have never been published, given the enormous significance such data has for chemical warfare", and also that "the centre's studies covered the grey area between agricultural research and anti-crop warfare" [5].

This twist was highlighted by reports about the presence of chemical warfare experts at Bhopal studying MIC's effects [13]. For example, it is known that from the Pentagon, a medical doctor was sent to collect military intelligence regarding the effects of the leaked gases. From Sweden, two doctors were sent to make a report for the National Defence Research Institute [6].

7.1.3.5 Other theories

There are other theories about how the water got in the tank [11]. Water could have entered at some point in the nitrogen line near the tank, through the refrigeration line, or directly through the process vent system. Serious problems manifest with these theories.

7.1.4 Comments

The direct cause of the gas leak was the large amounts of water that entered tank 610. A run-away reaction started, which was speeded up because of contaminants, high temperatures and other factors.

The two main theories as to how the water entered the tank are the sabotage theory and the water washing theory. UC has also pointed out contradictions in the statements from the witnesses [2].

However, sabotage would have been improbable if
- maintenance had been good;
- the safety systems had been working;
- the saboteur would have wanted to save his own life and health.

After these studies, the author is convinced that the water washing theory is the plausible theory. The actions of UCC shows the weakness of the sabotage theory.

Even if the supervisors had been properly trained and had acted earlier, they would not have been able to control the leakage, as the different safety systems were either under-dimensioned or not working. The leakage stopped when tank 610 was empty.

A very important factor is the temperature of the tank. It is in the UCC's interest to maintain that the temperature was never over +200o C, which would mean that only very small amounts of hydrogen cyanide were formed. However, it seems very likely that the tank temperature was far above this point.

The leakage, irrespective of the initiating cause, would not have reached this magnitude if
- The MIC had been stored in several small tanks instead of two big ones;
- The proper materials had been chosen for the pipeline system, so it would not have contributed to the contaminants;
- The maintenance had been appropriate so the risk of contaminants would have been minimised;
- The safety systems had all functioned as planned at start of the plant;
- The safety rules had all worked as planned at start of the plant;
- The stated safety precautions had been followed;
- The operators and workers had been properly educated.

7.1.5 References

1. *Bhopal Methyl Isocyanate Incident. Investigation Team Report*. 1985, Union Carbide Corporation: Danbury, CT.
2. Kalelkar, A.S. and A.D. Little. *Investigation of large-magnitude incidents: Bhopal as a case study*. In *The Institution of Chemical Engineers Conference on Preventing Major Chemical Accidents*. 1988. London.
3. Varadarajan, S. et al, *Report on scientific studies on the factors related to Bhopal Toxic Gas Leakage*. 1985, Indian Council for Scientific and Industrial Research: New Delhi.
4. *The Trade Union report on Bhopal*. 1985, ICFTU-ICEF: Geneva, Switzerland.
5. *Bhopal gas tragedy*. 1985, Delhi Science Forum: New Delhi.
6. Kulling, P. and H. Lorin, *The toxic gas disaster in Bhopal December 2-3, 1984* 1987, Forsvarets Forskningsanstalt (National Defence Research Institute): Stockholm, Sweden. [In Swedish.]
7. Chouhan, T.R., *Bhopal: The inside story. Carbide workers speak out on the world's worst industrial disaster*. 1994, New York: The Apex Press.
8. *Other workers speak out: Testimonies from Union Carbide Bhopal Plant personnel*, in *Bhopal et al. The inside story*, T.R. Chouhan, Editor. 1994, The Apex Press: New York.
9. Lapierre, D. and J. Moro, *It was five ast midnight in Bhopal*. 1st Indian ed. 2001, New Delhi: Full Circle Publishing.