Risk Assessment

The mining operations at Zawar mine are fairly mechanized. In underground mining operations, hazardous situation may arise leading to accidents. Risk assessment involves the identification of the various hazards or unsafe conditions that exist in the mine and related operations and to take precautionary measures to eliminate the risk of accidents.

Identification of Hazard and Precautionary Measures

Identification of Hazards in a mining unit is of primary significance in the analysis, quantification and effective control of accidents. A hazard is characteristic of a system/process that presents potential for an accident. All the components of a system/process need to be thoroughly examined to assess their potential for initiating an accident. Safety is relative and implies freedom from danger or injury. It calls for identification of hazards, risk and further suggestion on hazard mitigation measures.

In the Metalliferrous Mines Regulations (1961), possibility of occurrence of hazards and the mitigation measures are spelt out in detail. Accident or hazardous situation may arise due to occurrence of any one of the following causes.

- Outbreak of fire;
- An influx of noxious gases;
- An eruption of water or inundation;
- Premature collapse of any part of workings;
- An accident due to the explosives;
- A fracture or breakage of any essential part of winding system;
- Bursting of any equipment at high pressure;
- Air blast; and
- Subsidence.

The above causes and preventive measures are discussed below.

<u>Outbreak of fire</u>

Some precautions and remedial measures proposed to be adopted to prevent fires are:

- No inflammable material shall be stored in underground except in fireproof containers;
- To avoid surface fire, all structure with 10 m of shaft, ramp and incline to be constructed to incombustible material;
- Surface workshop, diesel filling station, compressor house and electric sub-station shall be provided with fire fighting equipments and to be maintained regularly;
- Dry vegetation shall not be allowed within a distance of 15 m from any entrance to the mine;
- Regular inspection will be done to remove accumulation of greasy material cotton waste, old conveyor pieces, waste hose pipes, wooden scrap, wood cuttings etc. and shall be removed regularly;
- A proper alarm system shall be installed to warn underground worker about outbreak of fire;
- Electric apparatus, electric cables etc. shall be checked regularly;
- Adequate number of persons will be trained in fire fighting; and
- Mock drills will be conducted on regular basis.

On the appearance of signs indicating that a fire has broken out, all persons other than those whose presence in the mine is deemed necessary for dealing with the fire shall be immediately withdrawn from the mine.

Fire fight operations would be carried out under the supervision of competent persons along with trained fire fighting personnel.

Sufficient supply of sand or incombustible dust or sufficient portable fire extinguishers shall be provided at entrance to a mine, landing and the bottom of every shaft or winze in use, engine room and at other place where timber, canvas, grease, oil or other inflammable material is stored. Water hydrants will be provided at all necessary locations. Suitable types of fire extinguishers will be provided at different locations to deal with different types of fire.

Influx of Noxious Gases

The following precautionary measures will be adopted.

- Inflammable gas shall be deemed to have been detected when it is indicated by the lowered flame of a flame safety lamp or where methane indicators are used they indicate one and a quarter per cent or more of inflammable gas;
- When any person detects the presence of inflammable gas, he shall immediately withdraw from the place and shall inform his superior official about the same;
- When inflammable or noxious gas is detected, all persons shall be withdrawn from the place, and the place shall be immediately fenced off so as to prevent persons inadvertently entering the same;
- No person shall be re-admitted in to the place where the gas was detected until a competent person has examined the place and has reported that the place is free from gas;
- In long drivages or blind workings, a flame safety lamp will be always maintained; and
- Persons will be trained in the use of flame safety lamps. The competent person will take steps to remove the gases by improving ventilation.

Irruption of Water/inundation

A water danger plan showing the following features will be maintained as required by regulations.

(1) The position of the workings below ground;
(2) Every borehole and shaft (with depth) drive, crosscut, winzes, raise, excavation and air passage connected therewith;
(3) The position of every dyke fault and other geological disturbance, with the amount and direction of throw;
(4) Levels taken in workings below ground at easily identifiable points sufficient in number to allow the construction of sections along all drives main headings and haulage roadways;
(5) Every source of water such as river, stream, water course, reservoir, water-logged workings on the surface, and also the outline of all water logged workings below ground lying within 60 meters of any part of the workings measured in any direction;
(6) Every reservoir, dam or other structure, either above or below ground, constructed to withstand a pressure of water or to control an inrush of water, along with reference to its design and other details of construction;

(7) Surface contour lines drawn at vertical intervals shall not exceed five meters; and
(8) The highest flood level of the area.

<u>Premature collapse of any part of workings</u>

Based on the rock quality assessment and the chosen method of mining, no premature collapse of any part of working is anticipated. However, following precautionary measures will be observed:-

- To prevent premature collapse of any workings, effective supports will be erected based upon the geotechnical mapping. All workings will be systematically supported to eliminate any possibility of premature collapse;

- Numerical modeling techniques will be used to determine the stable spans; and

- The hang wall and crown pillar will be instrumented with multi point boreholes extensometer and stress meter for ground monitoring on regular basis.

<u>Accident due to the Explosives</u>

Detailed guidelines have been provided in the regulations and various circulars. The measures proposed are:

- Explosives will be issued only to the authorized persons;

- Explosives and detonators will be transported in separate boxes under lock and key;
- The person holding the statutory certificates will carry out the blasting operations;

- Large diameter blasting would be carried out after withdrawing all persons from below ground;

- A register will be maintained at the gate checker office, where all section foremen will countersign indicating the removal of persons from their sections before carrying out large hole diameter blasting; and

- The blaster will ensure that all persons have taken proper shelter before blasting the charge.

<u>Bursting of any Equipment at High Pressure</u>

- All apparatus used as or forming part of the equipment of mine, which contains or produced air at a pressure greater than atmosphere pressure shall be so constructed, installed and maintained as to obviate any risk of fire, bursting explosion or collapse or the production of noxious gases;

- Every air receiver forming part of a compressing plant shall be fitted with a safety valve and an air gauge, which sows pressure in excess of the atmospheric pressure;

- Before an air receiver commissioned, the engineer or other competent person shall subject it to a hydraulic test at pressure at least one and a half times the maximum permissible working pressure; and

- A similar test shall be made after every three years. Proper records will be maintained.

The supply of air for air compressors shall be drawn from a source free from dust and fumes.

Precautions against Air Blast

No such danger is anticipated. However, the following precautionary measures will be observed in case of eventuality:

- Any large scale collapse of wall rocks into voids may displace the air in violent manner and cause accidents;
- Persons will be trained to deal with situations arising out of Air blasts;
- Air blast shelter would be established at suitable locations; and
- The drawal points in the stopes would not be totally emptied.

General

- Persons will be authorized for various skilled works;
- Every exposed part of any machinery used as, or forming part of, the equipment of a mine shall be adequately fenced by suitable guards to prevent danger;
- Only authorized and trained persons will be permitted to operate and maintain equipments; and
- Danger signs will be displayed at appropriate locations.

Use of Sodium Cyanide in Beneficiation Plant

During beneficiation of lead and zinc ore, cyanide salts are used for suppressing impurities present in the ore with a view to improve the separation of lead-zinc metals from the gaunge materials. The material safety data of sodium cyanide is presented in **Table-7.2.**

TABLE-7.2
PROPERTIES OF SODIUM CYANIDE

Sr. No	Data	Details
1	Boling point	1496^{O}C (2724 F) at 760 MMHG
2	Melting point	564^{O}C (1047 F) at 760 MMHG
3	Vapour pressure(MMHG)	1 (817^{0}C)
4	Vapour density	AIR (1): 1.7
5	Specific gravity	1.6
6	Evaporation rate	N/A
7	Solubility(H_2O)	37%
8	Volatiles by volume	0 (21^{0}C)
9	pH	11.7 (25% solution)
10	Physical state	Solid

Among various reagent used in the beneficiation plant, NACN is used in froth flotation process for depressing sphalarite, pyrite and certain copper sulphide. Cyanide salts are widely used in the selective flotation of lead-copper-zinc and copper zinc ores. The sodium cyanide renders there substances hydrophilic (water avoid) and thus prevents their flotation.

Sodium cyanide solution contains 53.1% available cyanide. Due to the solidiphic nature of cyanide ions, most of them (about 85%) form complexes with Fe and Zn and are discharged along with tailings about 10% of the free cyanide go along with tailing solution to tailing dam and balance about 5% of cyanide goes along with concentrates. The present consumption of sodium cyanide in beneficiation process is about 10 g/tonnes of ore treatment. Depending on the quantum of ore processed by Zawar mine, the monthly consumption of NaCN is 1.2 tonnes/month.

As part of the expansion, about 3.3 tonnes per month of sodium cyanide would be required.

Sodium cyanide salts are transported through rail in mildsteel contains with HDPE liners. After the use, the empty containers and containers liners of cyanide salts are discarded as hazardous waste transported to treatment storage and disposal facility (TSDF) located at Udaipur. A comprehensive report on HCN emissions in Zawar mines was prepared by NEERI and details are as follows:

<u>Tailing Disposal</u>

The final tailings from beneficiation process are pumped to tailing dam, which is situated at about 3.5 km away from plant through pipe lines. In the tailing dam, the water gets separated from the tailings and is recycled back to the process.

Present status of Generation of Cyanide Containers and liners: As mentioned earlier, a combination of various floatation reagents are used during the ore beneficiation process for floatation and suppression of various components of the ore. The rote of these reagents is to bring about changes in the surface properties of minerals over a wide range. The flotation reagent varies widely. In composition and include organic and inorganic compounds, acids and alkaline, salts of various compositions, water soluble substances and material which are practically insoluble in water.

Among various reagents used by HZL, sodium cyanide (NaCN) is used in froth flotation process for depressing sphalerite, pyrite and certain copper sulphide. Cyanides salts are widely used in the selective flotation of lead, copper and zinc. The sodium cyanide renders these substances hydrophilic (water avid) and thus prevents their flotation.

The sodium cyanide used by Zawar Mine is received in MS containers which are lined with HDPE liners. Once the entire quantity of cyanide is exhausted from the containers, the empty containers and HDPE liners which are contaminated with residue/traces of sodium cyanide are discarded as wastes. Present rate of generation of empty sodium cyanide containers and liners is about 10 to 12 containers/Month. The total weight of each drum with accessories (lid, gasket, nuts and bolts) ranges from 8.0 to 8.5 Kgs.

Present Status of Management of Cyanide Containers and Liners

The present practice of management of cyanide drum (with accessories) and liners involve three major steps. These include i) water rinsing ii) alkaline chlorination iii) deformation and disposal.

Water Rinsing

In the first step, the empty containers, HDPE liners, lids, gaskets, circlips, nuts and bolts are washed thoroughly with water in a concrete tank. The pH of water is 7.8 to 8.5. The washing operations are carried out manually by the trained workers wearing personal protective equipments. The wash-water from this operation is recycled to process for utilization of cyanide content. The washed containers and the accessories are taken out from the tank and kept by the side of concrete tank for next step of treatment.

Alkaline Chlorination

The second step involves alkaline chlorination of cyanide. The traces of cyanide remaining in the containers and the accessories after the first step of treatment are destroyed during alkaline chlorination. Alkaline chlorination is the most widely used cyanide (inorganic) destruction method. The process normally uses free chlorine at high-pH conditions to chemically destroy free cyanide and dissociable cyanide complexes, producing reaction products such as chlorides, carbon dioxide and nitrogen.

During this step, the tank is again filled with water. About 5 to 7% sodium hypochlorite is added to the tank and a solution is prepared by manual stirring. The washed containers, components and liners are then again immersed manually in sodium hypochlorite solution. This operation is carried out to ensure destruction of residual cyanide, if any, remaining after stage 1. The containers and accessories are immersed in the hypochlorite solution for 2-3 hrs. The pH of the solution is maintained at 9.5 to 10. The hypochlorite ions react with cyanide and convert it to carbon dioxide and nitrogen gas.

After completion of decontamination process, entire hypochlorite solution is drained out and pumped back to thickener from where it is pumped to mill overhead tank for recycling in process. Before disposal, containers and accessories are again rinsed with water and the rinse water is recycled to the process for reuse.

Deformation and Disposal

In the third stage, the decontaminated containers and liners are perforated at bottoms and sides and distorted in a safe enclosure so as to prevent reuse of containers and liners. The perforated and distorted containers, components and liners are finally disposed off at a hazardous wastes treatment storage and disposal facility (TSDF) being.

Monitoring of HCN Emissions during Decontamination Process

As apprehended by HZL, the monitoring of HCN emissions were carried out by NEERI team during the process of decontamination of empty cyanide containers and liners. During the monitoring studies, the air emissions at the surface of decontamination tank were captured through a vacuum pump and bubbled through a series of midget impingers containing 1 N sodium hydroxide solution.

During each measurement about 30 liter (@ 2LPM for 15 min) of air was sampled. After the required quantity of air was sampled for each measurement, the midget Impingers were disconnected and the NaOH solution was transferred to conical flasks for analysis. The air samples were taken at various stages of decontamination process. The cyanide in the NaOH solution was analyzed by titration using silver nitrate as titrant and p-dimethyl amino benzalrhodamine as indicator *(Standard Methods for the Examination of Waters and Wastewater, APHA-AWWA-WEF; 2Oth Edition, Washington DC,* 1998}.

It may be observed from Table-7.2 that none of the air samples indicated presence of HCN. This could possibly be due to very high solubility of sodium cyanide in water. Moreover, all the decontamination operations are carried at room temperatures, and at alkaline pH, which inhibits the release of HCN to vapour phase.

Observation, Conclusions and Recommendations

a) Based on the detailed reconnaissance survey and the data/information collected by the NEERI team, it was observed that present quantum of generation of empty cyanide containers and drum liners (10-12 drum/ month) is not significant.

b) The present practice of management of empty cyanide containers and drum liners involve water rinsing for recovering the cyanide followed by alkaline chlorination to destroy the traces of cyanide remaining, if any.

c) In order to evaluate most appropriate technology for treatment of empty cyanide containers and container liners at Zawar Mine. A detailed literature review was carried out with respect to various cyanide treatment processes. Based on this review, it was observed that cyanide treatment processes are classified as either a destruction based processes or a recovery based process. In a destruction process, either chemical or biological reactions are utilized to convert cyanide into another less toxic compounds. Recovery processes utilize a recycling approach in which cyanide is removed from the solution or slurry and then re-used in a metallurgical circuit.

d) There are several treatment processes that are well proven for wastes with low levels of cyanide. These include SO_2, air, Hydrogen Peroxide, Caro's Acid, Alkaline Chlorination, Iron Precipitation, Activated Carbon, Biological, Cyanide Recovery, Reverse Osmosis, and Natural Attenuation (Natural Degradation). The treatment method adopted at Zawar Mine, is therefore, a combination of cyanide recovery (water rinsing) and cyanide destruction process (alkaline chlorination).

e) Among various treatment options available for destruction of cyanide, the alkaline chlorination is a well proven and most widely practiced method for treatment of cyanide. The process normally uses gaseous or liquid chlorine at high-pH conditions to chemically destroy free cyanide and dissociable cyanide complexes producing reaction products such as chlorides, carbonates and hydroxides.

ii) The existing tank of 9 m^3 capacity may be divided in two chambers of equal capacity by providing a partition. The first chamber may be used for the water rinsing operation and the second chamber may be used for the alkaline chlorination. The reduction in the capacity of the existing tank will ensure better control of various parameters (viz. pH, free chlorine) during the decontamination process. This will also help in reducing the sodium hypochlorite consumption thus making the process more economical.

iii) In order to improve the mixing of chlorine ion with cyanide and the intermediate reaction products, a mechanical agitator as against the existing manual agitation may be provided in the above mentioned two chambers.

iv) Since pH and free chlorine concentrations are the two important factors responsible for cyanide destruction, these need to be continuously monitored and maintained during the decontamination process so as to ensure proper destruction of cyanide.

v) Depending on the concentration of cyanide remaining in the containers and the requirement of chlorine for oxidation of various intermediate compounds formed during decontamination process, actual requirement of sodium hypochlorite should be worked out.

v) In case of any upset conditions during decontamination process and to make the process full proof in terms of cyanide emissions, it is recommended to provide a movable vent hood that may be positioned over the rinsing and chlorination tank for capturing cyanide emissions, if any, due to upset conditions. The exhaust from the hood may be scrubbed with caustic solution for capturing cyanide emissions if, any.