After Bhopal: Tracing Causes and Effects

Shortly after midnight on Dec. 3 last year, a cloud of deadly methyl isocyanate vapor escaped from a storage tank at a Union Carbide chemical plant in Bhopal, India. Within hours, more than 2,000 people died and tens of thousands were injured. Since then, two questions have dominated investigations of the Bhopal tragedy: Why did it happen, and could such a disaster occur in the United States?

The answer to the first question is slowly emerging, although findings so far are incomplete and controversial. Last week, Union Carbide Corp., based in Danbury, Conn., reported the results of its investigation. A team of seven engineers and scientists did about 500 experiments in trying to match the chemical residues in the leaking storage tank in order to reconstruct the events at Bhopal. They conclude: "This incident was the result of a unique combination of unusual events."

The study suggests that somehow a large volume of water — between 120 and 240 gallons — was "inadvertently or deliberately" pumped into one of three tanks storing liquid methyl isocyanate. The investigators did not rule out sabotage. The presence of water triggered a heat-generating chemical reaction. The high temperature allowed chloroform, a solvent contaminating the methyl isocyanate, to decompose. The resulting chloride ions corroded the stainless steel tank, releasing iron, which catalyzed another "runaway" reaction. At some point, the tank could no longer withstand the steadily increasing temperature and pressure, and in the end about 50,000 pounds of methyl isocyanate escaped.

The Union Carbide report notes that several "critical" violations of company safety procedures also contributed to the disastrous leak. A refrigeration system that was supposed to keep methyl isocyanate cool and relatively unreactive had been shut down five months before the accident. A flare tower designed to burn off vented gases was not operating. An alarm meant to warn of rapid temperature rises did not sound at the time of the accident.

Responsibility for safety lies chiefly with local plant managers. Says Union Carbide Chairman Warren M. Anderson: "That plant should not have been operating."

Partly because the Indian government denied Union Carbide investigators access to important documents and to plant employees, uncertainty still surrounds the events in Bhopal. A spokesman for the Indian Embassy in Washington, D.C., protested that Union Carbide's implication that Indian plant personnel failed to do their jobs properly was "unjustified and unacceptable." The Indian government is conducting two inquiries of its own into the causes of the Bhopal disaster.

In addition, S. Varadarajan, India's chief scientist and leader of a technical team studying the accident, stands by his team's conclusion that only a small amount of water entered the storage tank, initiating a somewhat different but equally devastating sequence of chemical reactions. Indian scientists are preparing to open the storage tank for a more complete study.

Nevertheless, says Anderson, "We can say with a great deal of confidence what went wrong technically at Bhopal." Adds Jackson B. Browning, Union Carbide's vice president for health, safety and environmental affairs, "Now, after the investigation, ... we can confidently say: It can't

To honeybees, a picture is worth a thousand line angles

Honeybees are finicky foragers when it comes to searching for nectar — and for good reason. Some flowers provide a heartier meal; others are dangerous when honeybees land on them. How do honeybees distinguish nectar-bearing from non-nectar-bearing flowers and safe from dangerous flowers?

With "photographic images," says biologist James Gould at Princeton (N.J.) University. Gould's experiments, reported in the March 22 SCIENCE, show that honeybees can store flower patterns as low-resolution images, contradicting earlier studies that suggested bees remember only isolated features of flowers, such as prominent line angles or the ratio of edge to area.

"The old idea," Gould says, "is that they remember a checklist of characteristics — much like a description of a murder suspect whose hair and eye color are known, but with no photograph." Gould's data indicated that honeybees can remember how flower parts are arranged in relation to each other, a feat possible only when photographic images, not isolated features, are remembered.

Photos: Kenneth Lorenzen

Honeybee "drinks" nectar from orchard maid flower.

In his experiments, honeybees were given a choice between two similar patterns that differed only in the spatial relationship between their parts. One of the patterns provided a sugar reward, the other did not. After being reinforced on the pattern providing the sugar, the bees were offered the same patterns in another trial. This time the patterns' positions were reversed, and neither provided a reward. Yet in most cases bees chose the pattern on which they had been reinforced in the previous trial, suggesting that they had remembered the spatial relationships of the elements in the pattern.

Honeybees' ability to distinguish different flowers and flower parts can help them avoid dangerous situations. For example, alfalfa blossoms' unusual arrangement of petals and stamen can be fatal to honeybees. The pollen-bearing stamen of an alfalfa blossom is covered by a central petal. When an insect lands on the flower, the petal releases the stamen and sweeps pollen upward to facilitate pollination. The mechanism is adaptive for large insects, but honeybees trying to pollinate unopened flowers will be jolted off or trapped inside the central petal. In a separate experiment, Gould showed that honeybees quickly learn to distinguish opened from unopened flowers, "showing that they have good pictorial memory."

Gazania, a flower with many line angles.

The studies show that many scientists' "presumptive vertebrate-invertebrate dichotomy is false," Gould says. But in order to truly bring vertebrate bias down to size, Gould will have to show that honeybees have size constancy — the ability to remember something they first saw close up when they later see it from farther away. —*D.D. Bennett*