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Thirty Years after the Cataclysm: Toxic Risk Management in the Chemical Industry

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Abstract: This year marks the thirtieth anniversary of the worst industrial disaster in world's history in which almost four thousand people were killed and tens of thousands were seriously injured by a gas leak from a fertiliser plant. Neither the managers nor the toxicologists knew how poisonous the gas methyl isocynate was; and no one knew the antidote. Over the years there has been change in views and practices relating to handling of toxic substances in chemical industry. Research in inherently safe designs has accelerated. There have been advances in the field of Organisational theory and management of high reliability organisations. Evolution of CSR in the industry has been rapid though it seems more like greenwashing than a substantial change in business practices.

Key words: Risk · Chemical Industry · Toxicology · Organisation Science · CSR

INTRODUCTION

Central to the modern world economy, the chemical industry converts raw materials like oil, natural gas, metals and minerals into more than 70,000 different products. Globally, the chemical industry has a turnover of around 5 trillion dollars [1]. The chemical industry was widely respected as a harbinger of prosperity till half a century ago when Rachel Carson in her famous book “Silent Spring” [2] accused it of spreading not only poison but also disinformation. Carson also accused the public officials of accepting industry claims uncritically initiating what would ultimately get converted into environmental movement [3]. The debate at the time was limited to non-disclosure of harmful effects of chemicals and a cataclysmic event was not foreseen [4]. The world’s worst industrial accident in history occurred on December 3, 1984 which killed at least 3,800 people and injured tens of thousands via a poisonous gas later identified as Methyl Isocyanate (MIC). Since then, in the public mind the fear of the ‘dark chemical cloud’ trumps over the concern for resource depletion on account of population explosion and excessive consumption [5].

The epic story of the world's deadliest industrial disaster has been narrated graphically in Dominique Lapierre and Javier Moro’s [6] bestseller *It was five past midnight in Bhopal*. Even before the full impact of the terrible accident had sunk in, the public debate shifted to the societal role of multinational corporations. The company was vilified to such an extent that the then chairperson, Warren Anderson is still spending his retired life in hiding. The activists want him tried for culpable homicide insisting that it was his indifference to lives in poor countries that caused the disaster. More likely it was the indifference to toxicology that was responsible for the tragedy.

For the academics who follow the vicissitudes of the multinational corporations, it was particularly surprising that it was Union Carbide which was involved. Viewed from the Ivory Tower, Union Carbide was a well-managed enterprise and 1984 was a good year for the company. The company had affiliates and business interests in 36 countries and with sales of $9.5 billion and 12 new promising high-performance products, it had become - one of the largest industrial companies in the world. With the company initially in a denial mode about the extent of gas release and then calling it a ‘tear-gas’ type and providing no information on an antidote, no immediate relief was possible. The morning after the accident, Union Carbide executives were gathering with technical, legal and communications staff at its headquarters in Danbury, Connecticut taking stock of massive industrial disaster

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with no clue as to what to do. For weeks after the incident, the company's switchboard was receiving 500 calls a day. The company's spokespersons went on repeating: "We don't have the information. We'll have to get back on that" begging the question, "Why don't you know?".

The company had more than a decade of experience with MIC. There had been minor leaks at the company's plant located in West Virginia, as also in Bhopal. The management did not know that a gas that smells like boiled cabbage is as toxic as it turned out to be. Had the management known about the extent of toxicity, there would have been better process safety systems guarding against possible leakages caused by exothermic reaction. There would have been safeguards ensuring that a minor infraction like failure to insert a slip blind into a pipe being cleaned does not allow water to back up and enter the MIC tank catalysing a complex chemical interaction. If MIC had been stored in 55 gallon drums instead of 60 tonne tanks, leakage would have been minor. No one in Union Carbide knew that MIC can be degraded as a result of pyrolysis and interaction with water [7] Had the affected population been advised not to run but to stay indoors and splash water on their faces, thousands of life could have been saved. This paper seeks to analyse the various measures of toxic risk management in the chemical industry since the accident and attempts to delineate the direction of future research.

Since the accident occurred in a peripheral overseas plant, the immediate concern in the U.S. was: 'Can it happen here?' In response, the Union Carbide immediately closed its West Virginia plant. The company seriously underestimated the damage it had caused in India and refused to accept direct responsibility. It offered humanitarian aid of $1 million which was contemptuously refused by the host country. Ultimately, after a few years of litigation, Union Carbide paid a compensation of $470 million, became a smaller company and has since ceased to exist as a company having been acquired by Dow Chemicals. The impact of Bhopal, however, went well beyond the demise of Union Carbide as an independent company and changed views and practices about toxicology in the entire U.S. chemical industry. It provided impetus to the development and enactment of federal laws requiring companies to notify government and the public about toxic substances they make or use. Spurred by the Bhopal tragedy, the U.S. Environment Protection Agency brought about a network of local emergency planning councils, in which corporate specialists work with their neighbouring communities to safely deal with such disasters.

Inherently Unsafe: Synthetic chemicals started becoming components of consumer products at the beginning of the twentieth century. As the chemical industry advanced, it used toxic materials in larger and larger quantities. MIC, the toxic material that killed thousands of persons in Bhopal, is neither a product nor a raw material but an intermediate, which was convenient, but not essential to store in huge tanks. The attitude in the chemical industry at the time was that there was no need to worry about large stocks of toxic material as they could be kept safely. The accident at Bhopal destroyed that confidence. It became imperative that safety measures should not be add-ons but a part of the original design itself.

Research in inherently safer design had started in mid-70's (after an explosion at a chemical plant in Flixborough, England in 1974) but suffered from benign neglect because most inherently safer designs are difficult to backfit on an existing plant. Bhopal gave a huge impetus to this research. The designer is challenged to identify ways to eliminate or significantly reduce hazards, rather than to develop add-on protective systems and procedures [8, 9]. The main methods for achieving inherently safer design are [10].

- Minimize: Reducing the amount of hazardous material present at any one time, e.g. by using smaller batches.
- Substitute: Replacing one material with another of less hazard
- Moderate: Reducing the strength of an effect, e.g. using material in a dilute rather than concentrated form
- Simplify: Designing out problems rather than adding additional equipment or features to deal with them.

An inherently safer design evaluation does not always result in a clear choice about which of the alternatives identified and evaluated is best. An option which is inherently safer with respect to one or more specific hazards may introduce new hazards or increase the magnitude of other hazards. For example, use of a less toxic solvent may increase flammability. Decision theory tools could offer some potential benefits in this regard. As of now the industry using toxic materials lacks common understanding and tools for inherently safer process choices as scientists of different streams talk past each other.

Another problem with the current thinking in the field of inherently safer design is that it does not take into account the public perception of toxicity of chemicals. In 2008, an explosion occurred at the Bayer CropScience chemical production plant in West Virginia and the debris from the blast hit the shield surrounding an MIC storage tank [11]. Though there was no damage to the container, public perception of the MIC as the killer gas of Bhopal invigourated community pressure and the U.S. Congress appropriated $600,000 to fund a study by the National Academy of Sciences to review the current industry practice for the use and storage of MIC in manufacturing processes, including a summary of key lessons and conclusions arising from the 1984 Bhopal accident. In his testimony before a subcommittee of the House Committee on Energy and Commerce, Bayer's President, William Buckner, admitted to concealment of information due to "a desire to prevent that public debate from occurring in the first place". In the meantime, local residents filed a complaint in the District Court for restraining Bayer from manufacturing and storing MIC and succeeded in obtaining a temporary injunction in September 2013.

An application of inherent safety principle that has seen rapid development since Bhopal is to minimise number of deaths to a number as low as reasonably practicable (ALARP) in the event of a toxic release [12]. First stage is credible incident generation which could be near instantaneous release of the toxic gas which disperses into the atmosphere. It is possible to estimate concentration which will depend on the total mass of the material released, release height above the ground, distances and dispersion coefficients in the downwind direction, crosswind direction and upwards. Dispersion coefficients will in turn depend on the stability class of the toxic material [13]. The data relating to concentration obtained from the source and dispersion model is fed into toxic release effect model to estimate fatalities due to exposure to toxic concentration by the set criteria by toxicologists. A simple probit model indicating probability of death is given by the following equation:

$$Y= A + B \ln(c^n t)$$

where Y is the probit, c is the concentration in ppm, t is the exposure time in minutes. A, B and n are constants depending upon the nature of toxic substance and dose response complexities. A conversion from Probit to percentage of fatalities can be obtained by using error function [14]. Inherently safe design will attempt to bring down Y to ALARP level.

Within a plant handling toxic material, the location of various units have historically been decided on the basis of heuristic rules. However, heuristic approaches do not necessarily produce a safe layout [15]. Research in this area is of recent origin with the first paper coming out in 1996 [16] Of late, researchers have applied Layer of Protection Analysis (LOPA) tool which incorporates methods to characterise consequences and estimate frequencies [17]. Optimal layouts can reduce fatalities in a toxic release scenario [18]. Classic LOPA methodology can be extended by using probability distributions of risk instead of expected values [19]. The problem of neglecting public perception will, however, remain. The most widely read Statistics book in history is titled 'How to Lie with Statistics' [20]. Since much of the research is sponsored by the chemical industry itself, the credibility of such models is low. In any case, even after three decades, there is no consensus on cloud densities, elevation of the jetting plume, MIC densities, ground level concentrations and other details of the release [21].

Making Sense: Scholars are trying to analyse the events at Bhopal that don't make sense. We can tolerate the unexplained but not the inexplicable [22]. The incident initiated research in Sensemaking in crisis situations with a seminal article by Karl Weick [23]. Even in case of inherently safe designs, human errors cannot be designed away because these errors are caused by human variability [24]. And yet we do not understand much about such triggered events that can cause an industrial crisis [25]. In this context, sensemaking could be viewed as the process of social construction that occurs when discordant cues interrupt an ongoing activity and involves the development of plausible meanings retrospectively rationalising what people are doing [26].

Toxic releases are low probability - high consequence events that defy interpretations and hence impose severe demands on sensemaking. Our ability to deal with chaos depends on structures that have been developed before the chaos arrives [27]. About leakage in storage tank of MIC that cannot be stopped or isolated, the operating manual of the Bhopal plant stated "The situation will determine appropriate action. We will learn more and more as we gain actual experience". This was a typical 'The dog is allowed one bite method': Until our dog has bitten someone, we do not have to muzzle it or keep it on a leash. This method was acceptable when the consequences of the bite were small but not now when we have seen a bite of the size of Bhopal [28].

According to Richard D. Robinson, professor emeritus at MIT's Sloan School of Management, Union Carbide was “a corporation distinguished by a management with a keen sense of public responsibility” and had maintained a sophisticated environmental monitoring system backed by top management support [29]. While management scientists focus their analysis at the organisational level, theoretical literature in Sociology suggests that organisation may not always be a meaningful level of analysis [30]. Alternatively, it can be argued that in the instant case, ‘organisation’ was not the corporate entity as commonly perceived by the management theorists but the maintenance crew. Bhopal was an off-shore outpost. Inspectors from the company's headquarters had visited the plant two years prior to the accident and cited a number of serious safety problems. However, no follow-up was done to see that the safety problems were corrected; the problems remained and contributed directly to the subsequent disaster [31]. Eight weeks after the accident New York Times quoting a former project engineer reported; “The plant was losing money and top management decided that saving money was more important than safety. Maintenance practices became poor and things generally got sloppy” [32]. The control room was something of a nightmare for sensemaking [33]. There were malfunctioning valves, faulty indicators and missing control instruments [34]. The workers’ perception that their unit does not matter is as dangerous as decreased maintenance in raising the susceptibility to crisis. A deteriorating production facility blunts sensemaking tools which mask accumulating problems. According to Karl Weick [33] what the industry needs to learn from Bhopal is that each step in this chain can raise the low probability of a high consequence event to tragic levels.

In the engineering perspective, reliability, describes the ability of a system to function under stated conditions and is defined and affected by stochastic parameters. There is a growing realisation in the engineering profession that reliability and safety cannot be achieved by mathematical models because the ranges of uncertainty involved largely invalidate quantitative methods for prediction and measurement [35]. Moreover, encapsulating learning into routines could lead to fixation failures when unexpected events occur. Organisations that require high reliability are often worried about overloading of any one person who may under trying circumstances commit a mistake and these organisations design methods of avoiding such a contingency. There was no such problem of overloading in Bhopal. The operating crew for the night shift did not have much to do because their production units had been stopped 6 weeks earlier. They chatted about the plant’s gloomy future, smoked and chewed betel. The situation and sequence of events has been narrated with considerable accuracy in Dominique Lapierre and Javier Moro’s famous book *It was five past midnight in Bhopal*. At about 11:30 PM, one of the operators smelt MIC in the air but others insisted that it was the smell of mosquito spray and proceeded to the canteen for a tea break along with the supervisor. During the tea break another operator came into the canteen from the control room and said, ‘The pressure needle has shot up from 2 to 30 psig’. The supervisor said, ‘It is your dial that has gone mad’ and continued with the tea break. Around midnight, the operators’ eyes began to water and they smelled the distinctive MIC odour. Two of them walked out to the tank in order to compare the pressure reading at the tank with the unusually high reading in the control room. Both gauges gave the same high reading and a leak was spotted at a draincock. When the supervisor heard of the leak he ran out to the tank and saw an erupting column of gas. Transfixed, he murmured, ‘It’s not true’ [6]. Since there were no operations and only inert storage in the plant, it was assumed that nothing significant could happen, least of all a terrifying, uncontrollable, cataclysmic exothermic reaction spewing out a cloud of poisonous gas. It was not a case of loss of broad operational awareness on account of production pressure and overload. It was mindlessness coupled with thoughtless action that made it impossible to cope with the surprise of a non-routine event. To counter mindlessness, reliability is to be achieved through processes of cognition overlooked by most organisational learning and adaptation theorists.

Only an organisation that is preoccupied with possibility of failure, refuses to simplify interpretations and retains sensitivity to operations and committed to resilience can produce a capability to induce a rich awareness of discriminatory detail. This capacity has been called mindfulness [36]. Mindfulness is about interpreting weak signals, enlargement of the issues that are noticed and to act on what is noticed. Mindfulness is part of Eastern wisdom going back at least 2,500 years. While Eastern perspective focuses on mindfulness as a process grounded in meditation, western science views mindfulness as content [37]. Organising processes of collective mindfulness has greater importance in organisations requiring high reliability like the chemical industry dealing with toxic material. Instead of resting on its successes, each organisation needs to organise socially around failure in ways that induce mindfulness. Mindfulness enables discovery of anomalies and corrective action before errors could cumulate and result in a cataclysm. Many areas in the sphere of mindfulness remain unexplored. How similar is the 'void' created by meditation in the thought process similar to that created by a signal of unusual event as analysed in Western science? What is the two-way relationship between individual and organisational mindfulness? There is growing evidence that mindful organisation increases reliability low probability - high consequence scenario [38]. But there is virtually no research on how different cognitive processes interact to produce effective fault detection.

A growing body of research is coming to recognise that in case of toxic releases what were earlier thought to be technological failures have a strong human element to them. By shifting attention from faulty technology to people's interaction with technology and with each other this literature draws our attention to cognitions and actions during crisis [39]. When faced with a cataclysmic event, it becomes clear that our thinking and our capacities to respond are significantly inadequate. Substantial investments need to be made to develop inter-disciplinary teams that can act quickly when faced with low-probability high-risk events. Organisations can survive under changing circumstances by reconfiguring their routines and capabilities [40]. This applies to technology conversion process as also to management of risk in low-probability high-risk organisations.

Mission Irresponsible: Union Carbide was caught off guard and its reputation was permanently stained by the disaster - especially as the company tried to absolve itself of any responsibility arguing that its subsidiary and a disgruntled worker were to blame. After the Bhopal disaster, public resentment against the chemical industry using toxic chemicals in an irresponsible manner reached a very high level both in developing and developed countries and government intervention to reign in the industry seemed inevitable. To forestall such an intervention, the chemical industry launched its "Responsible Care" program, designed to prevent any future events through improving community awareness, emergency preparedness and process safety standards [41]. The programme launched in 1985 by the Canadian Chemical Producers' Association, now boasts of participation of 60 national chemical manufacturing associations. At the UN-led International Conference on Chemicals Management in Dubai in 2006, the industry launched a Responsible Care Global Charter along with a Global Product Strategy. In 2013, the programme was further enhanced though increased commitment towards safe operations and management of toxic chemicals as also reuse and recycling. At national level, member associations are responsible for the detailed implementation of Responsible Care in their countries and individual countries' programs are at different stages of development with different emphases in fostering capacity building, sharing of information, cooperative initiatives with government agencies and community projects such as development of wildlife habitats and tailored programs for schools. There are growing concerns about corruption and violation of human rights by the multinationals in the third world. It is also being realised that corruption and violation of human rights are interrelated [42]. Responsible Care Programme seeks to project a positive image of the industry. It has been described as "a typical CSR 1.0 approach – unilateral, defensive and incremental" [43].

People all over the world are now more alert to the dangers of toxic chemicals. The very thought of a factory using or storing toxic materials anywhere near them is anathema to most people today. It's an attitude referred to in the trade as NIMBY — "not in my backyard". There is a strong case for counteracting nimbyism. It could be done through education, persuasion or incentives and if nothing works by force of law. The chemical industry attempts to counteract nimbyism as also legitimate concerns of the local population through misinformation. Often they refuse to give full information on the pretext that giving out full information may aid potential terrorists. In case of its plant in West Virginia, Bayer CropScience admitted: "There were, of course, some business reasons that also motivated our desire for confidentiality. These included a desire to limit negative publicity about the company and to avoid public pressure to reduce the volume of MIC that is produced and stored by changing to alternative technologies". That transparency is integral part of CSR is yet to dawn on the chemical industry.

The national level associations justify joining the Responsible Care Programme by insisting that their members gain competitive advantage over non-members as also marketplace recognition. In the U.S., the members are also assured of liability protection, if they can demonstrate that an accident at their facility happened due to terrorist action. Certification as a Responsible Care company is no gold standard. Poisoning of river Elbe by the company Draslovka Kolin, a Responsible Care certified company in 2006 or hiding of 20 MT leakage of naphthalene by the company Deza, also a Responsible Care company raises the question whether the Responsible Care brings any real improvement or is merely a marketing strategy. Such events highlight the potential for opportunism to overcome the isomorphic pressures of even powerful self-regulatory institutions and suggest that effective industry self-regulation is difficult to maintain [44]. In any case the primary goal of the Responsible Care effort has been to change public concerns and opinion about chemical industry environmental and public health practices while also opposing support for stronger and more expansive regulation of toxic chemicals, even if warranted [45]. It is more about changing perceptions, than changing actions and the companies spend millions of dollars on public relations and greenwashing instead of making meaningful changes. The primary goal to oppose stronger regulations has remained a consistent and primary aim of the program to the present [46]. A poll commissioned in the U.S. in 1990 by the Chemical Manufacturers' Association to measure public approval of the chemical industry found that by comparison with other industries, the chemical industry was rated ahead of only the tobacco industry by the general public. To counter this negative image, the Chemical Manufacturers' Association changed its name to American Chemistry Council in 2000 and increased funding to its public relations campaign as also to political action committee that gives money to members of the U.S. congress. It has also resorted to pitting patriotism against environmentalism by using the term "American Chemistry" for "chemical industry". Bhopal tragedy has taught multinationals how to manage public perception through outreach programmes, media management and political action.

CONCLUSION

In the age of Damocles that we live in, occasional cataclysmic events reveal the quantum leap that has been made in our level of vulnerability. Johannesburg World Summit on Sustainable Development in 2002 had challenged the world community to ensure that, by the year 2020 toxic chemicals will be produced and used in ways that minimize significant adverse impacts on the environment and human health. In 2006, the International Conference on Chemicals Management (ICCM) in Dubai supported this goal and adopted the Strategic Approach to International Chemicals Management (SAICM) as a policy framework to foster the sound management of chemicals. Progress in the implementation of SAICM was reviewed at the third session of the ICCM held in 2012. The review highlighted the role of academic professionals, as they carry out research related to toxicology in addition to training the future health-care workforce. The review appreciated the role of frequently read journals catering specifically to the health sector and recommended to increasing the number of peer-reviewed articles on the toxicology and related subjects. The networks such as the INTOX network for sharing information and mutual assistance on poisons and toxicological issues should continue and expand their work. Consideration should be given by medical schools to residencies and fellowships or specializations in environmental health with an emphasis on toxicology. Importance of toxicovigilance and toxicosurveillance was highlighted. Union Carbide had donated funds to toxicology research at Carnegie-Mellon in Pittsburgh and to the Chemical Industry Institute of Toxicology and had initiated joint health research with the U.S. National Institute of Occupational Safety and Health. A system for identifying which chemicals pose a danger to humans was put in place in 1930's and there has never been a shortage of funds for research [47]. It is amazing that toxicologists did not know the extent of damage MIC can cause. Moreover, they did not know that MIC can be degraded as a result of pyrolysis and interaction with water; if they knew this was never communicated to the doctors and paramedics struggling in the city hospitals overflowing with dying patients. Toxicology is an intense vocation and many reputed toxicologists prefer not to have much interaction with the outside world. They need to be dragged out of the ivory tower and confront the real world, collaborate with other scientists as also managers in the field of crisis management. The details of the formation composition and size of the poisonous cloud that killed people in Bhopal is still a subject of debate. More research is required in the 'the environmental fate of chemicals' - the processes by which chemicals move and are transformed in the environment. As of now, there is no methodology for evaluating the environmental behaviour of chemicals that has gained wide acceptance; this is particularly true in the selection of mathematical models to predict environmental fate parameters.

In December, 1984 the world was aghast at the carelessness that can produce a Bhopal tragedy for it suggested a callousness that is unacceptable in any society, contravening basic moral principles of humanity. Past should never be forgotten because the inventions for the future are not spontaneously generated. At the same time discontinuity, complexity, fragmentation must be integrated into our reference frameworks. Inherently safe designs are likely to reduce the probability of major accidents as also the number of casualties when they do occur. People have no faith in such designs as the industry has a very low credibility when it comes to handling toxic chemicals. Responsible Care certified companies often hide the fact that toxic materials have been accidentally released. When such information cannot be hidden various tactics are employed to avoid giving out full information. Clearly, there is a need for more public pressure to be mounted on the industry to be transparent. In the past such pressure has worked in case of automobile industry and tobacco industry. A major difference is that in case of the chemical industry the victims have been more numerous in the developing countries. Even so, today a company will not try to wash its hands off in case of a major catastrophe as Union Carbide tried to do thirty years ago. That by itself ought to be incentive enough for further research in hard sciences of inherently safe designs, toxicology and environmental fate of chemicals as also soft disciplines of sensemaking, mindfulness and CSR in chemical industry.

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