

## **INVESTIGATION OF LARGE-MAGNITUDE INCIDENTS: BHOPAL AS A CASE STUDY**

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### **ABSTRACT**

The investigation of large-magnitude incidents is fraught with difficulties and the process of establishing the primary cause of an incident often requires an understanding of human nature in addition to the necessary technical and engineering skills. The salient non-technical features that are common to the investigation of large-magnitude events are discussed in general. The investigation of the Bhopal disaster is discussed as a specific case study in light of these salient features. The results of the overall investigation are discussed and it is demonstrated that the commonly-held view that water-washing of a certain header caused the disaster is physically impossible. Evidence is presented which indicates that direct water entry into the methyl isocyanate storage tank was the likely initiating cause of the Bhopal disaster.

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### **I. INTRODUCTION**

In the aftermath of a major accident or incident in the chemical industry, it is common practice to ascertain the cause of the event through an investigation. If the magnitude of the incident is very large in terms of its impact on people, property, or the environment, it is not uncommon to assemble several teams of investigators to seek the cause of the incident independently. In the United States, a large-magnitude event may be investigated by the company that owns the facility, the insurance group that provides the liability coverage, federal investigators (e.g., OSHA, EPA), and state and local regulatory agencies. When several investigations are being conducted concurrently, in spite of the differing interests that are represented by each investigating team, cooperation and fact-sharing generally occurs among the investigating teams. This cooperative spirit was evident to some extent, for example, in the investigation of the LPG disaster in 1984 in Mexico City<sup>1</sup>.

Given the significant amount of damage that is typically associated with a large-magnitude event, coverage by the news media is both extensive and exhaustive, especially if a number of fatalities have occurred. The news media represent yet another group of separate investigators and tend to focus on the human interest aspects of the tragedy. In addition, often with little hard information available, they actively speculate on the cause of the event in an attempt to "scoop" the story; that is, to be the first to report the cause to the world at large. In recent years, the news media with their surfeit of investigative reporters have become a predictable presence at the site of an incident.

Although no two major disasters are the same, our involvement in the investigation of more than a dozen events of significant magnitude has led us to believe that there are certain salient features that are common to most investigations. They include:

1. **Media Pressure** - In the immediate aftermath of a large-magnitude incident, both non-technical and technically trained reporters converge on the site, looking for quick "answers" to the question of what caused the event.

Most reporters are responsible, restrained, and unbiased in their reporting. However, a fringe group usually appears on-site that is more interested in developing causation theories, which seem to have great public appeal, regardless of their veracity.

In the case of the disaster at Bhopal in 1984, the cause célèbre was the "missing slip-blind" during a water-washing operation. An assertion was made that failure to insert a slip-blind prior to water-washing of some filters ultimately led to water entering the MIC tank and starting a reaction. This assertion proved to be false, as will be demonstrated later in this paper.

The difficulty with these incorrect causation theories is that, because the public and the media have a short attention span, the theories can become the conventionally accepted versions of what occurred. When a technical investigation discloses the actual cause much later, there may be less coverage, because the event is "old news" by then.

2. **Psychological Issues** - It has also been our experience that those people associated with a large-magnitude incident seem to evince an internal need to put some psychological distance between themselves and the incident. For example, there are those who feel -- in hindsight -- that even though they were not responsible for the event, they could have done more to reduce the magnitude of the event. And there are those who just wish it had not occurred on "their watch". There are also occasions when persons on duty distort and omit major facts to establish a reduced responsibility for the event. There is substantial evidence that such distortions and omissions occurred in Bhopal.
3. **Eyewitness Accounts** - When eyewitnesses are questioned about a major accident or incident, they tend to reveal only those facts that they personally consider important and pertinent. Thus, a good investigator must draw people out, using a line of questioning which elicits all pertinent facts. We have found that an eyewitness is most likely to be forthcoming and helpful if he or she is questioned immediately after the event. Once a story is told, whether accurate or inaccurate, it tends to harden. Further, where a deliberate distortion occurs, with the passage of time, the persons involved tend to coordinate their stories better. This puts a substantial premium on talking to persons involved quickly. In the Bhopal situation, the Union Carbide investigation team was blocked from doing this by the Indian Government for over a year. As a result, Union Carbide was unable to uncover the ultimate cause of the event until 1986.
4. **Contradictory Accounts** - When faced with contradictory statements from various

witnesses, an investigator has to weigh various accounts and then judge which account is likely to be correct, discarding the false account. This may require gaining an understanding of the probable motives of those persons who, knowingly or unknowingly, provided the incorrect accounts. It is also often possible to assess the accounts against known or technically established facts, to determine their accuracy. We encountered numerous cases of directly contradictory accounts of various situations that transpired during the Bhopal incident from those who were present during the event.

5. **Time Perception** - Although witnesses in a traumatic incident often recall the sequence of events with remarkable clarity, their perceptions of time during the actual incident sometimes differ. Therefore, when establishing the true chronology, witnesses' time perception must be evaluated against objective evidence. In the case of the Bhopal investigation, piecing together the correct chronology required that perceptions of time among different witnesses be accounted for in a consistent manner.

The above list of features is by no means complete. However, it does identify some significant issues that are manifest in incident investigations, and which should be considered by investigators of large-magnitude incidents. The very presence of these issues makes an incident investigation more than a purely technical exercise. In many ways, one can liken the investigation to attempting to correctly piece together a complex jigsaw puzzle, with the added challenge of having several pieces that are hidden, others yet to be discovered, and several extraneous pieces that do not belong in the completed puzzle at all and have to be discarded. To add to the investigator's difficulties, the "puzzle" has to result in a clear picture, even though assembled in a background of human tragedy and suffering, media attention, and a general aura of suspicion and hostility towards the plant and company investigation teams.

The above factors are those which we have identified in our investigation of large-magnitude incidents, and many of these factors played a role in the investigation of the Bhopal incident. The following sections will give a brief background of the investigation, elaborate upon some of the factors which were encountered and resolved during the investigation, and present some of the evidence and the conclusions of the investigation.

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## II. BHOPAL INVESTIGATION

### BACKGROUND

To the best of our knowledge, two separate major detailed technical investigations of the Bhopal event were authorized. One investigation<sup>2</sup>, sponsored by the Government of India (GOI), was conducted by a staff of scientists and engineers from the Council of Scientific and Industrial Research (CSIR), and it included other experts as well. A second investigation<sup>3</sup>, sponsored by the Union Carbide Corporation (UCC)\*, was conducted by scientists and engineers from UCC, Union Carbide India Limited (UCIL), outside experts, and attorneys. The two investigations went forward entirely independent of one another. (The Indian Central Bureau of Investigation (CBI) also conducted its own investigation.)

In addition to these major investigations, dozens of opinions, purportedly based on investigations of the incident, were offered by various newspapers, magazines, television and radio commentators, authors, organizations, consultants, and politicians. Such accounts generally proved

to be quite flawed and incomplete.

Union Carbide investigators were at the site of the incident at Bhopal within days of the event to provide assistance and to conduct an investigation, but found that the plant had been sealed and placed under the control of the CBI. The cause of the incident was not then apparent. The methyl isocyanate (MIC) production unit had been shut down six weeks prior to the incident and the storage tank (Tank 610) had been isolated at that time; all that was known was that the pressure had risen in Tank 610 during the third shift on a Sunday night, December 2-3, 1984, and that MIC had been released into the atmosphere. It was unknown whether the release had been triggered by the entry of a contaminant, water, or some other agent.

The search for the cause of the incident at that point was, however, a secondary consideration; a second tank (Tank 611) containing some 20 tons of MIC remained, and the first order of business was to assist in its safe disposal.

It was determined that the safest route would be to process the MIC and SEVIN carbaryl pesticide, which was then done promptly. The processing of this tank of MIC was conducted jointly by UCIL and the CSIR, with the assistance of UCC's technical team, in an activity labeled Operation Faith by the Indian Government.

Following the safe disposal of the remaining MIC in December of 1984, the UCC investigation team attempted to begin its investigation. However, the legal skirmishes had commenced in both the United States and India and the CBI essentially maintained complete control over the records of the MIC unit. Although the investigation team was permitted to see copies of records in the period immediately following the event, it was allowed to do so only by specifically requesting a copy of a particular record or document.

\*The author of this paper and the organization he represents were a part of this investigation team. Thus, if the team was unaware that a particular document existed, the document would never come to its attention, even though it might have a significant bearing on the outcome of the investigation.

Moreover, the CBI prohibited interviews with the plant's employees. The team submitted to the CBI a list of 193 plant employees whom it wanted to interview, but permission was refused. The CBI would only authorize discussions with the Plant Manager and the MIC Production Superintendent, neither of whom was on duty the night of the incident. In fact, the CBI was conducting a criminal investigation into the incident, and it contended that attempts by Union Carbide's investigating team to formally interview the workers would constitute "tampering with evidence" in the criminal investigation.

The problem of access to information was further magnified by this threat of criminal prosecution by the Indian government, Union Carbide's Chairman, Warren Anderson, who went to Bhopal to offer assistance and relief immediately after the incident, was placed under arrest upon his arrival in the city, and seven UCIL officers and employees were also arrested. This posture, in addition to physically preventing an investigation by Union Carbide, created an atmosphere of fear of criminal sanctions among the plant workers. Such an atmosphere, together with the sheer magnitude of the disaster, made witnesses even more defensive and uncommunicative than is usually the case in such investigations.

Further, the CBI conducted its criminal investigation into the incident using aggressive tactics. We believe this treatment played a major role in the development of a "cover-up" by plant employees. As noted earlier, there is a reflexive tendency among plant workers everywhere to

attempt to divorce themselves from the events surrounding any incident and to distort or omit facts to serve their own purposes. This is especially so where the investigation is criminal in nature. In addition, once an eye-witness has taken a defensive position under aggressive questioning by police making a criminal investigation, it becomes, as a practical matter, nearly impossible for the witness to later change that position to state the actual facts.

The team was permitted access to samples of the tank residue, and, after several months of extensive analysis of the residue of Tank 610, including more than 500 experiments, the UCC investigation team issued its report in March 1985<sup>3</sup>. The team concluded that the incident was caused when 1,000 to 2,000 pounds of water entered the tank. After subsequent experimentation and more extensive sampling much later, the amount of water was determined to be even greater. This large quantity of water reacted with the MIC in the tank, causing its temperature to rise to over 100°C, leading to a vigorous exothermic trimerization of MIC, resulting in rapid rises in temperature and pressure, and ultimately causing the major release. The incident occurred, despite the fact that the system had been designed and operated to keep out even small amounts of water, and the fact that no water had ever entered the tanks during the five years the plant had been in operation. Moreover, it was clear upon subsequent sampling and analysis that no water had entered either of the other two MIC storage tanks.

Because the MIC production facility had been shut down for over a month prior to the incident, and for a variety of other reasons that will be discussed, the investigation team concluded that direct entry of the water -- that is, by a direct connection to the tank rather than through the plant's piping system -- was likely. However, because the team had not been permitted to interview the plant employees and did not have full access to the records, it was unable to develop this theory further at that time.

The CSIR publicly issued its report<sup>2</sup> in December of 1985, approximately one year after the incident. The CSIR report also concluded that the event was caused by the entry of a large quantity of water into Tank 610. The CBI has not, to date, issued a public report of the findings of its own investigation.

## LITIGATION

For more than a year, the CBI continued to prohibit interviews with the plant's employees. In the interim, a new aspect to the investigation developed. The Indian Government filed a civil suit against Union Carbide Corporation in the United States, asserting that the Government was the sole representative of the Bhopal victims. Thus, the Government acted as the plaintiff in a civil case with an interest in proving Union Carbide Corporation to be liable, yet, in its institutional role, it continued to exercise complete control of access to the sources of proof, restricting Union Carbide's ability to learn the truth, and fostering a version of the facts which supported its own litigation interest.

The Government's position as a party to the civil suit ultimately provided certain benefits to Union Carbide's investigation. In December 1985, a U.S. magistrate<sup>4</sup> ordered the Indian Government to turn over copies of certain of the plant's records that had been seized, and these then became available for analysis by Union Carbide for the first time. Moreover, while it was before the U.S. court seeking information from Union Carbide, the Indian Government could not, as a practical matter, continue to restrict access to plant employees, which enabled Union Carbide to finally begin interviews. Despite having been denied access to the evidence for more than a year and despite being viewed with a great deal of hostility and suspicion, Union Carbide investigators

conducted a thorough review of the incident which included detailed interviews with virtually all of the relevant plant employees.

## **INTERVIEWS**

Union Carbide employees and representatives began to interview the plant's employees in January 1986. Many people spoke openly and willingly. However, the team anticipated that there would be problems in interviewing the plant's employees, and the team therefore was assisted by a person familiar with most of the employees. This proved advantageous because the team found that many would speak to him, even if they were unwilling to speak to the entire team. It also proved beneficial in assessing the credibility of each individual.

Language also loomed as a potential problem, although ultimately it did not prove to be troublesome. Although all operators spoke English, many were more comfortable speaking Hindi. Several members of the team were fluent in Hindi and, by translating each question and answer, the interviews progressed smoothly.

However, the team did encounter some problems in locating the involved employees and persuading them to talk about a traumatic incident that had occurred a year and a half earlier. The Bhopal plant had been shut down since the incident, and the employees, by and large, had sought other employment. Many of the former operators and other employees had departed Bhopal without leaving any forwarding addresses, and it took weeks of questioning former landlords and neighbors to determine their whereabouts. Several had relocated as far away as Nepal and remote areas of India. This required lengthy journeys -- in one case, only to find the wrong individual with the same name. Careful advance preparation was therefore necessary.

Many of the former MIC operators were later employed by the State Government as plant safety inspectors. Some of those who had been most directly involved refused to talk to the team and eluded many attempts. Because politeness is an Indian trait, in fact, some would make appointments for interviews, but then disappear just prior to the appointment. Once found, however, the customary politeness proved to be an advantage, and the investigators learned it was wise to nurse the obligatory cup of tea for hours to prolong the interview in order to obtain bits and pieces of new information.

Although the Indian Government has continued to refuse access to the original plant records, copies of some of them were produced in the civil suit, and the investigators were able to analyze them and use their content in the interviews.

The investigators conducted well over 70 interviews over the course of a year and a half. The significant aspects and findings of this investigation are presented in what follows. To better understand the findings, however, a basic understanding of the plant's layout and operation is necessary.

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## **III. BHOPAL PLANT LAYOUT AND OPERATION**

The plant layout is shown in [Figure 1](#). Methyl isocyanate (MIC) was produced at the Bhopal

plant by reacting monomethylamine and phosgene in the plant's MIC production unit. The refined MIC was then transferred to a separate MIC storage area (see [Figure 2](#)) where it was stored in two horizontal, mounded, 15,000-gallon, stainless-steel tanks. A third storage tank was kept empty for emergencies and for off-specification material awaiting reprocessing.

The MIC was used to make SEVIN carbaryl and several other carbamate pesticides. The MIC was processed into SEVIN carbaryl pesticide in the SEVIN unit. The MIC was transferred in one-ton batches to a charge pot in the SEVIN unit using nitrogen pressure. A nitrogen pressure of at least 14 psig in the MIC storage tank was necessary to move the material from the storage area to the SEVIN unit charge pot at a reasonable rate. From there, each batch would be reacted with alpha-naphthol to make SEVIN carbaryl.

On the night of December 2-3, 1984, the 41 metric tons of MIC in one of the storage tanks (Tank 610) underwent a chemical reaction which was initiated by the introduction of water to the tank. The reaction caused the release of MIC through the relief-valve system. This, in turn, resulted in the Bhopal tragedy. The exact means by which water entered Tank 610 that night was the subject of the investigation described in this paper. The team first considered and analyzed the purported cause of the incident which had been publicly reported by the media. This was the so-called "water-washing theory." This story is discussed next.

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#### IV. THE ORIGIN OF THE WATER-WASHING THEORY

As discussed in Section I, the media generally play a significant role in establishing public perception of the cause of large-magnitude incidents, often drawing conclusions before the facts can be established. In the days immediately after the incident, the story that emerged from the plant workers, as reported by the press (much of which ultimately provided to be fallacious), was as follows:

Shortly before the end of the second shift, at 10:20 p.m., the pressure in Tank 610 was reported to be at 2 psig. The shift change occurred at 10:45 p.m., and everything was normal until 11:30 p.m., at which time a small leak was reported downwind and in the area of the MIC production unit. The MIC supervisor said that he would deal with the leak after tea, which began at 12:15 a.m. The tea lasted until 12:40 a.m. at which time all was normal. At that point, the control room operator observed the pressure rise suddenly in Tank 610, and within minutes the indicator was off the gauge's scale. At 12:45 a.m., the safety valve on the tank opened, and gas came out of the stack of the vent gas scrubber. The operators ran to the tank and found it rumbling, and the concrete over the tank was cracking. The fire squad sprayed the stack to knock down the gas, and the reaction subsided an hour or so later. The workers claimed to have no idea as to why the pressure rose in the first instance. According to this account, the incident occurred suddenly and inexplicably.

There was, however, intense media pressure to quickly identify the cause of the incident. As noted above, some journalists tend to try to uncover a cause that is easy to understand and easy to explain; they also show a tendency to find and publicize an explanation that will have popular appeal. In the case of Bhopal, this caused the media to seize upon reports of an improper water-washing of a pipeline in the MIC production structure -- a report that first began to circulate only days after the incident. According to this story, an MIC operator was told to wash a section of a subheader of the relief valve vent header ("RVVH") in the MIC manufacturing unit. Because he

failed to insert a slip-blind, as called for by plant standard operating procedures, the water supposedly backed up into the header and eventually found its way into the process vent header ("PVH") through a tubing connection near the tanks. It then was supposed to have flowed into the MIC storage tank, located more than 400 feet by pipeline from the initial point of entry.

This was, to a layman, an apparently plausible, easily understood explanation of the water source, which did not require any detailed knowledge of the plant process or layout. It also was a theory that had popular appeal because it focused on a simple, minor human inadvertence which caused a great tragedy -- a "for-want-of-a-horseshoe-nail-the-kingdom-was-lost" explanation. It was readily accepted by those eager to believe the incident had been caused by improper operating practices at a purportedly shoddy chemical plant in a Third World country. The water-washing theory was also publicly embraced by the Indian Government.

Although the water-washing theory has superficial appeal, those engineers most familiar with the plant -- its valving, piping, and layout -- found the theory highly implausible. When Union Carbide finally gained access to the plant, talked to witnesses, and considered all the evidence, it concluded that the theory could not withstand even minimal scientific scrutiny. And, although the Indian Government holds in its possession records and test results that completely discredit this theory, it continues to embrace it nonetheless.

Several independent pieces of evidence demonstrate that water-washing of lines in the filter area could not possibly have been the cause of water entry into Tank 610. This evidence is discussed next.

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## V. EVIDENCE REFUTING THE WATER-WASHING THEORY

The details of the pertinent parts of the plant vent systems, shown in [Figure 3](#), will be helpful in understanding the material presented in this section. The water-washing theory assumes that water from an operation designed to wash a sub-header near four process filters (Point "A" of [Figure 3](#)) went through the relief valve vent header (RVVH), then through a connection to the process vent header (PVH) and then into Tank 610 (Point "B"). At least three independent, objective pieces of evidence establish that this could not have happened.

### 1. BLEEDER VALVE HYDRAULICS

The water was introduced using a hose with a 1/2-inch inlet. Even assuming all intermediate header-system valves to have been wide open, for water to have reached the top of the PVH riser near Tank 610 (Point "B" of [Figure 3](#)), it would have had to be under sufficient pressure near the point of introduction (Point "A" of [Figure 3](#)) to enable it to climb 10.4 feet. Associated with the filters near the washing operation, however, there are four 1/2-inch bleeder valves in parallel (see Items 18 of [Figure 4](#)). Of these, one was reportedly mechanically plugged, but the other three were reported by five eye-witnesses to be wide open and draining freely. With the 1/2-inch hose connection to the washing operation limiting the flow to about 10-15 gallons/minute, the three open bleeder valves would limit the water back-pressure above them to no more than about 0.7 foot of hydraulic head, clearly not enough to raise the water by 10.4 feet.



## 2. CLOSED INTERMEDIATE VALVE

In the above paragraph, we assumed for the sake of argument that all intermediate valves in the header systems between the water connection and Tank 610 were open. It should be noted that if any one of these valves was closed (and leak-tight), the water-washing theory must fail.

One such valve is the valve close to the water-washing operation, connecting it to the RVVH (see Item 19 on [Figure 4](#)). A plant mastercard (a detailed record of steps taken during maintenance) shows it to have been shut since November 29, 1984. The mastercard also reflects that the valve was physically tagged closed; after the incident, the tag was found to be still present on the valve. Furthermore, with the authorization of the Indian Government, the integrity of this valve was tested in a July 1985 simulation of the water-washing operation; in this one-hour test, no water leaked past this valve into the RVVH.

There is no way that water from the water-washing operation could have reached Tank 610 without first passing through this valve, which is documented to have been closed and leak-tight.

## 3. DRY HEADER PIPING

For water to have penetrated to Tank 610 from the water-washing area, it would have had to fill the 6-inch diameter connecting pipe, then a 65-foot length of 8-inch RVVH (with more than a dozen branches running off this line), and then some 340 feet of 4-inch RVVH. It would then have had to fill a 120-foot length of 2-inch PVH and a last 220-foot section of 2-inch PVH with the vertical legs at each end of this section. Calculations show that some 4,500 pounds of water would have been needed to fill all this piping, before any could get to Tank 610. Thus, if the water-washing operation were the source of the water, large quantities of water would have filled the associated piping.

As the incident later progressed and gases were ejected from Tank 610, the gases would have cleared the water from the main RVVH flow path out of the vent gas scrubber. On the other hand, all of the branch downlegs, as well as the 220-foot section of the PVH with the downlegs on either end of it, would have remained full of water, as the connection between the PVH and the vent gas scrubber had been previously blinded off to allow replacement of some sections of PVH. And, even though the vented gases were hot, the water in these sections could not have boiled or evaporated away, because these sections were dozens of feet away from the piping in which hot gases were flowing.

When the branch vent lines on the ground floor of the production unit and the branch vent lines connected to Tank 611 and to the spare tank were drained, only normal, small amounts of water (or no water at all) were found.

On February 8, 1985, the Superintendent of Police, CBI, ordered (see [Figure 5A](#)) that a hole be drilled in the lowest point of this 220-foot length of the PVH, to determine how much water was contained therein. The authorization acknowledges that this section of pipe had no bleeders or flanged joints. For the water-washing theory to have been true, there should have been hundreds of pounds of water still in this section of pipe, and so some empty 55-gallon drums were made available to collect whatever amounts of liquid would issue from the drilled hole.

When the hole was drilled, however, the pipe was found to be bone-dry. The line was

immediately purged with nitrogen to force any liquid out, but not a drop was obtained (see [Figure 5B](#)).

Thus, the water-washing theory is clearly untenable. The bleeder valves in the water-washing area would have had to be closed (but three were witnessed to have been open), the intermediate header valves would have had to be open (but at least one is documented to have been closed and leak-tight), and there would have had to be hundreds of pounds of water in the 220-foot section of the PVH drilled after the incident was over (but not even a single drop was found).

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## VI. SIGNIFICANT ASPECTS OF THE UCC INVESTIGATION

As indicated in Section V, it was clear to those investigating the event that it had not been caused in the manner that had gained popular acceptance -- inadvertent failure to place a slip-blind during water-washing of lines near the process filters. The UCC team also thoroughly considered other possible routes of water entry and became convinced that this incident had been initiated by the entry of water to the tank by means of a direct connection.

Evidence of a direct-connection entry was gathered only gradually, however, in large measure because of some of the psychological factors and motivations discussed earlier.

### PSYCHOLOGICAL FACTORS

Perhaps because of the enormity of the event, many people, even those only peripherally involved, tended to remember in detail and with great clarity the sequence of events of that night. Nevertheless, people experienced the event in different ways, thus yielding, for example, varying estimates of the duration of the actual release.

The tendency of plant workers to omit facts or distort evidence was also clearly evident after the Bhopal incident, making the collection of evidence a time-consuming process. In investigating any incident in which facts seem to have been omitted or distorted, it is necessary to examine the motives of those involved. The story that had been initially told by the workers was a preferable one from their perspective, because it exonerated everyone, except perhaps the supervisor. According to this version, the reaction happened instantaneously; there was no time to take preventive or remedial measures, and there was no known cause. Without a cause, no blame could be established.

Because critical facts were being deliberately omitted and distorted, the investigation team had to continually review and reanalyze each new piece of evidence and to assess its consistency and veracity with hard evidence and known facts. Ultimately, several firm pieces of evidence came to light -- evidence that simply did not fit the story told initially by the workers, and that eventually led to the conclusion that a direct water connection had been found by the workers, but had been covered up.

## LAST TRANSFER OF MIC TO THE SEVIN UNIT

The plant records show the following sequence of events. Although in the weeks prior to the incident the MIC manufacturing unit had been shut down, the SEVIN unit was operating, using the MIC that had been stored in the tanks. The operators were transferring MIC from Tank 611 to a one-ton charge pot for subsequent conversion to SEVIN. Plant procedure was to exhaust the contents of one MIC storage tank before using the MIC in the second tank, and 21 tons remained in Tank 611. Thus, although they experienced some difficulty in pressurizing Tank 610, which had been at atmospheric pressure for the previous six weeks, there was more than enough MIC in Tank 611 to meet the SEVIN production requirement and there was no need to use the MIC in Tank 610.

During the early period after the incident, when the Union Carbide investigation team was about to assist in safely disposing of the MIC remaining in Tank 611, the MIC in the SEVIN charge pot and the transfer line between the tank and the charge pot was sampled. The MIC was found to be greenish, with a higher-than-normal chloroform content (consistent with that of the MIC stored in Tank 610 prior to the incident), and with evidence of the presence of non-volatile reaction products of a water-MIC reaction. These samples caused a substantial amount of concern because it was then feared that there might also be a major problem with the MIC in Tank 611 as well. Precautions were taken to sample the MIC in Tank 611 and extensive analyses of the contents of Tank 611 were conducted. The MIC in Tank 611, however, proved to be on-specification and clear, with normal levels of chloroform, and no non-volatile reaction products. The investigation team, therefore, concluded that the last transfer to the SEVIN charge pot must have come from Tank 610, before its contents had severely reacted, rather than from Tank 611.

This piece of evidence was surprising because everyone had assumed that all transfers had come from Tank 611 during the period prior to the event. This assumption had been made because the last transfer, as logged by the SEVIN unit operators, occurred from Tank 611 at 23:30, or 11:30 p.m., just prior to the incident. In addition, prior to the time the pressure had begun to rise in Tank 610, there had been insufficient pressure to make a transfer from Tank 610. No operators had reported a transfer that night from Tank 610, although several stated a transfer from Tank 611 had occurred.

The team was well aware of the tendency of operators, after an incident of such magnitude, to distance themselves and minimize their involvement, and therefore it continued to explore the possibility that a transfer had been made from Tank 610.

Some of the copies of records released to Union Carbide in December 1985 were copies of the MIC inventory records, including those for the night of the incident. One log, which had been previously unavailable to Union Carbide's investigation team in December 1984, showed a final transfer of MIC from Tank 611 between 10:15 and 10:30 p.m., the evening of the incident. Although, initially, the log did not appear out of the ordinary, several unusual factors were noticed upon closer examination (see next-to-last entry in [Figure 6](#)):

- 1) The transfer was logged as having started at 10:15 p.m. on the second shift but between two operators who did not arrive until the third shift began at 10:45 p.m. later that night. It was logged in the handwriting of one of those third shift operations.
- 2) The logged time of the transfer was out of sequence with the remaining entries.
- 3) The operator who logged it normally used the 24-hour clock convention in recording transfers.

The investigators studied these records, and finally determined that the transfer had been originally logged at "0:15" to ":30", or 12:15 to 12:30 a.m., and had been altered later that morning

in an attempt to cover up the events and to move the time of the transfer back to a period of time in which the MIC operators could not be blamed.

The team thus concluded that the logs showed there had been a transfer from Tank 610 at 12:15 a.m. to 12:30 a.m. -- 15 minutes before the major release occurred. In addition to its proximity to the release, the transfer also occurred during the time of the tea break, which was highly irregular.

Water is known to be heavier than MIC, and the transfer line comes up from the bottom of the tank. With the discovery of this log, together with the results of the charge pot analysis, the UCC team concluded that there had been an attempt by the MIC operators to remove water from the tank just prior to the time the safety valve lifted, after the pressure had increased sufficiently in the tank to move the material out. This completely refuted the story that the workers had originally told regarding the instantaneous reaction. Moreover, it showed that the operators knew water had entered Tank 610. The transfer of one ton of material would have been wholly and obviously ineffective to relieve pressure in the 45-ton tank; the only reason for a transfer at that time was to get water known to be in the tank out of the tank.

This conclusion was further supported by the logs recorded that night in the SEVIN unit. These were made in duplicate, and one copy showed the time of an MIC transfer as 23:30, whereas on the other copy, found in the accounting records, the time of the transfer was missing. We believe that the SEVIN supervisor may have filled in the time of the transfer after the incident to make it appear that the transfer had not occurred close to the time of the major release, but was unable to do so on all copies because the second copy had already been sent (as required by plant procedure) to the plant's accounting office.

When the investigating team interviewed the SEVIN supervisor, he at first would not admit that he had gone into the SEVIN unit that morning at all, but he later admitted that he had entered there briefly to complete his logs. The morning after the incident he reportedly discussed the possibility of reacting the MIC in the charge pot into SEVIN, perhaps in an attempt to destroy any evidence of a charge from Tank 610.

## **CONTRADICTIONS**

Meanwhile, as the interviews with the operators and supervisors directly involved progressed, it became apparent that there were massive contradictions in their stories. For example, operators and employees from other units and another plant downwind of the MIC unit, together with some MIC operators, reported sensing small MIC leaks well before the major release occurred, and they notified their shift supervisors. However, those Bhopal plant supervisors denied hearing any reports about earlier leaks. In addition, the supervisors were unable to plausibly account for their activities during the 45-minute period prior to the release. They placed themselves with people and in locations for reasons that were entirely different from those that had been given by those individuals they were supposedly with.

Ultimately, the reasons for this became clear: witnesses from other units reported that these supervisors and the plant superintendent were taking a break in the plant's main canteen when they received word of the incident. Because previously they had been instructed not to take their breaks together, they masked their actions by claiming to know nothing until just prior to the major release.

The operators in the MIC unit also gave widely contradictory accounts. For example, some stated that the alarm signaling the major release went off only several minutes after tea began at 12:15 a.m., whereas others stated that the tea period in the control room was entirely normal, and they had not noticed anything to be amiss until just a few minutes prior to the major release. The control room operator initially told the media that he noticed the pressure in Tank 610 was 10 psig when the shift began; however, he later stated that the pressure remained at 2 psig until after tea.

Because some of the witnesses directly involved in the incident were initially unavailable for interviews, and because others were rendering obviously contradictory accounts, reports given by the more peripheral figures during the incident became highly important. For these individuals, primarily operators from other units or those who were not present at the time of the incident, there was no motive to distort or omit facts, and their accounts were thus deemed more reliable.

Ultimately, it became clear that the MIC operators knew at least 30 to 45 minutes before the release that something was seriously wrong, and that several had acted in an attempt to forestall the problem.

One of the more reliable accounts came from a witness who had no motive or reason to distort or omit the facts. He was the "tea boy", who served tea in the MIC control room just prior to the major release. With some difficulty, he was located in Nepal, in the Himalayas, and brought to Delhi. Despite the MIC operators' claim of a normal tea period, the tea boy reported that when he entered the unit at about 12:15 a.m., the atmosphere was tense and quiet. Although he attempted to serve tea, the operators refused it. After detailed questioning of scores of operators, it became apparent that those directly involved were unable to give consistent accounts because they were attempting to give very specific details of events that never occurred.

Therefore, the investigation team made an intensive effort to find logs that might have been initially overlooked and that might shed some light on the cause or course of the incident. Two of the significant findings were:

1) While reviewing the daily notes of the MIC unit for the period prior to the incidents, a sketch was found on the reverse side of one page, the first page available for writing. This sketch showed a hose connection to an instrument on a tank, and it appears to have been made to explain how the water entered the tank. 2) This effort to search the records brought to light even further evidence of attempts to cover up the story. For example, the time of the occurrence had been altered in log after log to reflect the incident occurring at a different time than had been initially recorded. This was true of the foam-tender log, the assistant security officer's log, the utilities log, and the stores register. Further, in some logs, the pages relevant to the period in question had been either completely, or partially, ripped out. It appeared clear: there had been a systematic effort to alter and destroy logs.

In many cases, the team found that the witnesses, especially the peripheral ones, were not aware of which facts were pertinent, and they revealed only those they considered important. Thus, it was necessary to talk at length to witnesses about all the facts and circumstances involved to draw out relevant facts.

For example, during a series of routine interviews with a variety of former plant employees held in the winter of 1986, an instrument supervisor, who was not on duty that night, offered a telling observation. Casually, he mentioned that when he arrived at the scene early on the morning following the incident, upon checking the instruments on the tank, as he had been instructed to do, he noticed that the local pressure indicator on Tank 610 was missing. This fact was of crucial importance because the instrument is on the tank manhead, and was one of the few places to

which a water hose could be connected (see Item 10 of [Figure 7](#)).

The witness was wholly unaware of the significance of his statement. Upon further questioning, the team learned that the indicator was not only missing, but a plug had not been inserted in its place, as would have been the case if it had been removed in the course of plant maintenance. Plant logs showed that the local pressure indicator had been present as of Friday, November 30, 1984, two days prior to the incident. The same instrument supervisor stated that he also found a hose lying beside the tank manhead that morning, and that water was running out of it. Other witnesses questioned later also recalled that the local pressure indicator on Tank 610 was found to be missing after the incident. After his statements subsequently became public in the litigation between the Indian Government and Union Carbide, the CBI subjected the instrument supervisor to six days of interrogation and intimidation during which they attempted, without success, to force him to change his testimony <sup>5</sup>.

Additional significant evidence of direct entry of water came from other peripheral witnesses. Within hours of the incident, reports of a direct water connection to the tank began to circulate among the plant employees. These were reported to the Indian Government by plant management but they could not be pursued at that time because the CBI had prohibited interviews of plant employees.

As it became evident that a massive cover-up had occurred among the more directly involved witnesses, these reports became more credible. The investigators, therefore, traced the origins of this report and spoke to an off-duty employee of another unit, who had reached the plant at approximately 2:00 a.m. the morning of the incident. He stated that he had been told by a close friend of one of the MIC operators that water had entered through a tube that had been connected to the tank. This was discovered by the other MIC operators, who then tried to open and close valves to prevent the release. Although the MIC operators used technical terms to describe the connection that the interviewee did not understand, he was able to draw the exact location of the connection, which proved to be the location of the local pressure indicator on Tank 610.

Another peripheral witness whose testimony proved to be of significance was an operator from a different unit who was on duty that night. He stated that, shortly after the release had subsided early that morning, at approximately 3:00 a.m., the workers from other units were discussing the incident in the plant. Two MIC operators told them that water had entered the tank through a pressure gauge.

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## VII. THE DIRECT-ENTRY CHRONOLOGY

The results of this investigation show, with virtual certainty, that the Bhopal incident was caused by the entry of water to the tank through a hose that had been connected directly to the tank. It is equally clear that those most directly involved attempted to obfuscate these events. Nevertheless, the pieces of the puzzle are now firmly in place, and based upon technical and objective evidence, the following sequence of events occurred.

At 10:20 p.m. on the night of the incident, the pressure in Tank 610 was at 2 psig. This is significant because no water could have entered prior to that point; otherwise a reaction would have begun, and the resulting pressure rise would have been noticed. At 10:45 p.m., the shift change occurred. The unit was shut down and it takes at least a half hour for the shift change to be

accomplished. During this period, on a cold winter night, the MIC storage area would be completely deserted.

We believe that it was at this point -- during the shift change -- that a disgruntled operator entered the storage area and hooked up one of the readily available rubber water hoses to Tank 610, with the intention of contaminating and spoiling the tank's contents. It was well known among the plant's operators that water and MIC should not be mixed. He unscrewed the local pressure indicator, which can be easily accomplished by hand, and connected the hose to the tank. The entire operation could be completed within five minutes. Minor incidents of process sabotage by employees had occurred previously at the Bhopal plant, and, indeed, occur from time to time in industrial plants all over the world.

The water and MIC reaction initiated the formation of carbon dioxide which, together with MIC vapors, was carried through the header system and out of the stack of the vent gas scrubber by about 11:30 to 11:45 p.m. Because the "common valve" (Item 16 of [Figure 7](#)) was in a closed position before the incident and the tank held a strong vacuum when it cooled down after the incident, it is clear that the valve was temporarily opened to permit the entry of water. This also permitted the vapors initially generated to flow (via the PVH) out through the RVVH. It was these vapors that were sensed by workers in the area downwind as the earlier minor MIC leaks. The leak was also sensed by several MIC operators who were sitting downwind of the leak at the time. They reported the leak to the MIC supervisor and began to search for it in the MIC structure. At about midnight, they found what they believed to be the source, viz., a section of open piping located on the second level of the structure near the vent gas scrubber. They fixed a fire hose so that it would spray in that direction and returned to the MIC control room believing that they had successfully contained the MIC leak. Meanwhile, the supervisors went to the plant's main canteen on break.

Shortly after midnight, several MIC operators saw the pressure rise on the gauges in the control room and realized that there was a problem with Tank 610. They ran to the tank and discovered the water hose connection to the tank. They discussed the alternatives and called the supervisors back from the canteen. They decided upon transferring about one ton of the tank's contents to the SEVIN unit as the best method of getting the water out. The major release then occurred. The MIC supervisor called the MIC production manager at home within fifteen minutes of the major release and told him that water had gotten into an MIC tank. (It later took UCC's and GOI's investigating teams, working separately, months to determine scientifically that water entry had been responsible.)

Not knowing if the attempted transfer had exacerbated the incident, or whether they could have otherwise prevented it, or whether they would be blamed for not having notified plant management earlier, those involved decided upon a cover-up. They altered logs that morning and thereafter to disguise their involvement. As is not uncommon in many such incidents, the reflexive tendency to cover up simply took over.

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## VIII. CONCLUSION

By their nature, large-magnitude incidents present unique problems for investigators. In the case of the Bhopal incident, these problems were compounded by the constraints placed on the Union Carbide investigation team by the Indian Government and, most significantly, by the

prohibition of interviews of plant employees for over a year. Had those constraints not been imposed, the actual cause of the incident would have been determined within several months.

Because the investigation was blocked, a popular explanation arose in the media as to the cause of the tragedy. A thorough investigation, which included scores of in-depth witness interviews, a review of thousands of plant logs, tests of valving and piping, hundreds of scientific experiments, and examinations of the plant and its equipment, was ultimately conducted over a year later. That investigation has established that the incident was not caused in the manner popularly reported, but rather was the result of a direct water connection to the tank.

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## **IX. REFERENCES**

1. Pietersen, J.M., "Analysis of the LPG Incident in San Juan Ixtahuapec, Mexico City, 19 November 1984", TNO Report 85-0222, 1985.
2. "Report on Scientific Studies on the Release Factors Related to Bhopal Toxic Gas Leakage", Indian Council of Scientific and Industrial Research, December 1985.
3. "Bhopal Methyl Isocyanate Investigation Team Report", Union Carbide Corporation, Danbury, Connecticut, U.S.A., March 1985.
4. In re: Union Carbide Corporation Gas Plant Disaster at Bhopal, India in December 1984. MDL Docket No. 626, U.S. District Court, Southern District of New York, Ordered November 8, 1985.
5. Interlocutory Application No. 19, Filed in Court of District Judge, Bhopal, in Regular Suit No. 1113 of 1986, Date, February 4, 1986.



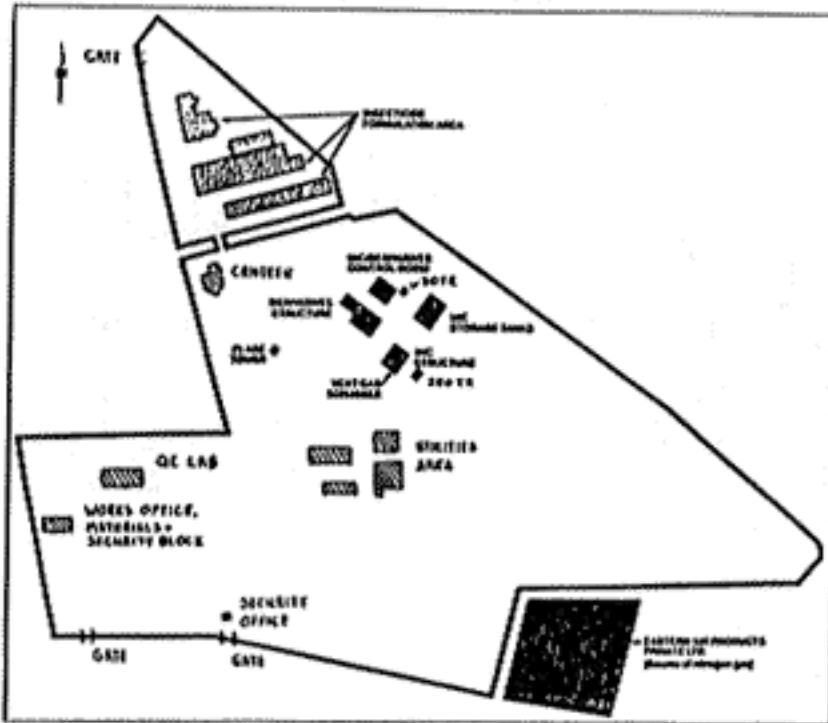


FIGURE 1. PLANT LAYOUT

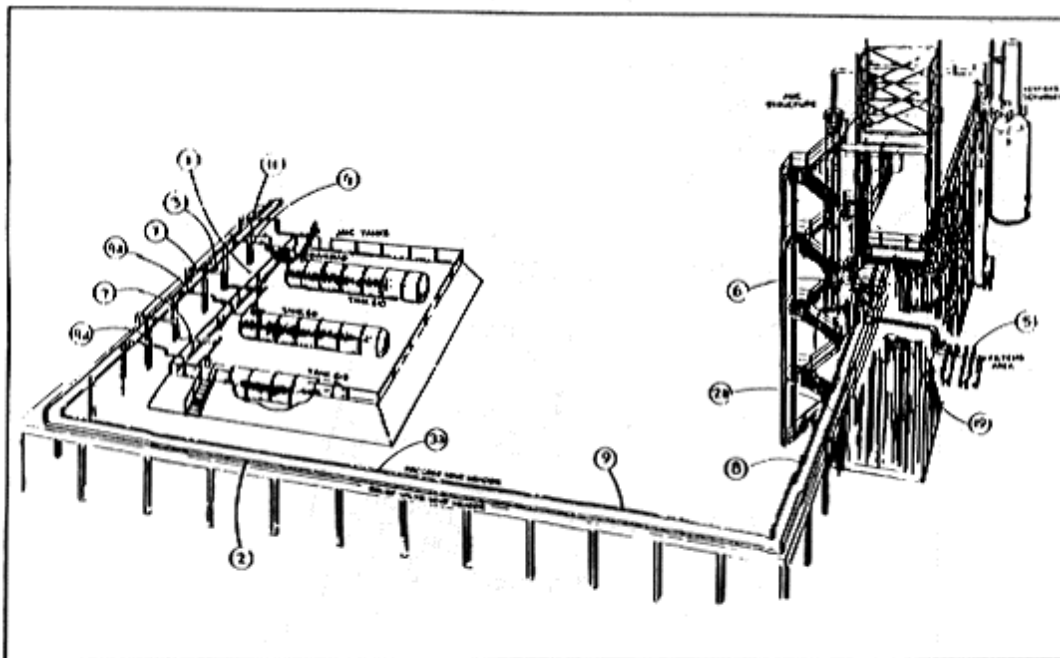


FIGURE 2. LOCATION OF MIC STORAGE TANKS

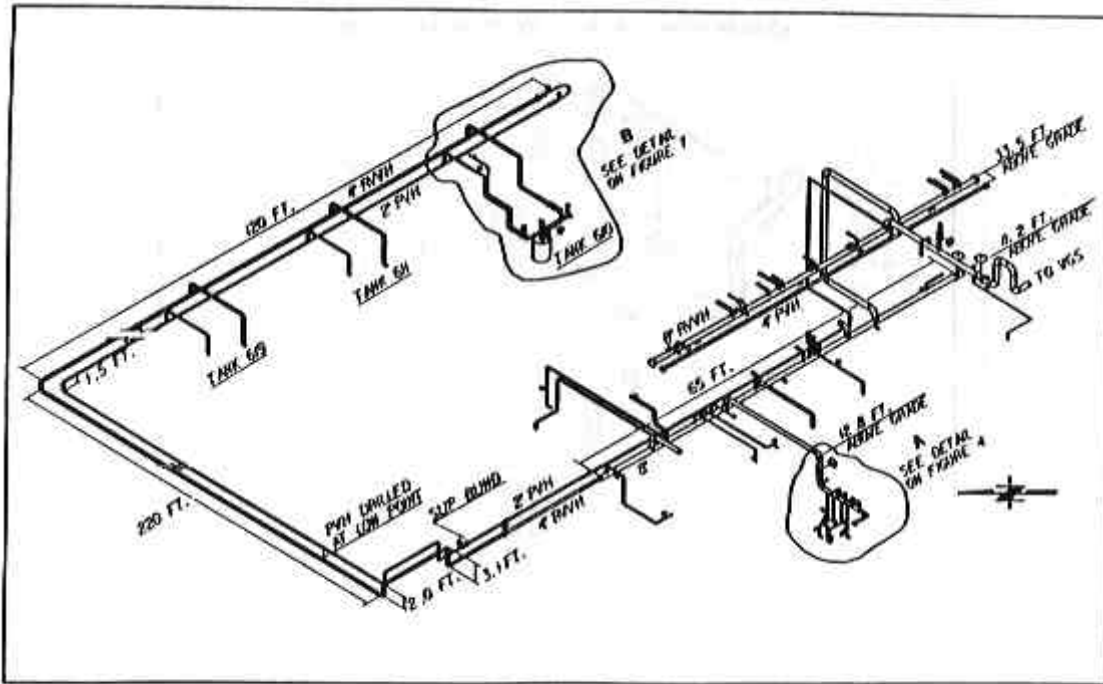


FIGURE 3. PVH AND RVVH PIPING CONFIGURATION

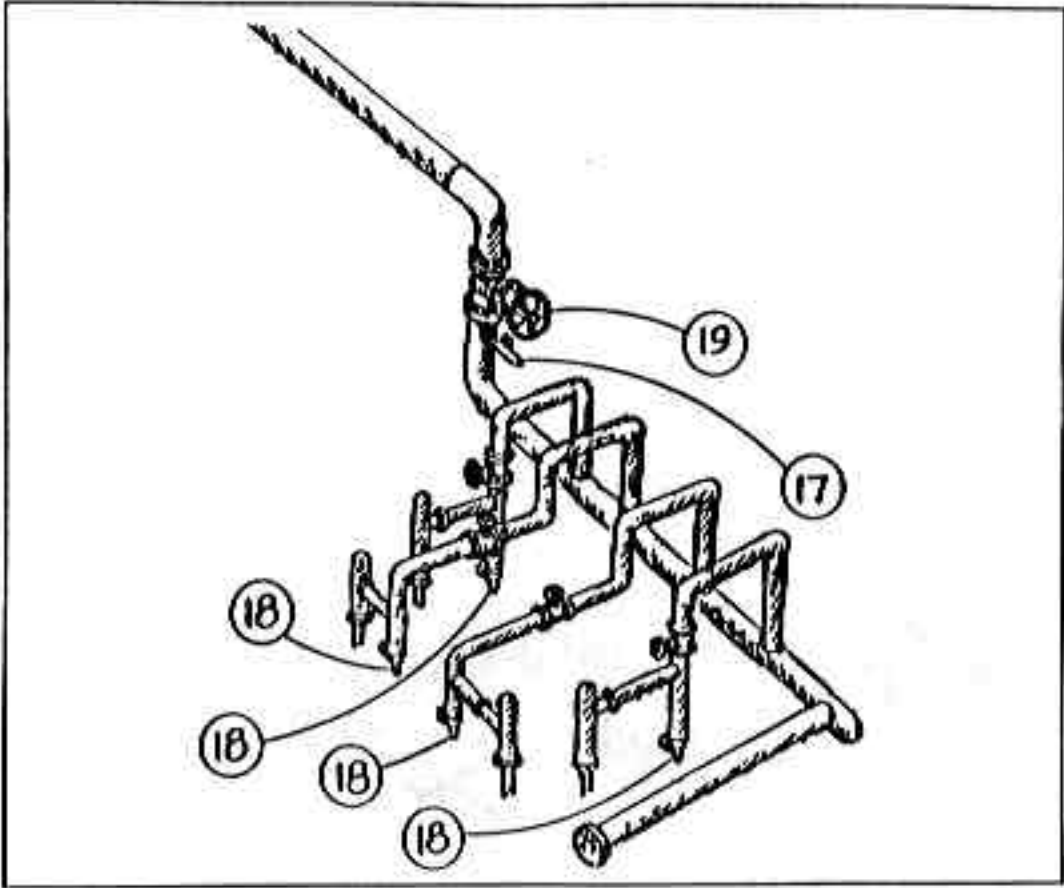


FIGURE 4. PIPING DETAIL -- WATER-WASHING AREA

To

8th February, 1985

Mr. J. Mukund  
Works Manager  
Union Carbide India Limited,  
BHEL PAL

Sub: Case 374 CIU(1), New Delhi

Dear Sirs

In order to determine whether there is any liquid in the section of PVH header running on the pipe rack between the MIC storage area and the manufacturing units, you are hereby instructed to drill or cut a hole in this section of pipe, since it does not have any flanged joints or bleeders. Every attempt should be made to collect the total maximum quantity of liquid which may be found in this pipe which should be carried out in the presence of CBI representatives. Samples of liquid, if found, should be preserved for analysis.

Yours faithfully,

Received 2 PM  
8/2/85  
T. Mukund

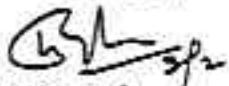
  
(MURARI LAL)  
SP/CBI, New Delhi  
Camp: Bhopal

FIGURE 5A. COPY OF ORDER TO DRILL INTO PVH

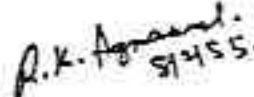
MEMO

Today, i.e. on 8th February, 1985, in the presence of S.P., CBI, Mr. J. Mukund, Works Manager, Mr. S.P. Chaudhury, Production Manager and another operator, an attempt was made to drain out liquid, if any, in the PVH Header near MIC Structure on the Pipe-track after drilling a hole in the side PVH at the lowest point.

After the hole was drilled, no liquid came out inspite purging the PVH header. *with nitrogen.*

Certain valves in the storage area which had been sealed by the CDI had been re-opened for this operation and re-sealed by CBI. A detailed statement prepared by UCIL is also enclosed.

  
S.P. Chaudhury  
Production Manager-UCIL  
*SP*

  
R.K. Agrawal  
SI / CBI / SPE / JBP  
Camp: Bhopal

8.2.1985

FIGURE 5B. COPY OF RESULTS OF DRILLING INTO PVH

### MIC UNIT INVENTORY AND TRANSFER SHEET

Rev. 01/19/71

INVENTORY		% AVAIL			INVENTORY		REMARKS
MATERIAL	TRANS. NO.	SPM	10 PM	5 AM	SPM		
Chassis	E-100	68	73				
Chassis	E-100	73	73				
MIC	E-100	73	73				
MIC	E-100	73	73				
Chassis	E-100	73	73				
Chassis	E-100	73	73				
Chassis	E-100	73	73				
Chassis	E-100	73	73				
MIC	E-100	73	73				
MIC	E-100	73	73				
MIC	E-100	73	73				
Chassis	E-100	73	73				
Chassis	E-100	73	73				

TRANSFER/LOADING												
MATERIAL	FROM	TO	PROVER				MICROPHONE				AS PER WFR. LOG	
			START	STOP	DURATION	FROM	TO	FROM	TO	BY		
<del>Chassis</del>	<del>E-100</del>	<del>E-100</del>	<del>73</del>	<del>73</del>	<del>73</del>	<del>73</del>	<del>73</del>	<del>73</del>	<del>73</del>	<del>73</del>	<del>73</del>	
MIC	E-100	E-100	73	73	73	73	73	73	73	73	73	
MIC	E-100	E-100	73	73	73	73	73	73	73	73	73	
Chassis	E-100	E-100	73	73	73	73	73	73	73	73	73	

101175-03

FIGURE 8. COPY OF ALTERED TRANSFER LOG SHEET

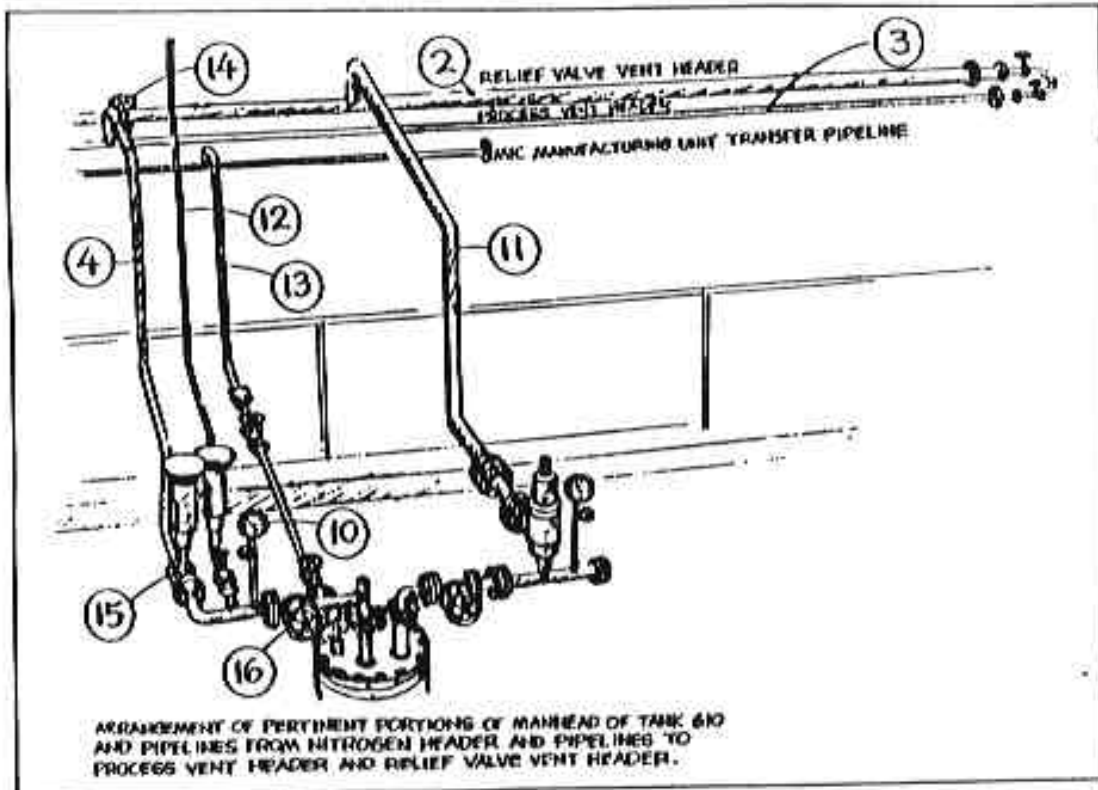


FIGURE 7. PIPING DETAIL -- TANK 610 MANHEAD AREA