International Journal of Mass Emergencies and Disasters
November 1987, Vol. 5, No. 3, pp. 223 -241

EVALUATING CHEMICAL HAZARDS IN THE AFTERMATH OF THE BHOPAL TRAGEDY

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This article addresses a number of policy concerns that have arisen in the aftermath of the chemical accident that occurred in Bhopal, India on December 2, 1984. In view of magnitude of that tragedy and its implications for the export of hazardous technologies to the Third World, evaluations of the chemical industry based upon simple extrapolations from past industry performance are inadequate. Future policies undertaken to regulate the industry must explicitly account for the long-term global uncertainties, irreversibilities, catastrophic potentials, and dependencies created by the development of chemical technologies.

This article reviews and reemphasizes a set of standards for assessing potential developments in chemical technologies in the aftermath of the Bhopal tragedy. At a minimum, the tragedy once again points out the need for routinely employing uncertainty, irreversibility catastrophic potential, and dependency as criteria for evaluating chemical hazards. With the possible exception of dependency, each of these criteria has received prior treatment and support in the scientific literature (cf. Slovic et al. 1974; Elster 1983; Perrow 1984; Henry 1974; Kates 1977). Yet because of their essentially critical stance toward the industry, they are rarely given the priority they deserve in decision-making. Their use as standards often engenders corporate resistance. The merit of these criteria, and the source of resistance to their use, is their ability to direct attention to potential long-term global effects of chemical production as a whole. This is in contrast to the necessary but insufficient policy of correcting or improving safety mechanisms within already existing chemical facilities in the hope that such a policy would be adequate to forestall future accidents.

CAUSES OF THE ACCIDENT

On the night of December 2, 1984, an accidental leak of the pesticide component methyl isocyanate (MIC) from Union Carbide of India, Ltd.'s (UCIL) production facility in Bhopal, India triggered what was up until then the worst industrial accident in history (Bowonder, et al. 1985, p. 8). 2500 persons, the great majority of whom were poor slum dwellers, lost their lives in that accident. Over 100,000 were evacuated:, and at least 50,000 individuals were severely impaired. Hundreds of thousands more face the prospect of long term disabilities and the possibility that a second, even mild, exposure to the chemical could be fatal (Bowonder et al. 1985, p. 9; Menon 1985, p. 135).

It is not surprising that the Bhopal tragedy cost the poor most dearly. Bhopal is one of the poorest cities in India (Diamond 1985, p. A-7). Most of the residential areas surrounding UCIL's facility were extremely impoverished, and many of the victims were grossly uninformed about the nature and seriousness of the threat (Ramaseshan 1985b, p. 37; **New York Times** 1985b, p. A-8).

Bhopal has grown swiftly since it was designated the capital of the state of Madhya Pradesh in 1956. Some of this growth undoubtedly can be traced to modernization efforts that opened the door for industries like Union Carbide to locate there in the first place. From the time of the plant's initial licensing in 1969, the population of the city has gone from 350,000 to over 800,000 in 1984 (Bowonder et al. 1985, p. 7).

In Bhopal, there is only one telephone per 1,000 people, and running water is a luxury. There are few conveniences that are commonplace realities for the populations of more industrialized nations. The city is intensely crowded, and people share living space with cows, goats, horse-drawn carriages, cars and bicycles. Sanitation is a major problem, and many of the persons who died in the recent accident were already physically debilitated (Report of the Delhi Science Forum Team 1985).

Everywhere there is the stark contrast between old and new, rich and poor. Industries like Union Carbide's facility and the attractive homes of plant managers and government officials stand out distinctly in a 2,000 year old city emerged in both tradition and squalid living conditions for the poor (**New York Times** 1985d, p. A-8). It is hardly surprising that Western technology has appeared as an attractive solution to the many problems that face cities like Bhopal and India in general.

The causes of the Bhopal tragedy have by now been thoroughly documented. General explanations for the accident have ranged from technical and human failures inside the Union Carbide facility (Bidwai 1985a, p. 58; **New York Times** 1985a, p. A-7), corporate negligence (Bowonder et al. 1985, p. 8; Bidwai 1985c, p. 71; Sharma and Singh 1985, p. 82; Ramaseshan 1985b, p. 41), regulatory failures on the part of the Indian and U.S. governments (Bowonder et al. 1985, p. 8; Lueck 1985; Ramanaseshan 1985b, pp. 37-38; Bhandari 1985, p. 114), to failures in global policies of agricultural development requiring technology transfers to the Third World (Gupta 1985, pp. 151; Rele 1985, pp. 156-157; **New York Times** 1985d, p. A-8; Mojumder 1985, p. 146).

Despite the intensity of effort devoted to finding answers for the Bhopal accident, it is unlikely that any ultimate causal factor will be isolated. As with most technological disasters in the twentieth century, the hazards system within which the accident occurred is too complex to allow any single causal explanation to dominate (cf. Perrow 1984, p. 8). Yet the search for explanations continues, guided by a desire to prevent Bhopal-like disasters from recurring in the future. This effort has been based on a commonsense assumption that future failures in chemical technologies will be, in their broad outlines, similar to past failures. If the latter can be isolated, they can be corrected or improved to minimize, if not totally eliminate, the risks associated with exposure to chemical hazards.

This argument needs to be supplemented by at least two considerations. Logically, the commonsense view of induction on which such arguments are based has been criticized (cf. Popper 1972, p. 3). Technical change produces outcomes that are fundamentally uncertain, and this uncertainty must be taken into account in any decision to implement or improve a hazardous technology (Elster 1983, Appendix 1). Empirically isolating specific hazards of chemical production is no longer a routine matter. Modern chemical production involves processes that are extremely non-linear, often employing multiple redundancies and interactive controls that by their very complexity confound the detection and assessment of hazards (Perrow 1984, p. 327).

To fully explore the implications of the Bhopal tragedy, and to develop ways to insure that such tragedies will not recur, it is necessary to examine the accident at UCIL's facility not only in relation to its own safety record, but to (1) the safety record of chemical facilities in general, and (2) the fundamentally uncertain outcomes of chemical production as a whole.

THE SAFETY RECORD OF THE BHOPAL FACILITY

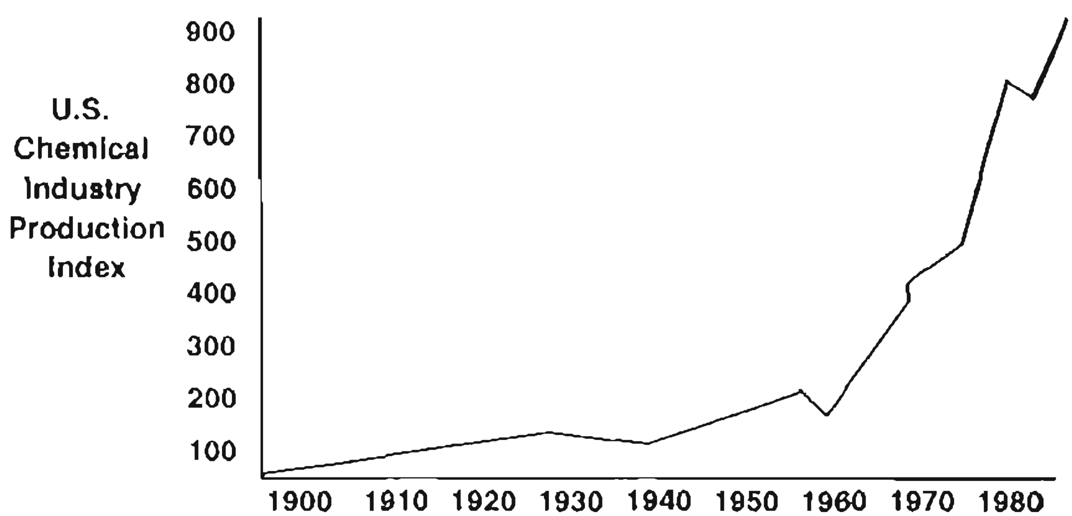
The safety record of the Bhopal facility in terms of fatalities or injuries up to the time of the accident was relatively good despite some problems. In 1981, a phosgene leak at the plant killed one worker. Accident reports were filed in the incident, as required by law, but little was done subsequently to correct problems (Bowonder et al. 1985, p. 8). Workers at various times reported eye irritation, minor chemical burns, or breathing problems (Ramaseshan 1985b, p. 41; Lueck 1985; **New York Times** 1985b, p. A-6), and workers' unions periodically complained to the plant's management of safety lapses or that employees were being used as guinea pigs for the detection of chemical leaks (Ramaseshan 1985b, p. 38). Such complaints, however, usually went unaddressed.

In 1982, a team of assessors from Union Carbide's parent corporation in Danbury, Connecticut arrived in Bhopal to find numerous technical safety violations at the plant. It was never independently confirmed whether any of these were subsequently corrected, although among the violations were many that eventually were found to contribute to the accident (Bowonder et al. 1985, p. 8). All things considered, the accident at Bhopal displayed features common to many industrial disasters--a relatively good safety record coupled with serious flaws in technology and organization for dealing with safety problems. UCIL's facility was often portrayed as a model for the chemical industry yet in retrospect may have been little more than an accident waiting to happen.

THE SAFETY RECORD OF CHEMICAL FACILITIES

In 1828, the German Chemist Fredich Wohler synthesized the first organic compound urea, an excretory product of many animal species. This discovery introduced a whole new era of industrial development in the West, and today literally tens of thousands of manufactured chemical substances are commercially available throughout the world. The introduction of new fertilizers, pesticides, and insecticides, all of which depended on basic research into chemical substances, rose at a steady rate during the first four decades of the Twentieth century. After 1940, however, the rate of growth has been tremendous.

Figure 1



U.S. Chemical Production Increase Between 1900 and 1980.
Source: Norris 1982, p. 5.

Chemical production facilities are familiar sights to almost everyone. They have been around for over 100 years and, except in rare incidents like Bhopal, have done very little dramatic or direct damage. Even in direct comparison to other forms of hazardous industry, the production of chemicals appears on the surface to be relatively safe (Perrow 1984, p. 345). From 1921 up until the Bhopal disaster, fewer than 5,000 fatalities associated with major chemical accidents have been recorded (see Table l; Bowonder et al., p. 8). A majority of these fatalities have occurred in Third World countries.

Table 1

Major Industrial Disasters of the Twentieth Century

YEAR	ACCIDENT	SITE	FATALITIES
1921	Chemical plant explosion	Oppau, Germany	561.
1942	Coal dust explosion	China	1572.
1947	Fertilizer ship explosion	Texas City, USA	562.
1956	Dynamite explosion	Cali, Columbia	1100.
1974	Chemical plant explosion	Flixborough, UK	28.[a]
1975	Mine explosion	Chasnala, India	431.
1976	Chemical leak	Seveso, Italy	0.(?)[b]
1979	Chemical warfare accident	Novosibirsk, USSR	300.
1984	Natural gas explosion	Mexico City	452.[c]
1984	Poison gas leak	Bhopal, India	2500.[d]

a 3,000 evacuated

b 700 evacuated, hundreds of animals killed, 200 cases of skin disease

c 4,258 injured, 31,000 evacuated

d 100,00 evacuated, 50,000 severely impaired

Source: Lagadec 1982; Bowonder et al. 1985.

In the United States alone from 1980 to 1984 there were 2051 reported injuries resulting from all chemically-related accidents. Of these, 146 were due to releases of toxic materials from chemical plants. The average number of injuries per plant accident over this time span was 12.2, and only one death for the entire industry was reported (Sorenson 1985, p. 9).

All things considered, these are relatively low figures. Still, there is some concern even among corporate owners that hazard potentials for U.S.-based industries are increasing. This concern is in part due to the fact that chemical production plants have become larger, more technically complex, and increasingly crowded in by growing urban environments (cf. Perrow 1984, pp. 120-122).

Data from recent U.S, accidents may also only indicate that industrialized countries have greater resources to devote to implementing and successfully carrying out plans for chemical emergencies. In Bhopal, as in many parts of the Third World, such resources are generally lacking and there is not the level of political pressure for strict enforcement of safety standards that is normally found in the U.S. (Bogard 1986, p. 76). The tragedy in Bhopal, by its sheer magnitude, has at least raised questions about any reassurances provided by past industry performance.

LONG-TERM OUTCOMES OF CHEMICAL PRODUCTION

Even acknowledging the relatively low fatality rates associated with the industry the long-term effects of chemical production on future generations and the natural environment are difficult to assess. Pesticide products; such as those that were manufactured at the Bhopal facility, can find their way into the world's oceans or accumulate in tissue (Kumar and Mukerjee 1985, p. 133). Indiscriminate use of pesticides has been singled out as one reason for the development of highly resistant strains of agricultural pests (Norris 1982). And in a phenomenon known as the "boomerang effect," some exported (and at times domestically banned) chemical pesticides may return in foodstuffs imported from the very countries to whom these pesticides were initially sold (Norris 1982, p. 2O).

These possibilities are causes for concern, for they point to long term uncertainties, irreversibilities, catastrophic potentials, and dependencies that are masked by the low fatality figures for the industry. When viewed in the long term and linked to general policy concerns such as the relation of agricultural production to economic development, i.e., to the entire hazards system involved in the production of chemicals, risk assessment based solely on past safety records of the chemical industry is insufficient.

The distinguishing feature of long term risks from chemical hazards is that so little is known about them. The crucial problem confronting policymakers over the last twenty to thirty years has been how to turn this essentially negative fact into a positive tool for the evaluation of the industry. An important insight into this problem was gained when it was shown that constraints on the ability to predict long-term outcomes of technical change could themselves be employed as standards for assessing such change. The formal knowledge that outcomes of chemical production may be uncertain, irreversible, catastrophic, or create dependence may, despite the limited knowledge of the content of those outcomes, allow decisionmakers to slow down, and thus gain some control over, the pace of technical change in the industry.

Uncertainty as a Decision Criterion

Uncertainty is a lack of information needed to determine the probable outcomes of an action or to order these outcomes by the magnitude of their effects (cf. Elster 1983, p. 187), In using uncertainty as a criterion of assessment scientists must therefore assume that if the worst possible outcome **can** happen, it **will** happen. The choice among alternative technologies thus must be based on worst-case scenarios from which the best-worst alternative is chosen.

In the Bhopal tragedy, uncertainty extended even to basic research questions regarding the toxicity and appropriate methods of treatment for exposure to methyl isocyanate (Menon 1985, p. 135; Bidwai 1985, p. 30). There are no recognized antidotes and in the aftermath of the accident physicians were able to provide only symptomatic relief to the Victims (Fera 1985, p. 52).

MIC production is itself only a small part of the overall problem. In a 1979 report, the General Accounting Office revealed that the Food and Drug Administration (FDA) analytical methods could not provide long-term data on 178 pesticides for which tolerances--allowable residue levels--had been established. Nor could FDA testers assure consumers that imported food is free of some 130 commonly used pesticides for which tolerances have not been set (Norris 1982). The full extent of potential pesticide poisoning is simply not known.

In the Bhopal accident, worst-case scenarios involving chemical spills apparently were not generated by Carbide corporation or its affiliate (Bidwai 1985b, p. 68). The basic uncertainty regarding MIC's toxicity and treatment was never divulged to city residents or plant workers (**New York Times** 1985b; **New York Times** 1985c). The latter were told to rely on watery eyes to detect the presence of a leak. And rather than informing residents that their very lives might be at stake in the event of an emergency, Carbide and UCIL's public announcements chose to stress the safety record of the Bhopal facility, its modern technology and, above all, the long-term benefits to Indian agriculture of increased pesticide consumption (Sharma and Singh 1985, p. 82; Gupta 1985).

Irreversibility

The criterion of irreversibility refers both to decisions regarding the implementation of hazardous technologies and to the consequences of those technologies themselves (Henry 1974; Elster 1983). The technologies of pest control in agricultural development are, like most scientifically based technologies of production, in a continual state of change. While uncertainty dictates that the details of these changes can be neither predicted nor fully controlled, it is possible to take account of the general fact that techniques **will** change, e.g., that alternatives to present chemically based pesticide technologies that are safer and less environmentally disruptive may become available. This is to some extent already taking place with the development of new biological and environmental methods of pest control (Norris 1982, p. 22; Mojumder 1985, p. 146). The irreversibility criterion stipulates that decisions regarding the implementation of chemical controls, whose long range hazardous consequences remain uncertain, be postponed until further information regarding safer alternatives is forthcoming. In other words, it is perhaps better to adopt a "wait and see" attitude regarding the possibility of better technologies than to make a decision for a present technology that may turn out in the future to be irreversible.

There is some evidence that the use of chemical pesticides in Third World countries like India have had limited positive effects on the overall production of foodstuffs (Farmer 1977). It is also evident that alternatives were available. Less hazardous techniques for synthesizing methyl isocyanate (not dependent on hazardous phosgene or chlorine reactions) were already in use in West German chemical facilities (Bogard 1986, p. 143). Despite this information, the technology available from Union Carbide was the one eventually chosen for the Bhopal plant. The end-product of both the U.S. and West German companies was of course MIC and equally hazardous. But it is disturbing that the decision to opt for Carbides technology was not delayed until more thorough research could have been done on the West German alternative. Once the production license to Union Carbide was granted by the Indian government, the decision proved difficult to reverse, and became more so as the plant was built and people started to move into the area.

The situation becomes more complex when biological alternatives for pest control are considered. Here research is still developing and largely unconsolidated. It is by no means certain that biological controls would be as effective in producing added crop yields as chemical pesticides. Nonetheless, it could be assumed that such information would have been forthcoming sometime in the future. If this future information were negative, e.g., if biological controls could have been determined by future research to be ineffective in increasing crop yields, not too much would have been lost by postponing the decision to opt for the MIC technology. A decision of postponement can generally be reversed. If on the other hand, later information about biological pest controls suggests it is a safer and equally effective alternative to a decision for chemical controls like MIC, the latter decision would be better were it not taken, for once taken it becomes difficult to reverse (cf. Henry 1974).

Irreversibilities regarding the consequences of hazardous technologies to the sociophysical environment can be either strong or weak (Elster 1983, p. 206). Strong irreversibility obtains if (1) one can only know where a hazardous threshold is by hitting it, and (2) it is impossible to back away from the threshold when it is hit. Weak irreversibility obtains when condition (2) is satisfied but not condition (1). The first condition is a very strong uncertainty criterion, saying we are not only ignorant of how far we can go in the implementation of a hazardous technology but that we will remain so until we have already gone too far. If we consider only the accident at Bhopal and its relatively contained effects on residents and the surrounding natural environment, the condition of weak irreversibility probably holds. From the information now becoming available from the tragedy, it is probably safe to say that future implementation of safeguards--improvements in early warning, preparedness, industry siting, land use, and the like--would substantially reduce the chances for a repetition of a similar tragedy occurring elsewhere. When viewed at the level of the global system of pesticide production and export and possible long range effects on health and the natural environment, however, the situation becomes very uncertain and one cannot readily dismiss the possibility of strong irreversibility. It is extremely difficult for scientists to know if or when global tolerances for chemical pesticides will be crossed and result in ecocatastrophe. From the date we have on the Bhopal tragedy, there is little evidence that strong irreversibility was ever a criterion in the decision to produce MIC. Corporate realities and India's pressing need to increase food supplies appear to have successfully directed attention away from the problem.

Catastrophic Potential

Linked to the problem of strong irreversibility is the potential for catastrophe in the pesticides industry. Perrow (1984, p. 343) defines a "catastrophe" as an accident that results in the death of over 100 "second party" victims, mainly suppliers and users of the hazardous system. For third and fourth party victims, e.g., innocent bystanders or future generations, Perrow's formulation is somewhat vague:

> For third and fourth party victims the most catastrophic systems are estimated to be nuclear power plants, weapons systems, and DNA accidents; all of these could be very very large indeed. Somewhat further behind are chemical plants (largely vapor cloud explosions and release of such toxins as chlorine gas).... Chemical plant . . . accidents would involve third and fourth party victims, but in the hundreds, normally, rather than the thousands or millions. (Perrow 1984, p. 343).

For Perrow, the chemical industry has a "middle range" catastrophic potential. Because of this moderate potential, combined with the high cost of developing alternatives for this industry, Perrow recommends chemical production be tolerated and improved in terms of safety rather than abandoned. Latter recommendation he makes for technologies such as nuclear power and nuclear weapons systems, both have high catastrophic potential and lower cost alternatives (Perrow 1984, p. 349).

Perrow, however, makes the mistake of drawing conclusions about the chemical **industry** on the basis of a notion of catastrophic potential primarily applicable to chemical **facilities**. An accident like Bhopal may indeed appear moderate when compared to possible fatalities or injuries resulting from other more hazardous facilities (nuclear power plants, for example). But, for reasons outlined below, it is a long step from this to say that the catastrophic potential of the chemical industry is substantially less than the nuclear industry. In view of possible long-term global effects, worst-case scenarios appear to be on par with one another. According to Norris (1982) these scenarios involve threats to the global survival system including but not limited to irreversible environmental damage and the evolution of what are called "super pests."

In terms of environmental damage, the long range effects of methyl isocyanate production are unknown. The past record with the indiscriminate use of other forms of pesticides, such as DDT, do not provide much comfort. Unlike MIC, the effects of DDT even seemed fairly innocuous at first. It is not acutely toxic to humans except at fairly high doses, and it is not readily absorbed through the skin, but over time, DDT proved dangerous enough to merit calling its use potentially catastrophic. Applied in a worldwide program to control malaria, DDT has been implicated in declining populations of waterfowl and ocean life, and laboratory tests have convinced scientists of DDT's link to cancer (Carson 1962).

In contrast to DDT, methyl isocyanate is extremely toxic at low dosage rates. But like DDT there is widespread concern about possible long range after-effects of MIC on different environments. In the air, MIC will undergo degradation due to sunlight, as well as reaction with moisture. The likely major products are methylamine dimethyl urea and other gases. In soil and water, methylamine will be the major product. It will be held tenaciously by soil particles until complete degradation. In plants, MIC may compete with carbon dioxide in photosynthetic processes. In both plants and animals methylamine would be the major metabolite. Some research has suggested that these metabolites are likely to participate in complex pathologies leading to kidney disease and failure (Kumar and Mukerjee 1985, p. 133). Once exposed to MIC, any further mild exposures could be fatal (Menon 1985, p. 135).

While low toxicity rates may have been responsible for the relative lack of concern over DDT's long range effects in the early years of its use, the absence of basic research into the long-term effects of MIC given its highly toxic nature is puzzling although not totally surprising. Catastophic potential was never explicitly employed as a criterion for the decision to produce MIC in the first place. Instead the proliferation of new chemical pesticides such as MIC comes about as a result of industry and government's constant search for a product that is both profitable and appears to meet the needs created by agricultural and economic problems in the Third World. Long-term uncertainties are ignored because attention to such uncertainties requires postponement of decisions that would address these needs.

The problem is compounded by the fact that in the chemical industry's war against pests that threaten the food supply, the pests may be winning. Many insects have short generation times, and some produce more than one generation per year. When a pesticide kills all but the resistant individuals in a population of insects, the survivors quickly produce new generations that show increasingly greater proportions of these resistant strains (U.N. Environment Programme 1979). Norris (1982, pp. 22-23) notes that the first approach of the chemical industry to the problem of pesticide resistant strains was the development and successive application of ever new synthetic chemical pesticides. But this resulted in strains developing that were resistant to not just one but many pesticides. These so-called "super pests" have had devastating economic effects in countries all over the world. Thanks to DDT, for example, Sri Lanka once had as few as 23 cases of malaria in a whole year, but is now experiencing 2 million cases a year, about the same level as before DDT was ever used (Norris 1982, pp. 22-23). And, because of resistant strains of pests, levels of foodstuff production in India have not come near meeting the optimistic numbers that were projected at the beginning of the Green Revolution (Chambers et al. 1977).

Multiple resistance is not the only danger of using different pesticides in succession to control increasingly resistant strains. Pests may also become cross-resistant, using their acquired resistance to protect them against pesticides to which they have never been exposed or which have not even been developed. All this is a long way from the accident that happened at Bhopal, but it points to a key factor in determining at a global level why an accident like Bhopal occurred in the first place. Pest resistance has developed through the overuse of pesticides, but the increasing proliferation of resistant pests has in turn required the increasing use of more and different pesticides at an ever expanding rate. Breaking this vicious cycle presupposes an awareness of possible derealities, such a recommendation would most likely go no where, and there are indeed real arguments to suggest that such a policy would cause more harm than good. Trying to overcome the dependency on chemicals--the Third World's and our own--involves reversing past decisions and generating new options with less potential for catastrophe. These actions are themselves laced through with uncertainty. What we should learn from Bhopal--and from the fact of our own limited scientific knowledge--is to slow down, to back off from the quick fix and spend more time looking for and developing safer alternatives. Third World governments should not feel so eager, or receive so much pressure from industrialized states, to adopt Western technologies that are themselves unregulated or considered dangerous.

An explicit focus on the uncertainties, irreversibilities, catastrophic potentials, and dependencies created by the use of chemical technologies places the burden of proof for their adoption squarely on the shoulders of the chemical industry itself. It is this industry's responsibility, above and beyond making profits and reducing costs, to present worst-case scenarios to the public so the latter can make informed choices. It seems that only when this is done can the chemical industry legitimately stress its past performance record, a record that, as noted above, is actually quite good in terms of short term safety. If the people of Bhopal had had an idea of the dangers they were creating for themselves when Union Carbide was licensed to build its plant there, e.g., if only they had employed basic and accepted scientific tools for evaluating the hazard, there may never have been a Bhopal--persons would not have been allowed to live outside the plant's gates, safety violations would not have been ignored and alternatives to MIC would have been more thoroughly investigated. Perhaps the plant would not have been built at all. We must live with "the Bhopal tragedy, but we do not have to allow another. The choices will be very difficult. Following Perrow, the future does not look optimistic for no more Bhopals--our technologies are too complex, too tightly coupled and too uncertain in their outcomes. But we can use Perrow's pessimism as grounds for a new start, at least aware that the potential dangers have been duly noted.

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