CHAPTER 7
FACILITIES, OBSERVATION AND ANALYSIS

BACKGROUND INFORMATION

7.1 VAPOUR CLOUD EXPLOSION

Prior to the Buncefield and now Jaipur incident, the most likely consequences from a failure of volatile liquid hydrocarbon containment, such as from a storage tank or from any other location in an installation, would have been assumed to be a flash fire and/or pool fire. The size of the flash fire would probably have been limited because the influence of the vaporization from atomized liquid cascade as it happened in the present case from a Hammer Blind Valve but was not identified as a hazard and the flash fire would have been associated with evaporation from an assumed quiescent pool in the bund. This incident, however, very clearly demonstrates that future risk analysis should consider the probability of an explosion resulting from enhanced vaporization of free falling or escape of liquid.

The tank terminal facility was only for storage of liquid petroleum products, namely MS, HSD & SKO, besides having a large storage of lube oil in drums. This is the first instance in the country and perhaps the second or third in the world in which storage and handling of these products (MS) under atmospheric pressure has resulted into such a catastrophic accident. Normally loss or escape of containment of any petroleum products of this nature occurs for a short duration and the release caused if ignited causes a pool fire, and in any case the situation is brought under control quickly. Certain scenarios have been considered in the consequence analysis appearing in the report submitted to the Committee titled “HAZOP Study”, (agency name not given and also undated). The scenario considered therein included pool fire. Further, major tank fires are normally roof fires which have also been considered in the said report. The scenario which emerged in the IOC Jaipur Terminal was not envisaged in such study, perhaps because it had not occurred anywhere else at the time the “Hazop” study was done.

The incident as the one which occurred at Jaipur Oil Terminal i.e. massive vapour cloud explosion has so far only one established precedent which happened in December 2005 in a very similar oil terminal (Buncefield Oil Terminal) Near Heathrow Airport in U.K. In this incident a large quantity of MS (reportedly 300 tons) had leaked because of overflow from a MS tank, which went unnoticed because of malfunction of tank level control and associated safety inter locks. Very recently on 23rd October, 2009, reportedly a similar incident occurred in a petroleum oil terminal in the Caribbean Refinery (which was under shutdown) at Puerto Rico, where too, a massive MS leak due to overflow of MS tank during ship unloading reportedly resulted loss of around 800 tons of containment which caused a massive explosion. Both these accidents were of catastrophic nature similar to Jaipur. No other such incident i.e. massive vapour cloud explosion in a petroleum product storage terminal has occurred/reported.

7.2 FACILITIES

In Major Accident Hazard (MAH) units such as the Jaipur Oil Terminal the location of facilities and plants as well as developments in land use around the facility over time, need to be critically reviewed regularly over a period learning from similar accidents both in the country and worldwide.

7.3 DESIGN

1. The IOC Jaipur POL Terminal built around 1995/96 and commissioned in early 1997 was engineered and constructed by well reputed public sector engineering company M/s Engineers India Ltd., (EIL) on LSTK basis. The

Terminal was designed as per the applicable national and international codes and engineering standards prevailing at that point of time, namely, API-650, ASME, ANSI, B31.3/16.5/16.29, NEMA etc. The material of construction was selected as per the best prevalent engineering codes internationally namely, ASTM, A-285 – Gr.C, A-106-Gr. B, ASTM A182 Gr. F-6, A-216, Gr.WCB, API 5L, etc.

2. The plant lay out design was carried out as per the then prevailing applicable statutes, (e.g, Petroleum Rules), OISD Standards/guidelines as applicable as well as good lay out design concepts as prevalent at that point of time. Fire fighting facilities were provided strictly as per the then applicable OISD standards. Other safety features namely, control system, interlocks etc., for safe operation as per good practice prevalent at that point of time, was provided by EIL.

3. The Jaipur POL Terminal, when commissioned in 1997 was termed as most modern and automated Marketing POL Terminal of IOC.

4. The Jaipur Terminal, in earlier years, had good safety records and received National Safety Council's Award for "Best of its Class" for three successive years from 2001 to 2003. Further it was adjudged "Runners up" in 2004.

5. In 1997, when this facility was commissioned, the location was decided by IOC keeping in mind that it was sufficiently away from Jaipur city, with residential/commercial/industrial areas few Kilometers from the block boundary and at the same time it was in proximity to the major product consuming centre. The earlier operating site which was very close to the then Jaipur city was relocated here.

6. The construction of this Terminal was done by M/s ATV Projects, a contractor with experience in construction of petrochemicals and refinery projects, short listed by EIL based on their competence.

   The overall process design of tank operations (which involves delivery, receipt of product etc.), viz. the first valve on the tank being a MOV followed by Hammer Blind and a hand operated valve is such that it makes it highly vulnerable to human error. However, in the event of operator error a fall back (check to undo it) was in the form of a remote closing facility from the control room. This was made defunct since 2003 or thereabout and the only way that the MOV could be closed was to go near it and press the 'close' button or else to close it manually by hand wheel which, of course, required being at the valve.

7.4 LAYOUT

Though the Installation was constructed quite recently, in 1995-96, a few areas where design could have been better done are worth pointing out. The installation ground area is very vast comprising of 105 acres for the marketing installation and 15 acres at the NE corner for pipeline, for facilities consisting of interface manifold, control room and crude oil booster pump with auxiliaries.

The terminal is in 105 acres area and in Phase I, storage facility around 80,000 KL capacity was constructed .All tanks of three products i.e. MS, HSD and kerosene were located in three separate dykes close to each other on the North West corner of the plot. The initial layout did not prudently consider the future expansion of the tank terminal. This was evident from the fact that additional two numbers MS tanks constructed in Phase II were to be located far away from three MS tanks of Phase I.

The marketing terminal fire water pump house and fire water tank location though complying with the statutes (Petroleum Rules) and was not violating the OISD guidelines was not ideally located. Experience gained from other accidents such as Cochin Refinery (1984) and similar incident elsewhere showed that fire water pump house as well as fire water tanks should be located far away from areas wherein fire and other emergency incidents can occur. This concept appears to have been taken into consideration in Jodhpur Oil Terminal.

7.5 ENGINEERING

As a good practice, the inside of the dyke should have minimum flanges and piping and any normal day to day operating facilities, like manifold, should be outside the dyke. Here, it was observed that the tank isolating facilities for different line-ups, the Hammer Blind assembly consisting of downstream hand operated gate valve (HOV) and from the tank side, a motor operated gate valve, were provided inside the dyke area. This appears to be the operating / design philosophy followed by IOCL for all their Terminals set up at that time. The motor operated valve was having 3 knobs of identical size, one for ‘Open’ operations, another for ‘Close’ operations and yet another for ‘Stop’ Operations at any intermediate position. All these knobs or push buttons were mounted on a panel close to each other and therefore vulnerable to human error, especially in times of an emergency when very quick responses are required, and also during dark hours when lighting in the area may not be adequate. In the absence of appropriate lighting at these control points for immediate and correct approachability, it would have been prudent to think of designing these operating points through a different type of mechanism.

Bleed valves have been shown on the P&IDs between MOV/HB/HOV. These were envisaged to check possible passing before opening any of the valves. However in the plant these have not been provided. From interview/discussions it transpired that none of the terminal personnel was aware of the purpose of the provision of these bleed valves on the P&IDs.

7.6 ILLUMINATION

No separate lighting other than the general tower lighting was available. The lighting arrangement in the terminal was poor. Operations after dusk had to be carried out in general lighting provided by light masts which provided insufficient lighting in the operating points resulting in operator's poor visibility. Separate lighting in tank area had not been provided at crucial operating points.

7.7 GREENERY IN TERMINAL

Extensive research was carried out into the Buncefield accident. This included phase (i) modeling and recreation of the blast conclusively indicated that the presence of extensive greenery i.e. dense rows of big trees along with low level raw vegetation greatly contributed to accelerate the "Deflagration" which first occurs in "Unconfined Vapour Cloud Fire/flash fire" to "Detonation" due to very fast acceleration of flame speed beyond 500 meters per second or higher. Jaipur terminal too had extensive greenery and rows of trees along the plant road leading to MS tank 401-A and also good growth of large trees both close to tank farm area as well as near portions of the boundary. The concept of providing green belt along the periphery of hazardous facility and also encouraging greenery within/close to plant area itself had been a practice for long. However, this practice needs to be re-examined for petrochemicals, refinery/petroleum terminals and such facilities wherein vapour cloud may form. The trees provide protection against fire (radiation effect) as well as toxic release. However, as seen in Buncefield and most likely in Jaipur in case of a "Vapour Cloud Explosion", they greatly enhance the blast effect and accordingly the severity of damage and accordingly from Buncefield experience there is a possibility of having a re-look in the extensive greenery in terminals such as Jaipur.

The investigation committee into the fire/explosion incident in the BP Texas Refinery in 2005 (where too a massive vapour cloud explosion took place) had also observed similarly, "As the degree of congestion (number of obstacles due to process equipment, pipe work) and confinement (extent of enclosure in 3 dimensions) of a vapor cloud increases, the magnitude of the resulting vapour cloud explosion also increases in the event of ignition…". In the Jaipur incident too, there was confinement of vapour due to buildings and trees which may have enhanced the effect of the blast. While the greenery interspersed with the plant and facilities may enhance any explosion effect in case of a leak, the Committee feels that as per current reckoning the green belt along the periphery of the site can be retained.

7.8 CRITICAL SITE EVIDENCE

1. Both the isolating valves in the outlet line of the MS tank T-401-A i.e. the tank MOV, and the hand operated valve were found fully open.

2. The hammer blind valve provided in between the above two isolation valves had both of the eye plates (blind and the open one) outside the hammer blind valve body casing, thus making its entire bonnet fully open to atmosphere.

3. The solid wedge position was such that it had been pushed to the wrong direction (west) and the open eye position was vertically on top of it and the open eye was hooked in that position. However, our experiments conducted (refer Appendix 6, Case No.4) reveal that this position of wedges can result with very high flow of liquid from the bonnet of the Hammer Blind valve.

4. The position of blind eye being in wrong position, at that position it would not have been possible to lower the open eye.

5. The open eye of the hammer blind had partially burnt PTFE gasket whereas no gasket was existing on the blind eye. Hence the blind eye was apparently not fitted with PTFE gasket.

6. The tank 401-A dyke drain valve leading to open storm water drain, was in open position with hand wheel missing, and the 401-A dyke drain valve leading to ETP was fully closed with its hand wheel also missing. These hand wheels could not be located.

7. Drains - the one starting from tank 401 running in west to east direction and the drains connected to it had thick black soot marks clearly indicating a drainage channel fire.

8. During subsequent visit it was seen that the spindle of both the dyke valves (Refer point No.5 above) were missing. The Investigation Committee, therefore, carried out close examination of this valve by arranging dismantling of its top bonnet at site. Very surprisingly following were seen:

a) The dyke drain valve leading to open storm water drain, whose gate was earlier found open, is now fully closed.

b) This valve spindle as well as the spindle of dyke drain valve leading to ETP was both of their stems broken at a point about inch from the root.

c) Broken stems position of both the spindles was blackish.

On rubbing the broken portions, it was observed that these spindles were made of brass, which is not as per the engineering specifications.

The above site observations can be well understood by referring following site photograph

Photograph of the broken spindle of the drain valve outside the dyke wall of Tk 401A

9. The BCC building had marks of thick soot on the first floor towards east, north and west sides. The building was totally damaged. The west side walls of the building had bulged outwards indicating a possible explosion of petroleum vapours accumulated inside the building. This building which was outside the danger zone of Installation had all kinds of ordinary electrical equipments, lighting and Air Conditioning equipments which are self regulating by on or off mechanism. Thus, this building had sources of ignition of petroleum vapours in the form of sparks generated from the electrical equipments.

10. The Installation had lot of trees in almost all the areas. After the accident it was noticed that the trees in the area of BCC building, Administrative building, canteen, stores, DG shed, PMCC building and car

parking area were snapped off in the middle and the fallen portion all were pointing towards tank No.401-A where the leakage occurred.

11.In between car shed and DG shed two tank lorries were seen. The tanks on these lorries had come off the chassis and had fallen towards the direction of tank No.401-A.

12. The trees in the areas of pump house, open areas beyond that, ETP area as well as the area of two MS tanks opposite to tank truck gantry all had snapped similarly but the fallen portions were pointing towards the Pipeline Division facilities.

13. The Pipeline Division housed booster pumping station for the Mundra to Mathura/Panipat pipeline. The pipeline pumping station was severely damaged in the accident. Pumping operations were reportedly stopped by the Pipeline Division staff after emergency alarm was sounded after 6.30 p.m. However, the huge capacity motors of booster pumps might still have high surface temperatures enough to ignite petroleum vapours accumulated there.

14. Thus, apparently there were two centres of ignition of petroleum vapours – one in the BCC building and another in the Pipeline Division facility.

15. A motor-bike was found on the northern side of SKO tank and the rider's body was found away from the bike. It is possible that sparks from the exhaust of the bike could have provided the source of ignition to petroleum vapours.

16. Similarly, it was reported that jeep of Pipeline Division was about to be pressed into use but the attempt to start its engine failed. During these

attempts any spark from the exhaust pipe (which may not have been fitted with spark arrester) also could provide the source of ignition.

7.9 OPERATING SCENARIOS

All the three valves on the delivery line of Tank 401-A were found in fully open position. The Hammer Blind was not only fully open but both sides of the valve i.e. the hollow wedge and the solid wedge were outside the body and kept one on top of the other (open eye in hooked condition and blind eye resting on the body).

The above condition of the valves indicates a grossly irregular operation which can never happen if a Standard Operating Procedure was followed.

The fact that the solid wedge is resting below the hollow wedge shows either lack of understanding and skill because in this position, the hollow wedge cannot move inside the valve body, or it may be due to the fact that only one operator was performing the operation of reversing the Hammer Blind.

When both the wedges of the Hammer Blind are outside the valve body, both the MOV and the Hand Operated Valve (HOV) should have been in closed position whereas both were found in fully open position. It may be worth noting that there was no physical indication available at the site to indicate whether the MOV was in the fully open (or fully shut) position. Only an approximate idea of the valve position can be understood from the threads on the valve stems. Since both the operators who operated the system did not survive the accident, and there are no recordings of valve positions, or other recorded evidence available to the Committee, we may not know exactly what led them to this condition, but the position of the valves does indicate that whatever operation was done immediately prior to the incident was a highly irregular one. Some likely sequences of valve operations, which may have been possible, are discussed below:

a HOV opened first – then Hammer Blind (HB) opened – some leak occurs due to reverse flow – RN Meena thinks passing MOV – some material goes in his eyes – he presses wrong button on MOV panel, – "open", instead of "close", and leak becomes huge. Reverse flow may occur in the event of sucking of air when the vent valve on the MS pump delivery line near exchange pit is open by the BPCL contractor's man before sealing the valve. However, the MS transfer pump has no bypass (from delivery to suction) and accordingly any reverse flow first has to come through the pump valve and then to the pump. Further it being a centrifugal pump, the impeller will have to rotate in reverse direction in case of reverse flow. It is most unlikely that non-return valve failed. Even if the non-return valve passes the pressure on the upstream side of the non-return valve will be too small to cause reverse rotation of the impeller resulting in reverse flow. Further, this small difference in height cannot result in a vertical jet of MS through the open bonnet of Hammer Blind valve, blinding Shri R N Meena. Hence this seems improbable. Even so, a clear violation is the opening of the HOV before the Hammer Blind is reversed.

b MOV was by mistake fully open before the entire operation started and leak started when HB was pulled out. However, this seems improbable as the leak would have been very heavy for anyone to be able to open the valve (HB) fully with the leak on.

c HOV was full open first, MOV was passing – RN Meena operates hammer blind valve and continues despite some material leaking – material goes in his eyes – again he goes to MOV to press close button but by mistake presses open button – situation worsens. On hearing the distress call over VHF, KR Meena enters the dyke to rescue RN Meena but succumbs to the leak. All persons interviewed in Jaipur and Jodhpur have said that they had never experienced any of the MOVs to be passing beyond a very small quantity. It must, however, also be pointed out that the internal investigation committee set up by IOC has observed "it is common knowledge that MOVs pass at times".

d HOV was full open first, MOV was open just a fraction before the line up operation was to be started in order to pressurize the pump section line (which was not supposed to be done at this stage) – RN Meena operates hammer blind valve and continues despite some material leaking – material goes in his eyes – again he goes to MOV to press close button but by mistake presses open button – situation worsens. On hearing the distress call over VHF, KR Meena enters the dyke to rescue RN Meena but succumbs to the leak. Again the violation of procedure is that HOV should not have been opened before reversing the Hammer Blind. In this case not only the HOV was first opened making it a violation, but also the MOV was not checked for being shut before attempting the Hammer Blind operation.

e RN Meena opened the Hammer Blind valve by pulling out the solid wedge, but forgot to put the hollow wedge inside the valve body thus leaving the bonnet open at the top. Due to absent mindedness, which incidentally Shri RN Meena was prone to, he pressed the open button of the MOV, and the situation got out of control.

In many of the cases above, it is assumed that the HOV was opened first, perhaps with a view to reduce back pressure and the leakage when Hammer Blind solid wedge was being reversed from close to open position, and in the event that MOV was passing.

It may also be pointed out that within the first few minutes of the start of the leak, all the available operating personnel were incapacitated – two of them lying presumably unconscious within the tank dyke area and the officer on duty having been rushed to the hospital. Had the third operator been available on site, had he been trained and acted in right manner such as using fire water fog nozzles or starting of the MS pump so that product could be diverted to any other tank (thereby the extent of the leak) by pumping to any of the other tanks and/or donning on the protective equipment (breathing mask and fire suit) and closed the MOV, the incident would have been very largely mitigated.

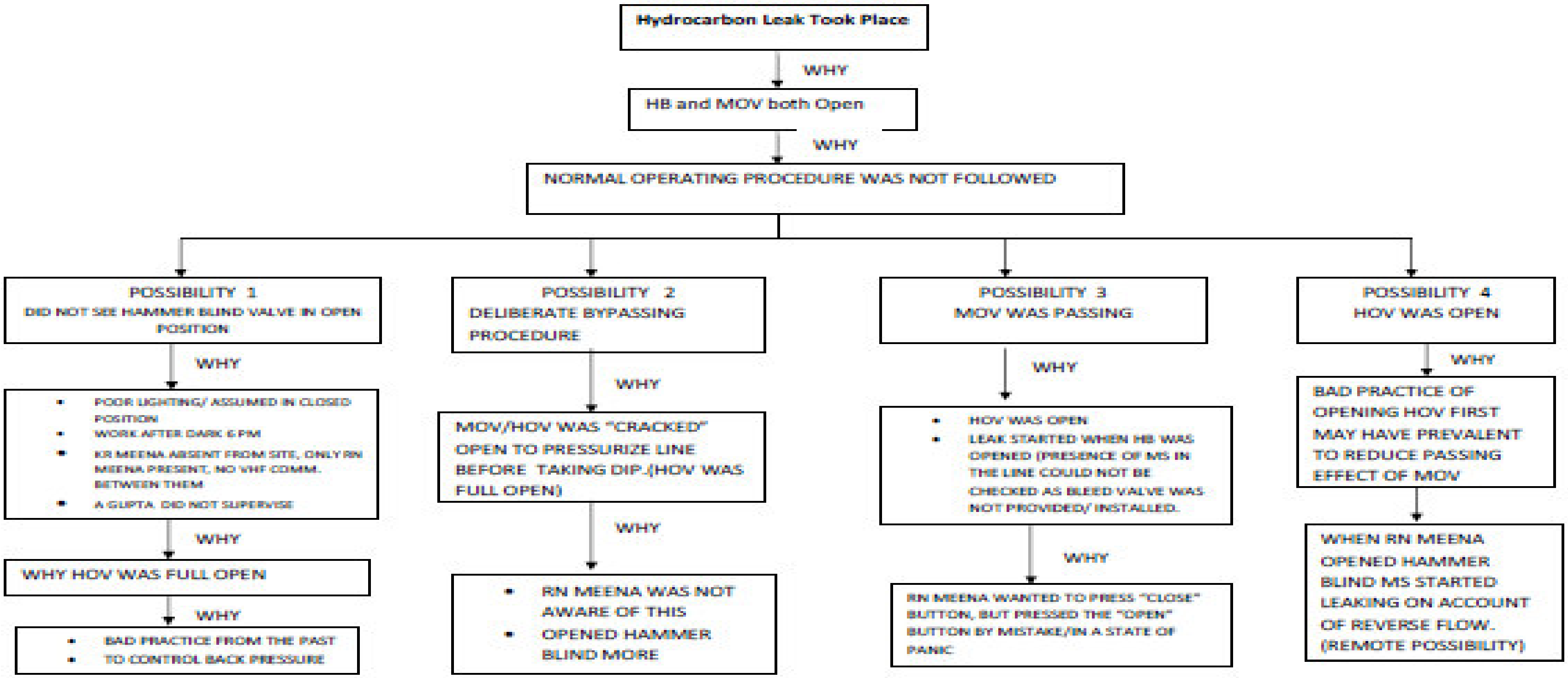
f Another possibility is when Shri RN Meena was on top of tank 401-A along with Shri Gupta and Shri Gangal for taking joint dip Shri K R Meena, who was standing in ground level inside the dyke area, had tried to communicate some message to Shri R N Meena, which Shri Ashok Gupta could not understand (as per the statement of Shri Gupta). KR Meena may have opened Hammer Blind Valve for making the line through may have left it open with both the wedges out and had gone perhaps to bring the O-ring and also to take tea, as the canteen was about to close. In the meantime, RN Meena came down and due to poor illumination may not have observed the proper condition of Hammer Blind Valve and may have thought that the Hammer Blind Valve have already been reversed by KR Meena. Therefore to pressurize the line he might have operated MOV. After opening the MOV there was a splash of MS from the opening of Hammer Blind Valve which had perhaps blinded RN Meena when the line was filled MS started escaping through the opening of Hammer Blind Valve with full pressure.

Amongst the contributory reasons for the incident, one need to highlight that the approachability of the Hammer Blind and the open/close button of MOV and the proximity of the two buttons making it possible that the operator may press the wrong button. Poor lighting in the area, lack of local indication showing whether MOV is fully open or close, may well result in human error.

On the likelihood of MOV passing the Internal Inquiry Committee, which was constituted by IOC to inquire into the incident, had made the observation, “it is common knowledge that MOV’s pass at times”. However, repeated enquiries by this enquiry committe with several operating personnel both at Jaipur as well as Jodhpur indicated that they had never experienced passing of MOV’s. The committee would have liked to check this point through an experiment but could not do so because of paucity of time. Other major contributory reason was the dyke valves, which, was also open and further aggravated the situation as there was no secondary containment.

The diagrammatic analysis of the above chronology of event is as given below:

INCIDENT SCENARIO ANALYSIS



Experiments were conducted with water in the fire water tank of the Pipeline Division with different openings of the tank body valve (equivalent to MOV) and Hammer Blind valve.These simulations provided an idea of the leak under different combinations of valve openings and the results are given in **Appendix 6**.

The entire operation clearly indicates:

a) Gross procedural violation

b) Absence of written down Standard Operating Procedures (SOPs) for Terminal Operation e.g. tank line up, tank receipt, emergency shut down of the entire tank farm etc

c) Gross dilution of work ethics/operating discipline and safety culture

d) Lack of adequate manning at vital operating points & supervisory control

7.10 FIRE FIGHTING READINESS

It was indicated to us that mock drills based on different scenarios were being carried out by the Jaipur IOC Installation. However, since no records could be furnished, it was not possible to ascertain the efficacy, effectiveness, the extent of the people's involvement and capability of the fire fighting operations. It was also not very clear as to who was really trained on the fire fighting operations, as their training records do not indicate so. During the interviews, it also came to light that the security personnel were never trained for fire fighting equipment use or on safety equipment and protective equipment use. However, the security personnel had some basic knowledge, as they came from para military forces. Fire water tank and fire fighting water pumps were supposed to be operated and maintained under the electrical contract, by the contract person, Mr. Hoshiar Singh of G&G Contractor. It was observed in the responses to the questionnaire from the security personnel that on the second shift, Mr. Hoshiar Singh was alone on the job as both of his assistants who were supposed to be manning the shift, had left duty since they were agrieved & agitated for not being paid their monthly dues over the last few months.

The electrical contractor, Mr. Hoshiar Singh, was also responsible for maintaining the fire header pressure and on need, subsequent operation of DG Pump sets, on the instruction of IOC shift officer/Manager. In the absence of officer (who was injured and who had collapsed), it was **not** clear in the Contract Management, during this absence period, whether Mr. Hoshiar Singh had any decision making capability to start the water fog nozzles, tank cooling, etc. Anyhow, it can be stated that no fire fighting activity was initiated for almost one and a half hours during which the MS leak was taking place, following which the explosion occurred. It was also observed that one of the fire fighting water tanks was completely empty as it was under maintenance since the last few months, leaving only one tank with gross tankage capacity of 2460 cubic meter which was inadequate though the same was complimented by the water storage facility of pipeline division through interconnection.