Hazard Concerns: MIC at Bhopal and Virginia and the Indian Nuclear Liability Act

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Oblivious to the anger and outrage expressed throughout the world after the methyl isocyanate leak in December 1984, the continued storage of MIC at the parent West Virginia plant until 2011, despite several accidents, indicates the limited effect of public safety concerns on corporate strategy. As in India, neither the US executive nor the judiciary seemed capable of withstanding pressures exerted by the chemical processing industry. This is an ongoing story of struggle. What gave Bhopal a fresh salience in the public mind was the Indian government's proposal to buy nuclear power reactors from the US, and to agree to legislation which would satisfy US manufacturers of the limits to their liability. Disconcertingly for the government, the Bhopal chief judicial magistrate's judgment in 2010 led to an explosion of public fury, forcing the government to introduce clauses in the nuclear liability legislation laying down responsibility on the technology supplier. If organic chemicals have awakened the world to the dangers of chemical substances, Bhopal brought home the fraught nature of industrial processes involving exothermic reactions.

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1

The leakage of methyl isocyanate (MIC) from the Union Carbide plant in Bhopal in December 1984 had profound implications in many areas of public life.[1] Efforts at effective regulation of industrial processes which involved storage of hazardous material, usually intermediates and final products in the chemical industry, can be dated from the worldwide political reactions to the accident (CE 1985c; EC 2012). Subsequently, attention moved to the elaboration of the design principles that should underlie the construction of industrial plants which generated hazardous chemicals, and the legislative and administrative measures that would ensure compliance with these principles (CE 1986b). It also brought into prominence MIC and its chemistry; until then this had been an obscure intermediate of relevance, principally, to the pesticides industry (C&EN 1985).[2] Ironically, in terms of the history of chemistry, too, the "biography" of MIC could be said to end, also in 1984, when DuPont commercialised a considerably more capital-intensive technology by which MIC became truly an intermediate, in a process which did not require its storage. It was now merely a stage in a continuous process to manufacture pesticides (C&EN 1985; CE 1986b).[3] A second end to the biography could be dated to 2011, when Bayer, now owners of the parent Union Carbide plant in Virginia, agreed to close it after years of protest by residents of the adjoining small town (Bayer 2011).[4]

However, what gives the history of this chemical fresh salience are a series of developments seemingly unconnected technologically. In 2008, the Indian government declared its intention to buy several nuclear power reactors from the United States (US) and agreed to a new legislation which would satisfy US manufacturers of the limits to their liability (Varadarajan 2008). The US firms wanted liability (in the case of nuclear accidents) to be confined to the plant operator and to a maximum of $450 million. Liability for design defects from the equipment supplier was fiercely opposed. By this time, however, the design defects in the MIC plant which led to the 1984 disaster were well known, as was the inability of the Indian judiciary and executive to pinpoint and get compensation in cases of poor design or even deliberate instances of "under-design" (CE 1985b; 1986a). With the announcement of a long-delayed verdict on compensation, there was an explosion of public anger which forced the government to introduce clauses in the nuclear liability legislation laying down responsibility on the technology supplier. In effect, the legislation was a reflection that neither the executive nor the judiciary-could be expected to uphold the rights of victims of humanly-created disasters, as both were vulnerable to powerful international pressures. Given the implications of the Bhopal case, the transfer of public concern from one hazardous technology (bulk production of MIC) to another (nuclear power generation) is not only of significance to the way in which technological developments are driven, but should rightfully be viewed as part of the career of MIC, and therefore of its biography.

As has been mentioned, MIC had been principally used in the pesticide industry. This paper starts with a brief overview of its laboratory examination, and then proceeds to its application in a proprietary process for the manufacture of a carbamate pesticide, carbaryl. As the Bhopal tragedy arose from the specific industrial technology used by Union Carbide, the paper examines the lengthy process which preceded the ultimate closure of a comparable large MIC production and storage facility in the US. This involved legislative and administrative measures in the US, along with mobilisation of the local community and workers in the plant. The paper concludes with a discussion of the effect of public recognition of the similarities in hazards posed by large-scale chemical reactions and nuclear reactions into a major innovation, of long-term equipment supplier liability.

2

Isocyanates were first synthesised in 1849 by the double decomposition of a dialkyl sulfate with potassium cyanate. During the period 1885-1900, a considerable store of information regarding the fundamental properties of isocyanates was discovered. Hentschel, in 1884, showed that an isocyanate could be obtained from the reaction between phosgene and the salt of a primary amine. This reaction was modified by Gattermann and Schmidt, who claimed an almost quantitative yield of MIC by their procedure.[5]

However, it was not until some 40 years later that the practical uses of these compounds were realised. Significant progress was slow, until the discovery of polyurethanes in 1937. However, by the late 1940s, the industrial applications of isocyanates had progressed to the point where such compounds were of major commercial interest, particularly in the field of polymers. Evidence for this growth was found in the patent literature of the post-war years and in the reports of German industry. By 1960, many isocyanates had been investigated.

The 25 and more methods for the preparation of isocyanates could be classed by the reaction involved. The most common method involved the reaction between an amine, or its salt, and phosgene. Curtius, Hofmann, or Lossen rearrangements and double decomposition reactions had also been widely used, in addition to a variety of miscellaneous methods.

There were three isocyanates of major commercial importance. Apart from MIC, almost all of which was used to make carbamate pesticides, the other two were toluene diisocyanate (TDI) and 4,4/-diphenylmethanediisocyanate (MDI), both of which were used almost exclusively to make urethane and isocyanurate polymers. Small amounts of MIC and other alkyl monoisocyanates were used for other purposes; for example, in the manufacture of certain pharmaceuticals (C&EN 1985).

Commercialisation of MIC

The chemistry of methyl isocyanate (CH_3NCO) was investigated and reported in 1927. However, it was not until the development of post-war interest in chemical pesticides, which led to the search for alternatives amongst pesticides, that MIC became of commercial interest. The growth of resistance by certain insect species to chlorinated hydrocarbon insecticides had aroused research interest in alternative chemical classes.[6] The handling hazard of many organophosphates emphasised the need for safer materials. In 1957, Union Carbide Corporation (UCC) announced the development of a carbamate pesticide, Sevin, known chemically as 1-naphthyl N-methylcarbamate, after four years of laboratory-scale and field testing. It was synthesised by Lambrech in 1953 and subjected to laboratory, and preliminary field tests, for two seasons. In 1956, Sevin was released for testing by government specialists in agricultural experimental stations. In 1958, it received the first official recommendation and was sold on an experimental basis. Unusual amongst organic insecticides at the time, it did not contain either chlorine or phosphorus. It had a distinct mechanism of operation on the nervous system to that of chlorinated hydrocarbons such as DDT, and had been demonstrated to be safer in its effect on mammals (D'Silva 2006: 32).

There were several routes for manufacturing the item. In the original three-step process, patented by UCC, 1-naphthol was dissolved in aqueous caustic soda to form sodium naphthoxide. This was added to a solution of phosgene in toluene to yield 1-naphthyl chloroformate. In the final step, the chloroformate reacted with methylamine to give 1-naphthyl N-methylcarbamate, or Sevin (Lambrech 1959). This was the process that UCC originally used when it started making Sevin in 1958 (C&EN 1985: 32). By 1966 this three-step process, held to be labour-intensive and unsuitable for modification for continuous operation, was sought to be replaced by a new technology by which the product was obtained by the direct reaction of 1-naphthol with MIC.[7] This reaction, carried out in warm benzene or toluene, gave an almost quantitative yield of the carbamate. In this process Carbaryl (Sevin) was produced by taking MIC, itself made by reacting methylamine with phosgene, and reacting it with 1-naphthol, i e,

Monomethylamine (MMC) + Phosgene —> Methyl Isocyanate (MIC)
Methyl Isocyanate (MIC) + 1-Naphthol —> Carbaryl

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UCC was one of the earliest transnational corporations (TNCs) to invest in India. In 1924 it opened an assembly plant for batteries in Kolkata.[8] The venture was officially incorporated, in 1934, with the name of Ever Ready Company (India). After a public issue of shares, the company, now named Union Carbide India Ltd (UCIL), diversified into chemicals in the early 1960s.[9] The industries UCIL entered were technology and capital-intensive, requiring technically skilled labour (Khanna 1984). These were still in the early stages of development and

UCIL leveraged the technologies available from its parent company to attain dominant market positions (Srivastava 1987: 36). In particular, the company utilised this strategy in the pesticides market, by claiming that it was then the sole producer of MIC in the world.[10] In 1966, UCIL created the Agricultural Products Division (US 1985b: 11-12). In furtherance of the project, UCIL first applied to the Government of India for a licence to manufacture pesticides in 1966. The Government of India, in response, granted a letter of intent to issue an industrial licence. A pilot plant was started near Mumbai, but, by a unilateral decision of the corporation in 1968, the facility was moved to Bhopal. The original letter of intent lapsed, and in 1970 UCIL wrote to the government with a new application, for which another letter of intent was granted in 1972.

After evaluating the market potential, UCC management in 1973 approved a proposal for the erection of manufacturing facilities for MIC and MIC-based pesticides (US 1985a). In October 1975, the government granted a licence to UCIL to produce 5,250 tonnes of pesticides in Bhopal. The Union Carbide Engineering Division in West Virginia was made responsible for engineering decisions, and plant construction. Its brief comprised conceptual design work, preparation of the design report (including operating manuals), appointment of a project manager, and training of those UCIL employees who would form the initial operating team. UCIL paid UCC for engineering expenses, with a technical service fee for the use of UCC technology, patents, and trademarks as well as continuous know-how and safety audits (US 1985a).

In its renewed application, UCIL stated that technology from Union Carbide in the US now made the project feasible. The company claimed that in the previous three years, UCC had made dramatic improvements in MIC production technology.[11] However, internal UCC documents show that the technology proposed had not been proven. A 1972 memo stated that "...The Methyl Isocyanate system has been operated a total of 448 days since start up in late 1965. Almost every item in this unit has failed and been replaced since start up."[12] In other words, over the 1,825 days spread over the five years from 1966 to 1971, the unit had been operational less than 25% of the time. Although the MIC technology sold to UCIL included the process improvements made over the first MIC plant at Institute, West Virginia, built in 1965-66, the plant in use in Virginia from 1978 onwards was more "streamlined", and fully automated (D'Silva 2006: 56). Despite the actual construction of the Bhopal plant commencing in mid-1978, these process modifications were not incorporated. In addition, new processes were planned in India for two of the primary intermediates and even the MIC to Sevin transformations had limited trial runs at UCC (UCIL 1973: 12).

Explicit Violations

Although UCC designed the Bhopal plant based on the plans of the existing MIC unit in West Virginia, some design modifications were introduced.[13] Evaluation of the minimum requirements of instrumentation "suiting Indian conditions" were specified as an overall criterion, and pneumatic rather than electronic controls were to be used, because electronic parts were "not available" in India (D'Silva 2006: 47). Thus, while computerised alarms and crises control procedures linked critical systems at the West Virginia plant and other industry plants handling MIC had electronically controlled four-stage backup safety systems, Bhopal lacked similar sophisticated sensors to alert technicians (DSF 1985; C&EN 1985: 30). It had a manual, single stage safety system. There were no computers to assist in identifying when and where problems occurred, and to commence automated abatement procedures. To detect MIC leaks, plant management relied on workers to sense the escaping gas through eye irritation. This was in explicit violation of Union Carbide's MIC handling procedures, which read, "Although the tear gas effects of the vapour are extremely unpleasant, this property cannot be used as a means to alert personnel" (*New York Times* 1985).

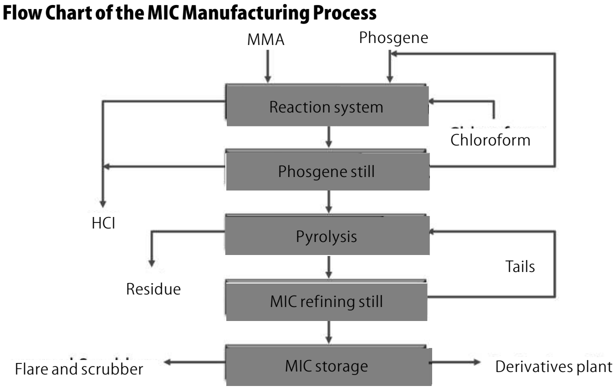
During the design stage for the plant modification to incorporate the backward integration, a difference of opinion arose over the question of creating substantial MIC storage capacity, comparable to the MIC plant at UCC's West Virginia unit, or a nominal storage level, determined by downstream process requirements (US 1985a).[14] UCIL management supported this latter approach. UCC, however, planned to produce MIC to sell to industrial customers in India and other Asian countries (ICFTU/IFCEGWU 1984). This strategy led to the installation of three large 57 kilolitre storage tanks, two for MIC storage and one as a safety backup for excess gas (Union Carbide 1985).[15] The engineering division of UCC also had an incentive to decide in favour of a storage tank design that could be patterned on the existing UCC plant in West Virginia.

Between 1977 and 1984, UCIL operated the plant for pesticide production. Initially, this entailed the mixing of different chemicals to create pesticides, with UCIL importing the necessary ingredients. In 1979 the company, through backward integration, modified the Bhopal plant to not only manufacture pesticides, but also the raw materials including phosgene and MIC.

Phosgene was manufactured by reacting chlorine gas (brought to the plant by tanker) with carbon monoxide, which was produced from petroleum coke by passing air over red hot coke in a production facility within the plant (Union Carbide 1985). Monomethylamine (MMA) was also brought in by tanker. The MIC manufacturing process was carried out with equimolar ratios of phosgene and an amine in a solution of chloroform. The reaction of phosgene with MMA in the vapour phase led to the formation of methyl carbamoyl chloride (MCC). The reaction products were quenched in chloroform, and then fed to a phosgene stripping still to remove the unreacted phosgene for recycling. The bottoms from the stripper were fed to a pyrolyser where MCC was decomposed into MIC and hydrogen chloride (HCl), which were further separated.[16] The pyrolyser condenser fed the MIC refining still (MRS) where MIC was separated from the chloroform in the upper part and was led directly into a storage tank. The bottoms of the MRS containing residues of MCC, chloroform, and other by-products were collected and recycled. The HCl which was formed was scrubbed with chloroform and extracted with water, producing aqueous

HCl which was disposed of by neutralisation. MIC was manufactured primarily to make the pesticide carbaryl (Sevin) as well as smaller quantities of other pesticides, aldicarb (Temik) and butylphenyl methylcarbamate.

Flow Chart of the MIC Manufacturing Process



Carbaryl was manufactured by the reaction of 1-naphthol with MIC. The MIC was gradually added to an excess of 1-naphthol in carbon tetrachloride solvent at 60-80 C, in the presence of a catalyst. The exothermic reaction had a yield of more than 95%.

During the green revolution, pesticide use increased dramatically, jumping from 8,620 tonnes over six million hectares in 1961 to 65,000 tonnes over 100 million hectares by 1983. This growth attracted over 50 new pesticide firms offering more than 200 varieties (Srivastava 1987: 17). Due to this influx profitability fluctuated, leading Union Carbide to re-evaluate its once optimistic attitude towards the pesticide market. The UCC Management Committee's decision to build an MIC plant in Bhopal faced serious questions of economic viability even before the commissioning of the plant (US 1985b: 30-31). The recognition of this financial reality led the UCC management over the next couple of years to consider several alternative strategies of utilisation of the Bhopal plant, none of which succeeded. In the winter of 1978, with the project about midway to completion, there was concern over both potential cost overruns and reduced estimates of the size of the pesticide market in India. The focus of discussion was whether a new design, smaller in scale, could be implemented at that late date. In the end, the decision was to maintain the basic design and proceed as originally planned because the project was too far advanced to pull back. The financial prognosis, however, did not improve. In 1979, the Bhopal project was termed by UCC as the major critical issue in the operations of its worldwide agro-chemical business. Its problem was to be characterised as identical to the Institute, West Virginia plant's problems – an oversized plant serving an undersized market (US 1985b: 31).

Increased competition, droughts and saturation in the market resulted in the Bhopal plant generating profits lower than predicted. Production levels at the Bhopal plant dropped throughout the 1980s, from 2,308 tonnes in 1982 to 1,647 tonnes in 1983. The Bhopal plant contributed 8% of UCIL's sales proceeds (*New York Times* 1984). By 1984, the plant was manufacturing a quarter of its licensed capacity of 5,250 tonnes (Fortun 2001: Introduction). Given financial considerations and the fact that several of UCC's divisions in the US were faltering, the Bhopal plant was a prime candidate for divestiture (Srivastava 1987: 76). UCC decided to dismantle the plant and distribute manufacturing operations amongst other countries. This plan was abandoned after it met considerable resistance from the UCIL management (Dembo et al 1990: 91).

As a compromise, UCIL was forced into considerable economy measures in the factory, including significant staff reductions (Fortun 2001: 92). A new plan was developed in February 1984: the MIC unit, considered to be of strategic significance to UCC would be retained but the rest of the Bhopal plant would be disposed of (US 1985b: 36). UCIL would thus continue to manufacture MIC, but would not formulate pesticides. Despite a history of accidents at the factory, a variety of safety devices were left inoperative. In November 1984, UCC directed UCIL to close the plant and prepare it for sale (Fortun 2001: 133).

However, before this plan materialised, the leak of MIC in December 1984 led to the permanent closure of the plant. On 3 December, according to Union Carbide, approximately 24,500 kg of un-reacted MIC escaped from one of the storage tanks together with approximately 11,800 kg of reaction products (AI 2004: 11). At least 15,000 people died between 1985 and 2003 because of the gas leak. This is in addition to the 7,000 to 10,000 people who died in the immediate aftermath, taking the total death toll to well over 20,000 (AI 2004: 12; BGIA 2008).

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The UCIL plant's location in a third world country led initially to responses that dismissed the disaster as something that could only occur in a country lacking a safety culture; a position quickly undermined by an incident at the UCC factory in Institute, West Virginia in August 1985, which shared many of the characteristics of the Bhopal disaster except the number of casualties. In March 1985, three months after Americans watched on the evening news men, women, and children dying as a result of the accident at the UCC plant, the company's chief operating officer, Warren Anderson, spoke to the United States Congress about the company's Institute, West Virginia plant (Chess 2001: 181). He reassured senators that the plant had been examined with a "fine tooth comb". The release of methyl isocyanate that caused the deaths in Bhopal was "inconceivable" in the US. According to a Harris poll, 50% of the respondents believed him. However, on the morning of Sunday, 11 August 1985 less than five months after Anderson's assurances, release of aldicarb oxime from the UCC site led to more than 130 people having to be treated for eye, throat, or lung irritation. After the West Virginia incident, another Harris poll showed that 91% of the respondents now felt that government "should crack down a lot harder on chemical companies such as Union Carbide than they have" (Chess 2001: 181).

Located along the Kanawha River about 20 kms from Charleston, the Institute plant site covered about 1.4 sq km. The facility was built in 1943 by the US government for the production of rubber during the second world war. The plant was then bought and operated by Union Carbide, from 1947 until 1986. In the US, the major consumption of MIC took place in the production of insecticides, carbaryl, carbofuran, methomyl, and aldicarb. Worldwide too, pesticide manufacture was the principal commercial use of MIC. Very small volumes of MIC had at times been used to manufacture pharmaceuticals, but it was uncertain how widely it continued to be used.[17]

UCC had begun alternative MIC technology research in November 1976 (US 2011a). The initial research focused on the area of "adducts", chemical structures that can, in principle, be easily added and removed from the desired chemical. The intention of introducing an adduct is to change undesirable characteristics of the chemical to which the adduct is attached. The adduct made MIC soluble in water and ultimately less hazardous should it escape containment. However, the MIC adduct was not easily removed and was found to contaminate the insecticide products. In July 1984, UCC researched a palladium-catalysed reaction that had the potential to completely eliminate both MIC and phosgene use. Here, the cost of the catalyst greatly outweighed any potential gains from this process. During its ownership, UCC reviewed 97 patents dealing with alternative technologies to MIC production but concluded that none could perform as well as the existing process. In the last year of the facility ownership, UCC found three different pyrolysis techniques that showed promise in eliminating phosgene and reducing the MIC stock, but it sold the facility before completing the studies.

After the Bhopal MIC disaster, UCC sold its agricultural division to the French chemical company Rhone-Poulenc SA (R-P). R-P continued the research into pyrolysis for a few years, but ultimately decided that the pyrolysis approach to manufacturing pesticides was not cost-effective. It also undertook research into different approaches to operating the processes that used MIC and phosgene, intended to reduce the stockpiles of both. In all, after five new techniques studied, R-P concluded that either the stress placed on the process equipment was too great or the new process would be unacceptably difficult to control. It also conducted research into various processes which would allow MIC to be synthesised and consumed in the process line. This form of production would eliminate the requirements for stocking MIC and could also remove the requirement of phosgene.

R-P analysed the process that DuPont has developed but it did not adopt the technology, possibly due to patent restrictions. Finally, R-P reviewed what was thought to be a promising process proposed by Enichimica Sintesi (Enichem) in Italy. This process manufactured carbamates from a precursor of MIC, dimethyl carbonate, which avoided any need for MIC storage. In the process, which the company claimed was competitive with current methods, diphenyl carbonate reacted with MMA to produce methylphenyl urethane. Methylphenyl urethane was transformed into carbamate, co-producing phenol, which could be recycled (CE 1985a, b, c). This was proposed for a facility in Brazil, and the suggestion was that it could also be used at the Institute facility. The available historical records did not explain why R-P did not implement the Enichem technology (US 2011a).

By 1994, R-P was the only company in the US that was continuing the practice of bulk storage of MIC. The other two producers, Sandoz and DuPont, had switched to continuous "no storage, direct feed" processes, which consumed the MIC to make pesticides as soon as it was produced (US 1989: 2). DuPont had commercialised a closed-loop catalytic process using a reactor design that generated MIC from materials far less hazardous than the traditional phosgene and converted it to finished pesticide as it was made. The process involved the reaction of methyl amine and carbon monoxide which yielded N-methylformamide. This was subsequently oxidised to MIC in the presence of a silver catalyst (C&EN 1985, 1992). This production pathway was safer for both the environment and worker health and safety.

Hazard of MIC Storage

Thus by 1994, there were 13 plants worldwide that produced MIC, none of which stored substantial quantities of MIC. Bayer AG, which consumed all MIC produced in Europe stored minimal amounts of MIC on-site. Bayer had also patented a non-phosgene route to MIC that reacted either N'N-dimethylurea or methylamine with diphenyl carbonate to produce the isocyanate, the co-product phenol could be recycled to diphenyl carbonate by reaction with phosgene or carbon monoxide (CE 1986a, b). Mitsubishi Kasei in Japan had also changed over to no storage, direct feed processes like the other US companies (Lapkin 1994: 23). Degussa AG had patented a process for production of MIC from potassium cyanate and dimethyl sulfate. Some smaller pesticide producers in south-east Asia apparently generated MIC for captive use by this route. The higher costs of raw materials made this route uneconomical except in special circumstances (Lapkin 1994: 19). In Israel, the Makhteshim Chemical Works at Beer Sheba had reportedly developed an MIC-free way to make its "carboryl" insecticides. The firm was said to react alpha-naphthol and phosgene to get a chloroformate ester, which it then combined with methylamine to make the active ingredient in carboryl (CE 1986a, b).

Thus, of the users of MIC worldwide, most produced MIC continuously and converted it as it formed, relied upon other producers' facilities to produce pesticide products on their behalf at the site of MIC production (known as tolling arrangements), or imported finished pesticide products or intermediates made with MIC. Public policy repercussions stemming from Bhopal had markedly changed the manufacturing and handling procedures of MIC. In the United States and Europe, rail or road shipments across state or country boundaries had been banned. Producers of MIC-based products had either to locate directly adjacent to an MIC plant, or to develop low volume closed-loop systems for immediate conversion to the final product.

In addition to using MIC for its own manufactures, R-P was the sole supplier of MIC to other companies that used it to make their own carbamate pesticides. DuPont, for example, used it to make Lannate (its brand of methomyl). FMC used it to make carbofuran, which was marketed by it (and also by Mobay) under the name Furadan. R-P also made another carbamate insecticide, methomyl, for Shell Chemical, which marketed it under the name Nudrin. And there were a number of other smaller volume customers. The arrangements must have been profitable for R-P and, presumably, for its customers, as well. R-P was thus the only producer of MIC that was utilising the substance for multiple end-products. While this made the task of reducing inventories more complex, one other worldwide producer, Mitsubishi Kasei of Japan, was known to be engaged in no storage, direct feed production for multiple end products (Lapkin 1994: 23)

The production and storage of MIC at the Institute, West Virginia facility represented a long-standing safety concern to the surrounding community, dating back to when the plant was owned by UCC.[18] There had been a number of accidents at the Institute plant. Between 1980 and 1984 there were 28 leaks of MIC according to UCC's records. As mentioned earlier, 135 people were affected by a leak of aldicarb oxime from the then Carbide plant in Institute. Another MIC-related accident occurred at the plant in 1990. As a result of this history, and especially after a major explosion in 1993, an informal alliance had formed of a local community group, People Concerned about Methyl Isocyanate (PCMIC), a union representing some of the workers inside the plant (the Affiliated Construction Trades, or ACT) and officials and professors from the West Virginia State College. The alliance had demanded that the company fund a fully independent, comprehensive safety audit of the facility, with an auditor selected and supervised by the community and workers' organisations. The proposal for this audit was modelled after a legally binding agreement between a R-P facility and its neighbouring community in Manchester, Texas.

In June 1992, a serious accident had occurred at an R-P chemical plant in Manchester, Texas as a result of a release of a cloud of sulfur dioxide. At least 27 people were sent to area hospitals. With the assistance of a state-wide environmental organisation, Texans United, the community won an agreement which gave them specific rights never before recognised in Texas. R-P agreed to pay for an independent environmental audit by an expert selected and supervised by a panel of community residents and Texans United. The agreement was legally binding because it was integrated to the firm's operating permit under the hazardous waste law.[19]

A similar agreement was being sought in Institute, West Virginia. While safety measures might help to reduce the likelihood of disaster, nothing but eliminating the large inventories of MIC at the site could ensure that a Bhopal-like disaster involving an MIC release would not occur in Institute. Therefore, any independent safety review had to focus on appraisal of MIC inventory reduction options. However, while R-P was forced into the strong Texas agreement by well-organised community pressure culminating in a challenge to the firm's proposed operating permit, it had not been willing to match its Texas agreement, in the absence of such pressure tactics in West Virginia. R-P officials explicitly stated that they would not allow a comprehensive community controlled safety audit consistent with the Manchester, Texas model.

In June 1994, PCMIC decided that this issue could not wait; they secured the services of two national service organisations, the Good Neighbour Project (GNP) for Sustainable Industries and the Environmental Careers Organisation (ECO), to commence an evaluation of MIC inventory reduction at the plant. These national organisations commissioned an inventory reduction evaluation, asking R-P to cooperate in this assessment. However, they were denied both a site visit and the detailed information that was needed to complete an appraisal. R-P also acknowledged in a meeting in November 1994 that they had never conducted an economic assessment of the feasibility of eliminating MIC storage through a no-storage direct feed approach. Despite the company's lack of cooperation, an analysis using publicly available data was published in October 1994, and circulated to the company and other experts (Lapkin 1994). Meanwhile, there was an explosion in August 1994 in the methomyl-Larvin pesticide unit of the plant followed by a leak and fire in February 1996.

The problem lay in the design of the plant complex. MIC was fed through three pipes to four pesticide manufacturing units (Ward 1994: 2). The first fed both R-P's methomyl-thiodicarb (Larvin) and FMC Corporation's carbofuran (Furadan) units. The second and third pipes ran to R-P's aldicarb (Temik) and carbaryl (Sevin) plants. Since both carbaryl and methomyl were already manufactured by continuous processes, the direct feed of MIC from the production unit to each of these reactors by proportional pumps could eliminate the need for substantial MIC storage for these pesticides, probably reducing MIC storage by more than 70%. Adapting the other two product lines, aldicarb and carbofuran, to this direct feed approach would, however, require their conversion from batch to continuous processes, which was likely to require substantial investments (Lapkin 1994). R-P, however, continued to hold publicly to the position that to remove MIC inventories entirely, there would have to be separate MIC production facilities for each downstream plant (Ward 1994: 6).

Safety Issues

After Bayer purchased the Institute facilities in 2001, it formed a team to review the overall safety measures and handling procedures for MIC, re-evaluating the existing literature relating to alternative methods of producing MIC (US 2009: 14-15). In May 2003 the team concluded that the current process was as safe as other alternative methods to produce MIC at Institute. This 2003 memorandum did not explain which alternative methods Bayer considered or whether the "close-coupled" process implemented by DuPont was among them. The memo also did not discuss the extent to which the company analysed the costs and benefits of changing its storage or inventory procedures. Instead, the memo recommended that Bayer should consider adding measures to mitigate the potential damage from an MIC release. The company concluded that forcing MIC inventory levels down appeared feasible, but would be costly. Although Bayer continued R-P's efforts to evaluate the Enichem process that would eliminate phosgene and the MIC stockpile, ultimately it reported that a by-product of this reaction led to the degradation in the effectiveness of the pesticide by nearly 50% (US 2011a).

There continued to be a series of gas release related incidents for some years (US 2011b). An Occupational Safety and Health Administration (OSHA) agency review of the plant in July 2005 cited the plant for eight serious and two wilful violations, which included violations of rules governing the management of highly hazardous chemicals. However, according to the official record, when US government shop floor safety officials inspected the plant in October 2007, they found no violations (CG 2008).

The situation changed dramatically in August 2008. An explosion inside a tank used to decompose waste methomyl blew the 2,500 kg tank into the air and across the plant. Only "random chance" sent it in the opposite direction from the MIC "day tank" located just 30 metres away. The waste tank contained about 9,500 litres of chemicals, including methomyl, when it exploded. Chemical pipes and venting systems in the unit were also broken open, and their contents released. These decomposition products include chemicals such as methyl isocyanate, hydrogen cyanide, acetonitrile, carbon monoxide, dimethyl disulfide, nitrogen and sulfur oxides, and methyl thiocyanate.

For almost 25 years, there had been little chances of the success of the campaign led by PCMIC in Institute, a small, unincorporated and mostly black community of 1,500 that grew up around the university. However, the 2008 incident that killed two workers and sent projectiles dangerously close to an aboveground MIC storage tank brought new scrutiny from the United States Congress and Chemical Safety Board. The explosion also showed larger, more affluent communities in the Kanawha Valley that they, too, could be in danger; towns that the community in Institute could not help but notice were predominantly white. In all, about 3,00,000 people lived in the 40 km MIC "vulnerability zone", which included the capital.

As of August 2010, Bayer had claimed that it had not found an alternative to MIC suitable for its products manufactured in West Virginia (US 2011a). It also claimed that it had improved safety and upgraded equipment after the 2008 incident, and that it had eliminated all aboveground MIC storage. There had been no supply onsite since August 2010, when the overhaul of that unit began and it was planned to reduce future stockpiles by 80%. MIC production was to be phased out entirely in 2012 as a part of a corporate restructuring, after meeting the demands of the farming community in the 2011 season (CG 2011b).

Abruptly, however, in January 2011, Bayer announced that it would stop making, using and storing MIC at its Institute plant as part of a corporate restructuring, involving an agreement to phase out the pesticide aldicarb because of concerns that it posed unacceptable dietary risks, especially to children. The facility would stop production of aldicarb, the active ingredient in its Temik brand insecticide, by the end of June 2012. By then, Bayer had also planned to stop production of carbaryl, the active ingredient in the Sevin brand pesticide. Both products were part of the carbamate family of pesticides and had been largely substituted by newer products, prompting a review by the company of its carbamates business.

But the facility and the products it made with MIC were already under a variety of pressures. Following a May 2009 ban on the use of the pesticide carbofuran in food, FMC Corp in August 2010 stopped producing that material at the Institute site. Leasing plant space at Institute, FMC made carbofuran in part with MIC that it purchased from Bayer. And Bayer had already announced in August 2009 that it would reduce its MIC inventory by 80%, by not rebuilding its methomyl-Larvin pesticide unit where the 2008 explosion occurred (CG 2011a).

In explanation of its sudden decision not to restart the MIC unit, Bayer cited the OSHA's ongoing inspection of the unit. OSHA had said it might not complete its work, which had started in March 2011, in less than six months. This timeline would prevent the company from meeting the demands of the 2011 crop season for the pesticide Temik, which was made using MIC (CG 2011c). Thus ended the effective stored life of MIC, tied as it had been to the production facilities at West Virginia, and given notoriety by the leak at the plant designed on its model at Bhopal.[20]

5

However, what gives the history of this chemical fresh salience are a series of developments (only) seemingly unconnected technologically. In 2005, the Indian government announced that it proposed to buy several nuclear power reactors, from the US and elsewhere and agreed to new legislation which would satisfy US manufacturers of the limits to their liability. The US firms wanted liability (in the case of nuclear accidents) to be confined to the plant operator and to a maximum of $450 million. Liability for design defects from the equipment supplier was fiercely opposed (Raju and Ramana 2010).

Comparable Danger Posed by Nuclear Power

Significantly, 25 years previously, a professional chemical engineering journal had in the aftermath of the Bhopal disaster noted a defining moment in the public perception of the chemical processing industry (CPI) (CE 1985a). In response to this public mood, both industry and the Nuclear Regulatory Commission (NRC) in the US had recognised the close similarities in post-accident scenarios in these two industries. In 1980, sometime after the Three Mile Island accident, the NRC and the Federal Emergency Management Administration (FEMA), which coordinated responses to natural and manmade disasters, wrote a new rule. Its provisions called for siren warnings within a 16-km radius of nuclear power plants, mock emergency exercises in which community organisations participated, and the development of emergency evacuation procedures. NRC coordinated with nuclear power utilities to develop appropriate plans, and then it and other federal and state agencies decided whether a power plant could be licensed. The emergency response plan was only a part of the overall licensing process. An official at NRC felt that it would be appropriate to extrapolate their experiences to the chemical industry. An industry observer felt that the chemical industry was facing a situation similar to the one encountered by the nuclear industry 15 or 20 years earlier. The nuclear industry had then attempted to respond to sociopolitical concerns with technical jargon and without any sensitivity to public opinion. The journal concluded by noting the distinct possibility that the United States Congress would mandate that the Centre for Public Integrity (CPI) be subject to controls similar to those that the nuclear power industry operated under. Although subsequent history showed that public concern could not override the CPI's lobbying prowess, this social recognition of the comparable levels of danger posed by nuclear power installations and chemical processing facilities was a harbinger of Indian reactions to the nuclear liability issue.

In its legal suit against UCC, the Government of India had introduced the legal concept of "multinational enterprise liability" (Mokhiber 1985). This raised the issue of whether the liability of a TNC was limited to the extent of its local assets in the host country, as UCC argued, or whether it was the global entity as a whole that was liable, given that the damages exceeded local net worth as the Government of India argued. Although the attempt by the Government of India to have the trial in the US was rejected, this was an early indication of how public opinion in India viewed the question of supplier liability. By this time, the design defects in the MIC plant or even deliberate instances of "under-design" which led to the 1984 disaster were well known. It had also become known that the effects of the leak had not only immediate effects, horrifying in themselves, but long-term effects across generations; thus the full extent of the disaster began to be comprehended. As in the case of Hiroshima and Nagasaki, the victims were not only the workers and general population in the affected areas of the city, but their children and possibly subsequent generations with no reliable end point.

'Miscarriages of Justice'

Finally, what made "Bhopal" a term universally associated with horrific industrial disasters was the inability of initiatives taken under the legal system in India to adequately encompass the scale of the disaster in terms of fixing liability and raising adequate compensation for the victims, their families and their progeny. Decisive political action by the Government of India could possibly have overcome this liability, but with its overriding objective of attracting further foreign investment, a political demand for adequate compensation was inconceivable. It was with this in mind that the government passed legislation which consolidated all claims compensations to itself enabling it to modulate these demands to its perception of internal and external political implications of any steps it took.

These were "miscarriages of justice" at the political and executive levels. The judiciary was equally contemptuous of the dimensions of the calamity (Gonsalves 2010). The Supreme Court took a number of steps that effectively circumscribed the penalties that could be imposed. Initially, it presided over an out-of-court settlement for a small sum of money. Later, under public pressure, it conceded the potentially criminal nature of the disaster. However, in a momentous order, it prescribed that the offences could only be tried under the category of manslaughter. It was under this legally imposed infirmity that when the court of the chief judicial magistrate in Bhopal finally decided the case in June 2010, almost 26 years after the disaster, the punishment awarded was a two-year term of imprisonment and a nominal fine.

Even before the judgment of the chief judicial magistrate was announced in 2010, movements organised in support of the Bhopal victims had formed an alliance with movements protesting against the blanket decision to large-scale import of US nuclear technology. With the announcement of the verdict, there was an explosion of anger which forced the government to introduce clauses in the nuclear liability legislation laying down responsibility on the technology supplier ("admin" 2009; Panchu 2010: 11; Varadarajan 2010). Despite the context in which it originated, this was path-breaking legislation, welcomed in the developing world, though perhaps understandably, not with any great publicity. In effect, the legislation was a reflection of public recognition that neither the executive nor the judiciary could be expected to uphold the rights of victims of humanly created disasters, as both were vulnerable to powerful international pressures. This, indeed, was the ultimate, enduring tribute to the victims of the MIC leak disaster.

NOTES

1 During the early morning hours of 3 December 1984, about 40 tonnes of methyl isocyanate escaped from a storage tank at the Union Carbide plant at Bhopal. The cloud enveloped the residential colony surrounding the plant. In addition to the 7,000 to 10,000 people who died in the immediate aftermath of the gas leak, at least 15,000 people died between 1985 and 2003, taking the total death toll to well over 20,000 (AI 2004: 12; BGIA 2008).

2 A search in *Chemical and Engineering News* archives, from its inception in 1923, demonstrates that 85 of the 88 articles referring to MIC date from the Bhopal gas disaster.

3 However, a review of isocyanate chemistry published in 2001 noted that MIC remained one of the six most *industrially* important speciality monoisonates. See Richter and Riester (2001): Table 3.

4 This left the bulk production of MIC in the hands of firms in China (C&EN 2011).

5 The first three paragraphs are based on a reading of the reviews of isocyanate chemistry by Saunders and Slocombe (1948), Shoichiro (1972), Tarbell (1976), Union Carbide (1976) and Richter and Riester (2001).

6 This, and the following paragraph, is based on material in C&EN (1957) and Back (1965).

7 There is some uncertainty about the date when MIC was actually introduced into the carbaryl production process. Although both D'Silva (2006: 34) and US (1985b: 17) agree that MIC production began in late 1965/1966, *Chemical and Engineering News*, in its analysis of the Bhopal gas leak, states that "...UCC had started manufacturing MIC around 1957, mostly for sale, but also for use in producing its own soil pesticide Temik (aldicarb). For reasons it would not disclose, it changed to the MIC route for making Sevin as late as 1973" (C&EN 1985: 32).

8 For a critical view of UCC history and commercial practices, see Dembo et al (1990).

9 Up to 1956, the Indian subsidiary was wholly owned by the parent company in the United States. After the public issue of shares, UCC's holdings fell to 60% (D'Silva 2006: 34). This was further reduced to 50.9% in 1977-78 through a rights issue, in which UCC did not participate, after the amendments to the Foreign Exchange Regulation Act in 1973 (D'Silva 2006: 36).

10 D'Silva (2006: 209) Appendix A-6, Letter from UCIL to the Ministry of Petroleum and Chemicals seeking permission for visit of engineers to the US.

11 In direct contradiction, according to a news report, for five years UCIL's application for an industrial licence lay pending, with officials in the Ministry of Industrial Development feeling that its "technology was obsolete" and being "dumped in India". Finally, four months after the Emergency (1975-1977) was declared, the licence was granted. The entire department was against granting the industrial licence, according to R K Sahi, who was then deputy director in the ministry. "We knew that it was discarded technologies being transferred to India. It was obsolete in the US, but it was being dumped in our country. We all knew that", Sahi told *The Hindu* on Monday (Jebaraj 2010).

12 UCC internal memo addressed to Gordon E Rutzen, UCC engineer involved in design of Bhopal Plant in 1972 (US 1985b: 17).

13 Plants for production of carbon monoxide (CO) and 1-naphthol were designed specifically for Bhopal. In the first case, methane used in the West Virginia plant was unavailable in Bhopal, and was replaced by coke. Here, too, a commercially available process using coke was rejected because licence fees payable in dollars would have added "unnecessarily" to project costs, while coal of a suitable quality was not available. The Virginia 1-naphthol plant used "sophisticated technology" and "unusual materials of construction", and was suitable for large scale production. None of these conditions, it was held, was appropriate for the Bhopal plant (UCIL 1973: 10-11). In the event, the custom designed 1-naphthol plant in Bhopal faced so many problems that it was never used (US 1985b: 34).

14 When the plant was first designed, Edward A. Munoz, the managing director of UCIL, took the position that large volume storage of MIC was contrary to both safety and economic considerations. In a sworn affidavit to the Judicial Panel on Multidistrict Litigation considering the Bhopal case, Munoz said that he had recommended, on behalf of UCIL, that the preliminary design of the Bhopal MIC facility be altered to involve only token storage in small individual containers, instead of large bulk storage tanks. However, UCIL was overruled by the parent corporation, which insisted on a design similar to UCC's Institute, West Virginia plant (ICFTU/IFCEGWU 1984). See also (C&EN 2009).

15 The allowable tank size in Europe, Japan, and the US was 17.5 kilolitres, with a mandatory maximum 50% filling limit (Mehta et al 1990).

16 Pyrolysis is a term for chemically decomposing organic materials through heating – a form of thermal decomposition.

17 An example was cimetidine (Tagamet), an antiulcer agent which originally utilised MIC in a manufacturing step; here the producer, Smith Kline, had changed to a different synthetic route. Eli Lilly originally used MIC in the US as a reactant to produce tebuthiuron (Spike). However, they had moved their production operations to Brazil, and simultaneously redesigned their process to eliminate the use of MIC.

18 The following paragraphs in the main text are based on information in Lapkin (1994).

19 Among the features of the agreement were a broad audit, which included review of regulatory compliance, safety training, accident prevention, emergency response, waste analysis and information systems, monitoring programmes, and waste minimisation practices; public disclosure of company documents, including hazard assessment and risk analysis, lists of accidents/upsets/near-misses/corrective actions, and waste minimisation and reduction plans; R-P committed to "negotiate in good faith" on the audit recommendations; citizens were entitled to accompany the auditor and conduct other inspections by appointment.

20 According to a report in July 2011, Bayer was transferring its MIC production facilities to China (C&EN 2011).

REFERENCES

"admin" (2009): "The Real Sell Out", *newsclick.in* http://newsclick.in/india/real-sell-out accessed on 2 February 2011.

Amnesty International (AI) (2004): *Clouds of Injustice: Bhopal Disaster 20 Years on,* http://w.awwmnesty.ch/de/laender/asien-pazifik/indien/dok/2009/25-jahre-bhopal/clouds_of_injustice_2004.pdf, accessed on 31 January 2012.

Back, Richard C (1965): "Carbarmate Insecticides: Significant Developments in Eight Years with Sevin Insecticide", *J Agr Food Chem*, 13(3): 198-99.

Bayer (2011): "Bayer Crop Science Announces Decision Not to Resume MIC Production", http://www.bayercropscience.com/bcsweb/cropprotection.nsf/id/84634C20BB57C2D3C125785700503244, accessed on 23 January 2012.

Bhopal Group for Information and Action (BGIA) (2008): *Presentation to the Group of Ministers on Bhopal*, 17 April, http://legacy.bhopal.net/march/padyatra2008_gom.html, accessed on 17 January 2012.

CG (2008): "Blast Rocks Bayer Plant; Injuries Reported; Area Roads Closed; Residents Told to Shelter in Place", *Charleston Gazette*, http://wvgazette.com/News/Bayerexplosion/200904270376, accessed on 24 January 2012.

– (2011a): "Bayer to Phase Out MIC; Cut 220 Jobs", *Charleston Gazette*, http://wvgazette.com/News/Bayerexplosion/201101110865, accessed on 24 January 2012.

– (2011b): "Decades-old Threat from Toxic Gas Drifts Away", *Charleston Gazette*, http://wvgazette.com/News/Bayerexplosion/201103182860, accessed on 24 January 2012.

– (2011c): "Most Claims Dropped from Bayer Suit", *Charleston Gazette*, http://wvgazette.com/News/Bayerexplosion/201104210930, accessed on 24 January 2012.

C&EN (1957): "New Carbamate for Killing Bugs: Carbide's Sevin Is Not Only Highly Toxic to Many Insects But Is Also Unsafe to Humans", *Chemical and Engineering News*, 35(38): 94-96.

– (1985): "Methyl Isocyanate: The Chemistry of a Hazard", *Chemical and Engineering News*, 63(6): 27-33.

– (1992): "CHEMRAWN in Moscow Provides Practical Approaches to Industry Goals", *Chemical and Engineering News*, 70 (45): 7-12, 41-42.

– (2009): "Safety Board Retreats: Citing Antiterrorism Law, Bayer Pressures Chemical Safety Board to Cancel Public Meeting on Fatal Accident", *Chemical and Engineering News*, 87(11): 40, http://pubs.acs.org/cen/email/html/cen_87_i11_8711news6.htm, accessed on 6 February 2012.

– (2011):"Preventing Disaster", *Chemical and Engineering News*, 89(30), accessed on 3 February 2012.
CE (1985a): "US CPI Start to Feel Effects of Bhopal Tragedy", *Chemical Engineering*, http://www.che.com/articles/1985-1999/Vol92/chevol92_num6_51.html, accessed on 30 January 2012.
– (1985b): "Italian Firm Boasts 'Safe' Carbamate Process", *Chemical Engineering*, 92 (10), 2http://www.che.com/articles/1985-1999/Vol92/chevol92_num10_14.html, accessed on 30 January 2012.
– (1985c): "Bhopal, a Year Later: Learning from a Tragedy", *Chemical Engineering*, http://www.che.com/articles/1985-1999/Vol92/chevol92_num25_66.html, accessed on 30 January 2012.
– (1986a): "Indian Scientists Conclude That Design Problems Caused the Tragedy at Union Carbide's Methyl Isocyanate (MIC) Plant in Bhopal, India a Little Over a Year Ago", *Chemical Engineering*, 93(1), http://www.che.com/articles/1985-1999/Vol93/chevol93_num1_06.html, accessed on 31 January 2012.
– (1986b): "CPI Alter Their Ways of Dealing with Toxics", *Chemical Engineering*, 93 (21), http://www.che.com/articles/1985-1999/Vol93/chevol93_num21_51.html, accessed on 30 January 2012.
Chess, Caron (2001): "Organisational Theory and the Stages of Risk Communication", *Risk Analysis*, 21(1): 179-88.
DSF (1985): "Bhopal Gas Tragedy" *Social Scientist*, Delhi Science Forum, 13(140): 32-51.
Dembo, David et al (1990): *Abuse of Power: Social Performance of Multinational Corporations; The Case of Union Carbide* (New York: New Horizons Press).
D'Silva, Themistocles (2006): *The Black Box of Bhopal: A Closer Look at the World's Deadliest Industrial Disaster* (Victoria, Canada: Trafford Publishing).
European Commission, Directorate-General for the Environment (EC) (2012): *Chemical Accidents (Seveso II) – Prevention, Preparedness and Response,* http://ec.europa.eu/environment/seveso/index.htm, accessed on 31 January 2012.
Fortun, Kim (2001): *Advocacy after Bhopal: Environmentalism, Disaster, New Global Orders* (Chicago: University of Chicago Press).
Gonsalves, Colin (2010): "The Bhopal Catastrophe: Politics, Conspiracy and Betrayal", *Economic & Political Weekly*, 45(26-27): 68-75.
ICFTU/IFCEGWU (1984): *The Report of the ICFTU-ICEF Mission to Study the Causes and Effects of the Methyl Isocyanate Gas Leak at the Union Carbide Pesticide Plant in Bhopal, India, on December 2nd/3rd 1984*, International Confederation of Free Trade Unions and International Federation of Chemical, Energy, and General Workers Unions, http://bhopal.net/oldsite/documentlibrary/unionreport1985.html, accessed on 20 January 2012.
Jebaraj, Priscilla (2010): "Did Emergency Allow Carbide to produce MIC in India?", *The Hindu*, New Delhi, http://www.thehindu.com/news/national/article456600.ece, accessed on 2 May 2011.
Khanna, Sushil (1984): "Transnational Corporations and Technology Transfer: Contours of Dependence in Indian Petrochemical Industry", *Economic & Political Weekly*, 19(31-33): 1319-40.
Lambrech, J A (1959): United States Patent 2 903 478.
Lapkin, Milton (1994): *Reducing the Storage of Methyl Isocyanate at Rhone-Poulenc's Facility in Institute, West Virginia: An Interim Technical Report to People Concerned about Methyl Isocyanate,* http://wvgazette.com/static/watchdog/micreport.pdf, accessed on 23 January 2012.
Mehta, Pushpa S et al (1990): "Bhopal Tragedy's Health Effects: A Review of Methyl Isocyanate Toxicity", *The Journal of the American Medical Association*, 264(21): 2781-87.
Mokhiber, Russell (1985): "Paying for Bhopal: Union Carbide's Campaign to Limit Its Liability", *The Multinational Monitor*, 6(10), http://www.multinationalmonitor.org/hyper/issues/1985/0731/mokhiber.html, accessed on 1 February 2012.
New York Times (1984): "Union Carbide of India: Image Is Shattered", 12 December: A9.
– (1985): "The Bhopal Disaster: How It Happened", 28 January.
Panchu, Sriram (2010): "Bhopal Gas Leak Case: Lost Before the Trial", *Economic & Political Weekly* 40(25): 10-11.
Raju, Suvrat and M V Ramana (2010): "The Other Side of Nuclear Liability", *Economic & Political Weekly*, 40(16): 48-54.
Richter, Reinhard and Ralph D P Riester (2001): "Isocyanates, Organic" in *Kirk-Othmer Encyclopaedia of Chemical Technology,* http://www.scribd.com/doc/30134019/Isocyanates-Organic, accessed on 11 January 2012.
Saunders, J H and R J Slocombe (1948): "The Chemistry of the Organic Isocyanates", *Chem. Rev.*, 43 (2): 203-18.
Shoichiro, Ozaki (1972): "Recent Advances in Isocyanate Chemistry", *Chem. Rev.*, 72 (5): 457-96.
Srivastava, Paul (1987): *Bhopal: Anatomy of a Crisis* (Cambridge, Massachusetts: Ballinger).
Tarbell, D Stanley (1976): "The Past 100 Years in Organic Chemistry", *Chemical and Engineering News*, 54 (15): 110-23.
Union Carbide (1976): *Methyl Isocyanate* (New York: Union Carbide).
– (1985): "Bhopal–The Company's report: based on the Union Carbide Corporation's report-March 1985", *Loss Prevention Bulletin*, Union Carbide, 063: 1-4, http://www.scribd.com/doc/71597731/bhopal, accessed on 29 January 2012.
UCIL (1973): *Methyl Isocyanate based Agricultural Chemicals Project No 73-8,* Union Carbide India Ltd, http://bhopal.net/oldsite/carbidedocuments/completepages/02dec1973projectproposal/UCC04206-page12.gif, accessed on 11 February 2012.
United States, Judicial Panel on Multidistrict Litigation (1985a): *Affidavit of Edward Munoz January 24, 1985, MDL Docket No 626,* http://www.bhopal.net/source_documents/munoz%20affidavit1985.pdf, accessed on 23 January 2012.
United States, District Court, Southern District of New York (1985b): *In Regard: Union Carbide Corporation, Gas Plant Disaster at Bhopal, India, December 1984 Michael V. Ciresi et al Memorandum of Law in Opposition to Union Carbide Corporation's Motion to Dismiss These Actions on the Grounds of Forum Non Conveniens* MDL Docket No 626, http://bhopal.net/source_documents/Ciresi%20memorandum%201985.pdf, accessed on 10 February 2012.
United States, Environment Protection Agency (1989): *Prevention Reference Manual: Chemical Specific, Volume 13: Control of Accidental Releases of Methyl Isocyanate* nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=2000TK6S.txt, accessed on 10 February 2012.
United States, 111th Congress, House of Representatives, Committee on Energy and Commerce, Majority Staff (2009): *Memorandum: Supplemental Information Regarding the 2008 Bayer Chemical Plant Explosion,* http://www.fas.org/sgp/congress/2009/042109supp.pdf, accessed on 11 January 2012.
United States, Chemical Safety and Hazard Investigation Board (2011a): *Pesticide Chemical Runaway Reaction Pressure Vessel Explosion: Investigation Report,* Report No. 2008-08-I-WV, January 2011, http://www.csb.gov/assets/document/Bayer_Report_Final.pdf, accessed on 29 January 2012.
United States, District Court, Southern District of West Virginia, Charleston Division (2011b): *Case No 11-cv-00087 Maya Nye and Others vs Bayer Crop Science Plaintiffs' Memorandum in Support of Preliminary Injunction,* http://wvgazette.com/static/watchdog/MIC_PI_Brief.pdf, accessed on 26 January 2012.
Varadarajan, Siddharth (2008): "Reality, One Bite At a Time", http://svaradarajan.blogspot.in/2008/10/dear-bill-foreign-secretarys-letter.html, accessed on 4 February 2012.
– (2010): "Nuclear Liability Law Has Sting in Tail for the US Too", http://svaradarajan.blogspot.com/2010/03/nuclear-liability-law-has-sting-in-tail.html, accessed on 7 December 2010.
Ward, Ken (1994): "Is MIC Unit Safe or a Potential Bhopal?", *Sunday Gazette-Mail,* 8 May, http://wvgazette.com/static/watchdog/micstory.pdf, accessed on 5 February 2012.