ST0408473

SCIENCE

PLAINTIFF'S EXHIBIT

DOW-2476

A Lethal Ingredient: Human Error

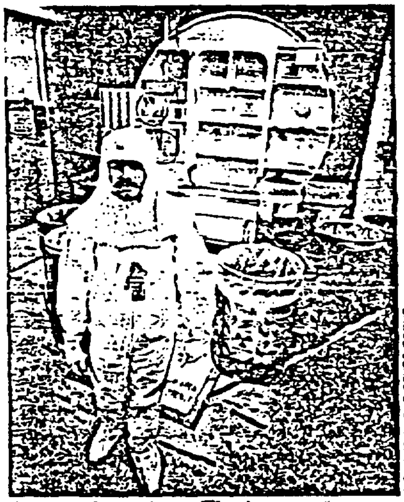
SUMMARY: Recent industrial catastrophes, along with the greater size and complexity of plants, have prompted a search for safer equipment and better ways to run it. Upgraded sensors, stronger buildings and smaller hazardous inventories offer promise of reducing the dangers, but the main goal is to anticipate and forestall mistakes by humans.

The world's most catastrophic industrial accident began ever so simply. Late in the evening of Dec. 3, 1984, pressure unexpectedly built up in an underground storage tank, filled with 45 tons of a deadly compound known as methyl isocyanate, at Union Carbide Corp.'s pesticide plant near the central Indian city of Bhopal. A scrubber designed to neutralize the chemical didn't stop the gas from escaping and filling the night sky with a vast, thick fog.

The breeze pushed the cloud over Bhopal, where it burned eyes, throats and lungs and killed many of those it touched within mere minutes. Most of the victims died when the gas blocked the air passages in their lungs, triggering massive asthma attacks; others were asphyxiated when fluid accumulated in their lungs.

Before it was over, the disaster would claim the lives of more than 2,300 people and injure more than 150,000 others. Many of those who survived were blinded or afflicted with permanent lung, liver or kidney damage. Three full days passed before the air was declared safe to breathe.

The incident at Bhopal occurred in the middle of a global chain of industrial disasters that included the 1984 explosion of liquefied petroleum gas that killed 452 persons in Mexico City and the 1986 reactor accident at the Soviet Union's Chernobyl



RICK BROWNE / PICTURE GROUP

At a nuclear plant: The human factor

nuclear power plant that caused untold death and suffering across the Ukraine.

This chain of catastrophes has prompted the international chemical and power industries to undertake a major effort to find ways to remove as much danger as possible from facilities. Since Bhopal, for instance, the World Bank has implemented strict safety design and emergency planning measures for all chemical projects it funds in developing nations, and the Environmental Protection Agency is cracking down on plant safety in U.S. communities. Emerging from this effort is the rapid development of many techniques and technologies for making chemical and nuclear plants safer, even if those plants are handling materials as volatile and dangerous as ever.

Much of the problem lies in the fact that, by and large, global industrial production is being centralized in large plants. Since this increases the potential for catastrophic damage, "there is increasingly the requirement for designers to demonstrate that an installation will meet strict safety targets," says Jens Rasmussen, professor of human factors engineering at Denmark's Riso National Laboratory. And, he notes, "control of safety in industrial installations is becoming an increasingly complex problem."

If there is a consolation in the recent accidents, it is that they have prompted many companies to reevaluate their facilities, their methods of operation and their inventory requirements. Soon after the Bhopal tragedy, Monsanto Co. audited "each of its locations worldwide to determine how its toxic material hazards were being managed," says Dennis Wade, a Monsanto process safety manager. After the audits, "the inventory of hazardous materials had been reduced by about 50 percent. Of even greater importance was the reduction in risk that resulted from this reduction in inventory."

Many companies also have significantly upgraded their fire- and leak-detection equipment. The industry is perfecting remote scanning systems that can monitor large processing areas or long stretches of pipeline and detect the precursors of a problem quickly enough for preventive action to be taken. Some of the most modern systems employ sensors that can detect the infrared or ultraviolet radiation from a small fire. Others shoot lasers at a plant's processing area; the beams are monitored for any changes that could signal the beginning of a problem.

Technicians also are developing foams that restrict the spread of vapors from all types of chemical spills, even those of volatile, water-reactive liquids. Previously, foam was considered effective only against liquids unmixable with water.

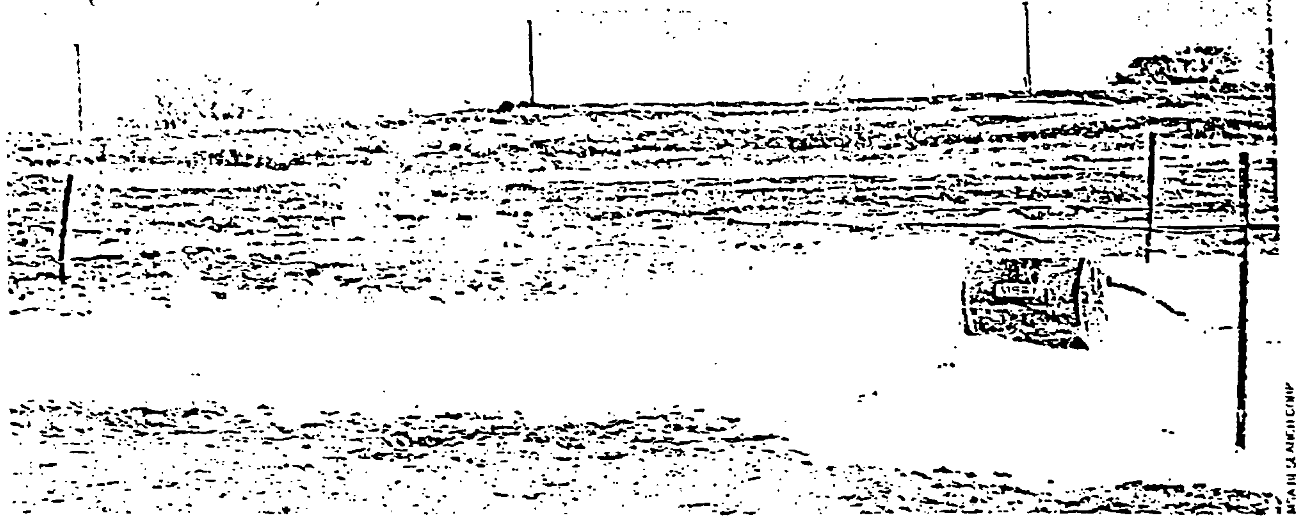
Some situations can be improved simply by strengthening existing structures with new materials. John Closner, a consultant

RICHARD KOZAK / INSIGHT

Complex reactor controls pose risk of information overload and confusion.

ST0408473

ST0408474



The use of foam for containing toxic vapors — here, from nitrogen tetroxide — is being applied to more types of chemicals.

for Preload Co. Inc. of Garden City, N.Y., says that "the risk of major accidents can be reduced by using prestressed concrete" to build dikes around metal storage tanks and pressure vessels and to line tanks, storage vessels and blast-resistant control buildings.

Researchers also have dedicated much study to better understanding the effects of hazardous releases. Dennis Ripple, a technical manager at the Celanese Corp., says this "can allow designers to improve plant layouts and enhance fire and explosion protection, make design decisions on inventories of hazardous materials and design adequate containment systems. [They] can also improve emergency planning for predictable events."

The more researchers analyze chemical and power plant disasters, the more evidence they find that most accidents can be linked to human error. As a result, they are increasingly focusing their study on the human factor in safety. But to date, many of their conclusions and proposed solutions are surprisingly basic and disappointingly obvious.

"Major chemical accidents generally have multiple causes traceable to mistakes made during design, maintenance and operation," Rasmussen says. "Human activities play an important role in most accidents, typically not due to particularly exotic errors or mistakes, but to slips and misunderstandings which are commonplace in normal human activity and which have their tragic effects only under particular circumstances."

Others agree. "People are the one component of the systems that we cannot redesign or modify. We can design better pumps, compressors and so on, but we are left with Mark I man," says Trevor Kletz, a professor of chemical engineering at Great Britain's Loughborough University of Technology. According to statistics, three or four errors will occur in every 1,000 operations. But those raw numbers do not account "for stress or distraction. And that can put the error rate up six or seven times," he says. "None of us works in isolation. We are affected by the mental climate of the situation where we work."

The best way to deal with human error "is not to tell people to be more careful but to try to remove opportunities for error by changing the work situation. . . . Designers must design [so as to allow] for no weakness of human nature," says Kletz. Adds Barry Gibson, a senior hazards engineer at E.I. du Pont de Nemours & Co., "The fact is we've got situations where we have a mistake, when the simple solution would be to eliminate the options that can lead to the mistake."

Kletz also stresses that it is important to recognize that there are different kinds of human error. "If a man makes a mistake, it may be because he does not know what to do. Or it may be because he does not want to do what's asked of him. Some are caused because a man is asked to do something he is not capable of doing, physically or mentally. And some errors occur because some workers have so much to do — or don't have enough to do — that they switch off onto automatic pilot and do some of the things without thinking about them. Something can be done about these."

One obvious solution is more thorough training, but Kletz notes that some mistakes are made expressly because people are well-trained. "When we are well-trained, we give certain functions to lower levels of the brain. We put ourselves on autopilot," he says. "We'd never get through the day if everything required our full attention, so we do things without thinking."

There are also accidents that occur "because people were asked to do something that ordinary people are incapable of doing," Kletz says. "I remember an accident at a plant that was equipped with a number of alarms. Something happened and all the alarms started sounding, and the operator didn't have a clue as to what was happening. He just stood and gazed at them." Soon there was an explosion.

"Afterward, it may have sounded logical to say to the operator, 'Why didn't you just assume the worst?' But in fact people do not work that way. When you open them up to too much information, they don't just assume the worst. They just switch off. This applies to management situations as well."

Often "the error was inevitable, given the way the situation was designed," says Kletz, who points out as a prime example control panels loaded with lights and buttons. "In the West, we expect control panels to be numbered from left to right. But in Japan, they expect the panels to be numbered up and down from right to left."

Simplification applies in a variety of ways, Gibson says. "You always see labels on bottles that say, 'Not for internal consumption. In case of accidental ingestion, consult a physician immediately.' Why don't they just say, 'Don't drink this. If you do, see a doctor quickly.' "

His favorite example of convoluted instruction comes from a military guide describing a change in its method of packing bombs in crates. "The instructions with the crate said, 'Caution. The bombs in this crate are packed in a different manner than usual. Compared with the old methods, the bombs are now packed upside down, so the crate therefore must be opened from the bottom.' But to 'prevent' confusion, the bottom had been labeled 'top.' "

That kind of confusion can easily lead to disaster, warns Gibson, and is therefore a case in which the study of human tendencies can be most helpful. "I hope we will begin to look a little more seriously" at the human aspect of safety, he says. "And we should use it not like a plumber who comes to fix something but more like an architect to help design systems more in tune to humans and their capabilities."

Clearly, the groundwork has been laid. But still to come is the most important part: using these basic findings to make the dangerous workplace as risk-free as possible by eliminating the opportunities for humans to err.

— *John Holmes*

ST0408474