IARJSET ISSN (O) 2393-8021, ISSN (P) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

ISO 3297:2007 Certified ⁜ Impact Factor 7.105 ⁜ Vol. 9, Issue 5, May 2022

DOI: 10.17148/IARJSET.2022.9571

LAYER OF PROTECTION ANALYSIS OF CHLORINE STORAGE AND FILLING TANK AT TRAVANCORE COCHIN CHEMICALS, ELOOR

Mathew Thomas[1], P. Nithiyanand[2], S. Saravanakumar[3], B. Surender[4]

Student, Department of Industrial Safety Engineering, Excel College of Engineering and Technology,

Tamil Nadu, India

2Assistant Professor, Department of mechanical Engineering, Excel Engineering College, Tamilnadu, India.

3Assistant Professor, Department of Safety and Fire Engineering, Excel Engineering College, Tamilnadu, India.

4Assistant Professor, Department of Safety and Fire Engineering, Excel Engineering College, Tamilnadu, India.

Abstract: For a chemical industry, risk associated with chemical processes is very high. Impact of those disasters is not limited to those industries alone. So, it is very necessary to evaluate the risk associated with the same. LOPA is semi quantitative methodology, which can be used to find out the risk of various processes in an industry. Our goal was to calculate the risk associated with the CHLORINE filling and storage tank and suggest some additional mitigation, if required

Chlorine is a toxic gas and can cause severe damages to human, aquatic, and animal life in the case of leakage. Splashes of liquid chlorine on the eyes and skin can lead to immediate irritation, chemical burns, and serious damage to the body tissues. Chlorine gas leaks are not uncommon in chlorine manufacturing industries while processing, handling, storing, and transporting, especially storing large quantities in big containers.

For completing this project, we have visited TRAVANCORE COCHIN CHEMICALS, Eloor and we got to know various safety systems associated with CHLORINE storage and filling station. Discussions were made with the experts from safety field and have clarified our doubts associated with the same. We referred some books regarding the LOPA technique from which we got valuable knowledge to complete the project.

After completing this project, we understood that the effect of this scenario is not only limited to the safety of an asset or safety of human being but also the impact of the same to the environment is very high. After evaluating the risk associated, we were successful to give out possible risk reduction methods required to minimize the impact to human being, assets and environment.

Keywords: Layer of protection, Brine purification, Chlorine storage, LOPA, IPLS

1.INTRODUCTION

The project deals with the conduction of layer of protection analysis of chlorine storage and filling station at TCC. TCC is one of the MAH industries in Kerala. The chlorine found to be hazards by the data's obtained from the safety audit.Thehazop study is also done as part of PHA for this project.

The Travancore Cochin Chemicals Ltd. situated in the Udyogamandal industrial belt of Kerala is a state public sector industrial unit producing basic chemicals catering to the needs of vital industries like pulp and paper, textiles rayon, soaps and detergents, insecticides etc. The vital importance of T.C.C in the industrial field of Kerala is evident from the fact that almost all the chemical industries in the state are the consumers of various products of the company.The main products of T.C.C and the present capacities are given below:

Products	**Annual Capacity (M.T)**
1.Caustic soda lye	57750
2.Caustic soda flakes	30000
3.Liquid chlorine	23760

4.Hydrochloric acid	39600
5.Sodium hypochlorite	15000

Table1

Incorporated in 1951 through the pioneering efforts of M/s. Seshasayee Brothers, the company went into commercial production in 1954 to become the first unit in the country producing rayon grade caustic soda. The production capacity was 6600M.T/yr. M/s. Seshasayee Brothers were the managing agents for the company until 1960, when the state govt. took over the management of the company. Thereafter, it was period of rapid expansion for the company till 1967 when the capacity reached 33000M.T/yr in 3 stages. The 4th stage expansion in 1975 added another new plant of 33000M.T capacity and the oldest plant of 6600M.T capacity was decommissioned. But soon the company went into trouble because of the delay in developing the market for the additional capacity.

By modernizing the plants and aggressive marketing and by professionalizing the organization the company was brought back to profit. Thus the 80’s and 90’s were a period of continuous improvement in profitability and productivity for the company. By mid-90’s, the company started the next phase of modernization and technology up gradation by changing over to environment friendly membrane cell technology. In 1997, the first membrane cell plant was commissioned and the old mercury cells of the 60’s were decommissioned. But the prolonged power cut that followed and also a steep hike in power cost during this period put the company into trouble again. Coupled with this, there was a general industrial stagnation throughout the country during the late nineties. The result was another period of acute sickness for the company. Because of the timely intervention by the state government with a package that consisted of various cost cutting measures, restricting of the work force with a 40% reduction in strength, and other productivity enhancement measures, another turnaround was made possible. The mercury cell plant was stopped completely and the membrane cell plant capacity wasincreased in steps to regain the lost capacity.

A plant of capacity 25MT/Day was addedin 2005. Another plant of same capacity added in 2006. The new product with brand name EKO CLEAN a new sanitary product being intro introduced to domestic market by the company recently. The company is operating profitability and is poised for further expansion /diversification programs. As part of all round quality improvement, the company secured certification of ISO 9001:2000 quality management systems. The company also got National award for Energy conservation in the chlor-alkali sector in the year 2005. The company achieved the highest turnover of Rs.142 crores during 2006-07 and company has been generating profitability for the last three years.

2.PROCESS DESCRIPTION AND PRODUCTS

Salt is dissolved in water to bring up the concentration to 310gpl. Chemicals are added with air agitation to precipitate the calcium, magnesium, and sulphates which are harmful to the electrolysis process and the Membrane. (Barium carbonate for Sulphate removal, Sodium carbonate for the calcium removal with air agitation for the proper mixing, and Caustic soda for Magnesium removal.) The precipitated impurities are removed in two steps, by settling (Clarifier) and filtration. The brine is again passed through Ion-Exchange Tower to bring down the concentration of impurities Magnesium 15ppb level. Ultra-pure brine is fed to the anode compartment of the Electrolyser and De-mineralized Water to the Cathode side. On electrolysis, we get Chlorine and Depleted from the Anode compartment and Caustic Soda and Hydrogen from the Cathode compartment of the Electrolyser. Depleted brine after De-chlorination is returned to the saturator for Re-saturation with fresh Sodium Chloride to bring up the concentration to 310gpl. As above the process continues in cyclic manner. Chlorine coming out at a temperature of 850C is cooled with cooling water Titanium cooler, to bring down the temperature to 500C. (The condensate collected is recycled to brine system.) Chlorine is further cooled to 32°C in the second stage cooler and filtered in Candle Filter (water spray at inlet of filter) to remove any salt carry over in the stream. The Chlorine coming out is divided in to two streams. One stream goes to Chlorine liquefaction and the other to HCl plant for production of hydrochloric acid.

The brine purification process consists of a primary system and an additional secondary purification system. This operation is needed to avoid any undesirable components (sulphate anions, cations of Ca, Mg, Ba and metals) that can affect the electrolytic process.

The initial stage of purification uses sodium carbonate and sodium hydroxide to precipitate calcium and magnesium ions as calcium carbonate (CaCO3) and magnesium hydroxide (Mg (OH)2). Metals (iron, titanium, molybdenum, nickel, chromium, vanadium, tungsten) may also precipitate as hydroxide during this operation. Sodium sulphate is controlled by adding barium Carbonate to remove sulphate anions by precipitation as barium sulphate (BaSO4).

Precipitation of barium sulphate can take place simultaneously with the precipitation of calcium carbonate and magnesium hydroxide.

The precipitated impurities are removed by sedimentation in a clarifier followed by filtration using anthracite filter.
Thepurified brine should contain ideally: -
Ca: <2 mg/l
Mg: <1 mg/l
SO4: <6 g/l

To maintain the high performance of the ion-exchange membrane, the feed brine must be purified to a greater degree. The precipitation step alone is not enough to reduce the levels of calcium and magnesium and additional softening using ion exchange process is required. The ion exchange chelating resin treatment is designed to decrease the alkaline earth metals to ppb level. The resin is periodically regenerated with high purity hydrochloric acid and sodium hydroxide solutions. Generally, one resin exchange column is in operation while another resin exchange column is regenerated.

Membrane systems operate with brine recirculation and desaturation. The depleted brine leaving the electrolysers is first dechlorinated. For the membrane process, there is a preliminary stage of hydrochloric acid addition (to reach pH 2-2.5) in order to achieve better chlorine extraction. The acidic brine is sent to an air blown packed column to extract the major part of the dissolved chlorine, followed by chemical dechlorination using sodium bisulphate. The pH of the dechlorinated brine is then brought to an alkaline value of 8~ 9 pH with caustic soda, to reduce the solubilisation of impurities from the salt. Depleted brine, with a concentration of 210±10 g/l, is re-saturated by contact with solid salt to achieve a saturated brine concentration of 300-310 g/l. The pH of the brine sent to the electrolysers may be adjusted to a pH of 8 ~ 9 with hydrochloric acid in order to protect the anode coating, to keep the formation of chlorate at a low level and to decrease the oxygen content in the chlorine gas.

In electrolysis section saturated sodium chloride brine solution is fed to electrolysers in which the cathode and anode are separated by ion exchange membrane. Brine solution flows through the anode compartment where chloride ions are oxidized to chlorine gas. The sodium ions migrate through the membrane to the cathode compartment, which contains flowing caustic soda solution. The demineralized water added to the catholyte circuit is hydrolysed, releasing hydrogen gas and hydroxide ions. The sodium and hydroxide ions combine to produce caustic soda, which is typically brought to a concentration of 32±0.5% by re-circulating the solution before it is discharged from the cell. Depleted brine is discharged from the anode compartment and resaturated with salt, after dechlorination.

Generally, before the chlorine can be used, it goes through a series of processes for cooling, cleaning, drying, compression and liquefaction. The Chlorine treatment process usually takes hot and wet cell gas and convert it to a cold, dry gas. Chlorine gas leaving the electrolysers is at approximately 80°C and saturated with water vapor. It also contains brine mist, impurities such as N2, H2, O2 and CO2. Electrolysers are operated at essentially atmospheric pressure with only a few milli-atmospheres differential pressure between the anolyte and the catholyte.

In the primary cooling process, the total volume of gas to be handled is reduced and a large amount of moisture is condensed. Cooling isaccomplished in two stages, with cooling water in the first stages and with chilled water in thesecond stage.Care is taken to avoid excessive cooling because, at around 10oC, chlorine can combine with eater to form a solid material known as chlorine hydrate. Maintaining temperatures above 10oC prevents blockages in process equipment. Chlorine is then passed to the drying towers

Chlorine from the cooling system is more or less saturated with water vapor. The water content is typically 1-3 %. This must be reduced in order to avoid downstream corrosion and minimize the formation of hydrates. Drying of chlorine is carried out almost exclusively with concentrated sulphuric acid. Drying is accomplished in counter-current sulphuric acid contact towers, which reduce the moisture content to less than 20ppm. Dry chlorine leaving the top of the drying towerpasses through high efficiency demisters to prevent the entrainment of sulphuric acid droplets. The spent acid usually becomes a waste product.

After drying, chlorine gas is compressed in Sulphuric acid liquid ring compressors at low pressures (~ 3 bars).

Chlorine is further cooled to 18°C to reduce water and NaCl carry over before passing through drying tower where, sulphuric acid flows counter to the chlorine stream. The moisture content is brought down to less than 150ppm. Dried chlorine is compressed in sulphuric acid ring compressor to a pressure of 2 to 3 kg/cm² and cooled to 0 to minus 10°C in chlorine liquefier with Freon refrigeration to produce Liquid Chlorine. Liquid Chlorine is stored in Carbon steel tanks from where it is pumped out with compressed air to be filled in Chlorine Tonner's. The uncondensed chlorine along with non-condensable gases is sent to the HCl synthesis unit for HCl acid production.

Chlorine for HCl acid production is drawn by the chlorine blower to be delivered to the three HCl synthesis units at a pressure of 1800 to 2000mm WC. Hydrogen from Electrolyser is cooled in plate heat exchanger and goes to the hydrogen holder. A blower draws the hydrogen from the holder and delivers it to the HCl synthesis unit at a pressure of 2000mm WC. Hydrogen and Chlorine burns together to give hydrogen chlorine gas, which is absorbed in water to give 30% HCl acid. Cooling water keeps the system temperature for this exothermic reaction within limits. Acids is collected in service tank and then pumped to main storages from where it is supplied to consumers.

Chlorine is reacted with sodium hydroxide solution of suitable strength to produce sodium hypochlorite solution of required composition. This is accomplished in chlorine absorption towers where chlorine comes in contact with caustic soda solution in counter current manner. There are two towers, which are put into service in series. This is to avoid accidental release of chlorine gas to atmosphere.

Waste Chlorine is reacted with lime solution to dispose of chlorine safely. This is accomplished in absorption towers made of concrete where chlorine comes in contact with lime solution in counter current manner. There are two towers, which are put into service in series to avoid any release of chlorine gas directly to atmosphere.

32% lye coming out from the electrolyser is received in service tank and then pumped to main storages after cooling or directly to Caustic Concentration plant for the production of 50% lye or Flake as per requirement. 32% caustic soda solution coming from the main storage is further concentrated to 50% in two stages using steam in caustic soda evaporators in order to make it a sealable product. A part of 50% liquor is further concentrated to 100% in a third evaporator where heattransfer salt at 400°C is used for boiling the liquor at atmospheric pressure. The heat transfer salt is re-circulated though the evaporator, which is heated to the desired temperature in a furnace, using furnace oil as fuel. The waste steam evolved from the third evaporator is utilized in the first evaporator operated at vacuum for concentrating the 32% lye. Molten caustic soda solution from the third evaporator is flaked in a flaking device and the product is packed in 50kg bags. 50% Lye: is obtained by two stages evaporation in evaporators. First in EV1 where vapours from final concentrator are reused as heating medium and the system works under vacuum (economizer); and then in EV2 where high pressure steam is used as heating medium. The production of flakes: 50% lye is further concentrated in EV3 where high temperature Heat Transfer Salt is the heating medium. HTS is heated to 4500- 4200 C by circulation through a furnace where Furnace oil/Hydrogen is fired. The caustic melt coming out at a temperature of about380°C is fed to the flaking machine. A thin layer cools down on the surface of the drum (Cooling Cylinder). It is scraped off during the rotation and collected in polythene bags on weighing scale.

The Boiler House consists of two numbers of flue tube, oil-fired, automatic, three pass horizontal package boilers with the following specifications

Boiler Name	**Type**	**Boiler No.**	**Registry No. of Boiler**
1.IAEC Siller Boiler	UN- 150 x 12 Kgs/cm2	IS 77	K 248
2.IAEC Siller Boiler	UN- 200 x 14 Kgs/cm2	IS 132	K 301

Table 2

Liquid chlorine is filled in Tonners (maximum capacity 900 Kg) and Cylinders (80 to 100 Kg) (tested every two years), both made of seamless carbon steel and provided with valves conforming to IS 3224 having complete brass body or alloy of aluminium-silicon bronze with Monel or S.S spindle and PTFE gland packing, using chlorine stored in the 4 Nos. of storage tanks (capacity 50 MT) in the chlorine filling station. The cylinder is provided with one valve while the tonner with two valves (protected by a hood) near its centre, each connected to an internal reduction pipe, one terminating in the gas phase (upwards) and the other in the liquid phase (downwards). Cylinder filling is affected by transferring chlorine from storage tanks kept pressurized to 10 Kg/cm2 with dry air to the cylinders/tonners maintained at low pressures.

The water supply system consists of a pumping station at the Edamula River side near Kalamassery Bridge, a Treatment Plant located near TCC Colony, clear water reservoir and pump house at factory site and pipe lines. The quality of water available from the Edamula River is generally within the acceptable limits with respect to the various parameters except for the pH; it is slightly in the acidic side. There is a seasonal variation in turbidity and salinity. The water treatment is mainly confined to the removal of turbidity, pH correction and sterilization consists of coagulation, sedimentation, filtration and chlorination. Salinity cannot be removed by conventional water treatment process. However, constructing salt intrusion barrier downstream the river during summer checks excessive increase in salinity.

3. LAYER OF PROTECTION ANALYSIS

A Chemical industry is obligated to provide and maintain a safe, working environment for their employees. Safety is provided through inherently safe design and various safeguards, such as instrumented systems, procedures, and training. The Layer of Protection Analysis (LOPA) method is a Process Hazard Analysis tool. This method is utilizing the hazardous events, event severity, initiating causes and initiating likelihood data developed during the Hazard and Operability analysis. The LOPA method allows the user to determine the risk associated with the various hazardous events by utilizing their severity and the likelihood of the events being initiated. Using corporate risk standards, the user can determine the total amount of risk reduction required and analyse the risk reduction that can be achieved from various layers of protection. If additional risk reduction is required after the reduction provided by process design, the basic process control system (BPCS), alarms and associated operator actions, pressure relief valves, etc., a Safety Instrumented Function (SIF) may be required.

The team identifies the safeguards used to mitigate the hazardous event. If the team determines that the safeguards are inadequate, the team will make recommendations for further risk reduction. The team is instructed to list all safeguards. The team often lists safeguards that only partially mitigate the process risk. The team also does not address whether the safeguards are independent from one another. This often results in the team assuming more risk reduction from the safeguards than is possible based on the integrity of the individual components.

Furthermore, a team’s perception of the integrity of a specific safeguard impacts the assumed risk reduction for that safeguard, resulting in inconsistency in the number of required safeguards for successful mitigation of the process risk. Unfortunately, the inconsistency can result in over- and under protected process risk, depending on the team composition.

Consequently, there must be an independent engineering assessment of the safeguards to ensure that adequate risk reduction is being provided.

In a typical chemical process, various protection layers are in place to lower
the frequency of undesired consequences: the process design (including inherently safer concepts); the basic process control system; safety instrumented systems; passive devices (such as dikes and blast walls); active devices (such as relief valves); human intervention; etc. There has been much discussion among project teams, hazard analysts, and management about the number of and strength of protection layers. Decisions were sometimes made using subjective arguments, emotional appeals, and occasionally simply by the loudness or persistence of an individual

In LOPA, the individual protection layers proposed or provided are analysed for their effectiveness. The combined effects of the protection layers are then compared against risk tolerance criteria.

The genesis of this method was suggested in two publications:
1.In the late 1980s, the then Chemical Manufacturers Association published the Responsible Care® Process Safety Code of Management Practices which included “sufficient layers of protection” as one of the recommended components of an effective process safety management system (American Chemistry Council, 2000). The Chemical Manufacturers Association is now the American Chemistry Council.
2. In 1993, CCPS published its Guidelines for Safe Automation of Chemical Processes (CCPS, 1993b). Although it was called the risk-based SIS integrity level method, LOPA was suggested as one method to determine the integrity level for safety instrumented functions (SIFs).

The initial development of LOPA was done internally within individual companies, in some cases focusing on existing processes, e.g., converting a control system to DCS. However, once a method had been developed and refined, several companies published papers describing the driving forces behind their efforts to develop the method, their experience with LOPA, and examples of its use. In particular, the papers and discussion among the attendees at the CCPS

International Conference and Workshop on Risk Analysis in Process Safety in Atlanta in October 1997 brought agreement that a book describing the LOPA method should be developed.

In parallel with these efforts, discussions took place on the requirements for the design of safety instrumented functions (SIF) to provide the required PFDs (probability of failure on demand). United States and international standards (IEC 61508, (IEC, 1998) and IEC 61511, (IEC, 2001)) described the architecture and design features of SIFs. Informative sections of the IEC standards suggested methods to determine the required SIL (safety integrity level), but LOPA was not mentioned until the draft of IEC 61511, Part 3 appeared in late 1999.

In response to all this activity, CCPS assembled in 1998 a team from A. D.Little, ARCO Chemical, Dow Chemical, DuPont, Factory Mutual, ABS Consulting, International Specialty Products, Proctor and Gamble (P&G), Rhodia, Rohm and Haas, Shell , and Union Carbide to tabulate and present industry practice for LOPAin this book.
This book extends the method outlined in Safe Automation of Chemical Processes (CCPS, 1993b) by

- developing concepts and definitions for use throughout industry,
- showing how numerical risk tolerance criteria have been developed by different companies,
- defining the requirements for a safeguard to be considered an independent protection layer (IPL),
- demonstrating how LOPA can be used for purposes other than the classification of SIF systems, and
- recommending documentation procedures to ensure consistency of application within an organization.

While the LOPA methods used by various companies differ, they share the following common features:

- a consequence classification method that can be applied throughout the organization;
- a method for developing scenarios;
- specific rules for considering safeguards as IPLs;
- specified default data for initiating event frequencies and values for IPLs;
- a specified procedure for performing the required calculations; and
- a specified procedure for determining whether the risk associated with a scenario meets the risk tolerance criteria for an organization and, if it does not, how this is resolved and documented.

Every piece of hardware may fail at one time or another. Failure requires repair or replacement. However, control and safety functions provided within the same hardware show that system failures and repair leave the process unprotected, which is unacceptable in most operations. There's also the need to spread risk. Like financial investors who diversify their investments, designers and operators of control and safety systems need to prevent one system's failure from causing devastating effects. Broadly speaking, risks can be classified into 3 categories:

- Negligible risks - risks broadly accepted by most people as they go about their everyday lives.
- Tolerable risk - we would rather not have the risk but it is tolerable in view of thebenefits obtained by accepting it.
- Unacceptable risk - the risk level is so high that we are not prepared to tolerate it. The losses far outweigh any possible benefits in the situation.

There is no single method that can totally eliminate all risks. Therefore, several methods must be implemented to reduce the risk of an accident. The concept of protection layers applies to the use of a number of safety measures all designed to reduce risk by reducing either the likelihood of potential incidents resulting in an impact on people, environment or property, or by reducing the magnitude of the impact should an incident occur. Multiple, Independent protection layers (IPL), also known as the "defense-in-depth" approach, generally consists of the following independent layers

- process design
- process control system
- critical alarms and operatorsupervision/response
- automatic shutdown and interlocks (SIS)
- physical protection (e.g., pressure relief valve, containment)
- plant emergency response (e.g.,firefighting)
- community emergency response (e.g., notification, evacuation)

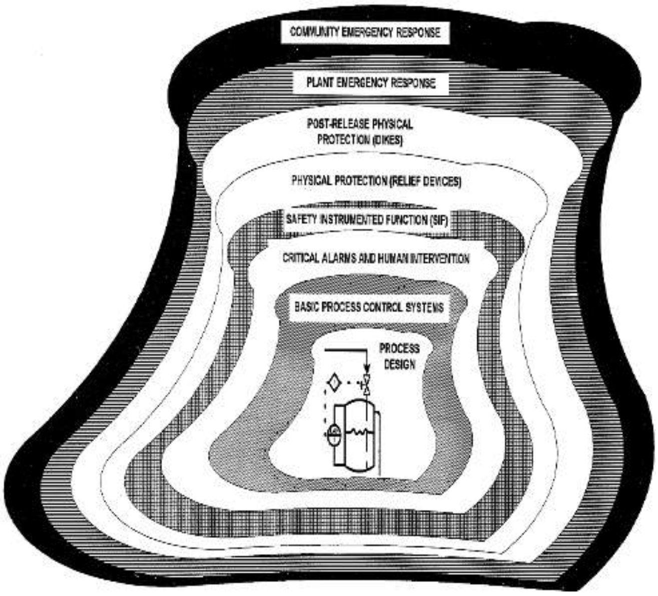


Fig.1 Layers of protection

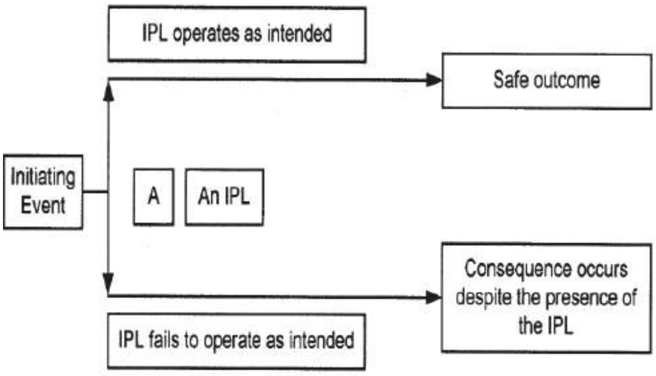


Fig.2 Event tree showing effect of IPL success or failure when demanded

In many companies, it is assumed that some scenarios cannot occur because of the inherently safer design of the process equipment. For example, the equipment might be designed to withstand the maximum pressure for a particular scenario, batch size might be limited, inventory lowered, chemistry modified, etc.; i.e., scenarios are eliminated by the inherently safer design. In other companies, some inherently safer process design features are considered to have a nonzero PFD—that is, they do have possible failure modes that have been observed in industry. These companies consider such Inherently safer process design features as IPLs. The design of the IPL is intended to prevent the consequence from occurring. For example, a pump may have an impeller that is too small to generate high pressure in a downstream vessel. The latter approach allows a company to compare the risk between plants designed using different equipment standards; the analysis can result in different failure rates for similar pieces of equipment which in turn might require additional IPLs for the equipment with higher failure rates. The LOPA analyst should be aware that inherently safer process design features may have a PFD and appropriate inspection and maintenance (auditing might be required (e.g., a small impeller may be replaced with a larger impeller during repair or maintenance, batch size may be changed, etc.). Whether process design should be credited as an IPL, or considered as a method of eliminating a scenario, depends upon the method employed within a particular organization.

The Basic Process Control System (BPCS) is responsible for normal operation of the plant and in many instances is used in the first layer of protection against unsafe conditions. Normally if the BPCS fails to maintain control, alarms will notify operations that human intervention is needed to re-establish control within the specified limits. If the operator is unsuccessful then other layers of protection, e.g., pressure safety valves, inherently safe process design, or Safety Instrumented System need to be in place to bring the process to a safe state and mitigate any hazards.

These systems are the second level of protection during normal operation and should be activated by the BPCS.

Operator action, initiated by alarms or observation, can be credited as an IPL when various criteria are satisfied to assure the effectiveness of the action. Company procedures and training may improve the performance of humans.

A Safety Instrumented System (SIS**)** consists of an engineered set of hardware and software controls which are especially used on critical process systems. A critical process system can be identified as one which, once running and an operational problem occurs, the system may need to be put into a "Safe State" to avoid adverse Safety, Health and Environmental (SH&E) consequences. Examples of critical processes have been common since the beginning of the Industrial Age. One of the more well-known critical processes is the operation of a steam boiler. Critical parts of the process would include the lighting of the burners, controlling the level of water in the drum and controlling the steam pressure. SIS functionality is not compromised. SIS is composed of the same types of control elements (including sensors logic solvers, actuators and other control equipment as a Basic Process Control System (BPCS). However, all of the control elements in an SIS are dedicated solely to the proper functioning of the SIS.
The specific control functions performed by an SIS are called Safety InstrumentedFunctions (SIF). They are implemented as part of an overall risk reduction strategy which is intended to eliminate the likelihood of a, previously identified, SH&E event that could range from minor equipment damage up to an event involving an uncontrolled catastrophic release of energy and/or materials.
Safety instrumented systems are most often used in process (i.e., refineries, chemical, nuclear, etc.) facilities to provide protection such as:

- High fuel gas pressure initiates action to close the main fuel gas valve.
- High reactor temperature initiates action to open cooling media valve.
- High distillation column pressure initiates action to open a pressure vent valve.

These devices, when appropriately sized, designed and maintained, are IPLs which can provide a high degree of protection against overpressure in clean services. However, their effectiveness can be impaired in fouling or corrosive services, if block valves are installed under the relief valves, or if the inspection and maintenance activities are of poor quality. If the flow from the relief valves is discharged to the atmosphere, additional consequences may occur which will require examination. This could involve the examination of the effectiveness of flares, quench tanks, scrubbers, etc.

These IPLs are passive devices which provide a high level of protection if designed and maintained correctly. Although their failure rates are low, possibility of failure should be included in the scenarios. Also, if automatic deluge systems, foam systems, or gas detection systems, etc., meet the requirements of IPLs, then some credit can be taken for these devices in specific scenarios.

These features (fire brigade, manual deluge systems, facility evacuation, etc.) are not normally considered as IPLs since they are activated after the initial release and there are too many variables (e.g., time delays) affecting their overall effectiveness in mitigating a scenario.

These measures, which include community evacuation and shelter-in-place, are not normally considered as IPLs since they are activated after the initial release and there are too many variables affecting their effectiveness in mitigating a scenario. They provide no protection for plant personnel.

Each protection layer consists of a grouping of equipment and/or administrative controls that function in concert with other protective layers to control or mitigate process risk. An independent protection layer should:

- reduces the identified risk by at least a factor of 10
- have high availability
- designed for a specific event
- independent of other protection layers
- dependable and auditable

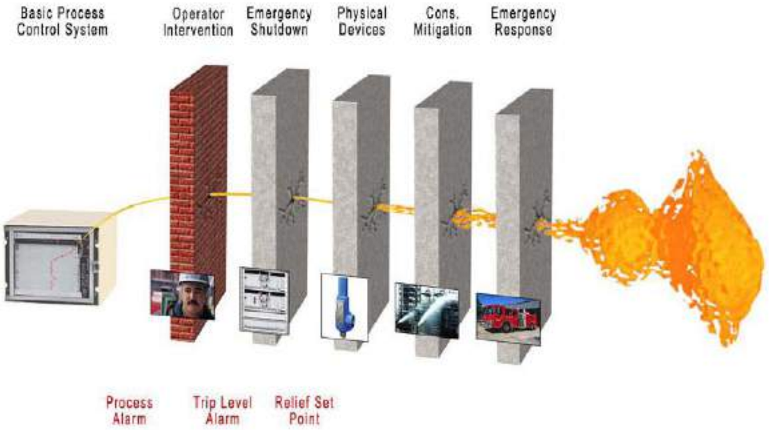


Fig.3 Process of protection by each layer

For an accident to occur, each safety layer must fail simultaneously. So the more layers present, the higher the probability they all will not fail simultaneously. In other words, the risk can be reduced to very low levels by providing a sufficient number of protection layers, and by making each layer highly reliable.

Each protection layer consists of a grouping of equipment and/or administrative controls that function in concert with the other layers. Protection layers that perform their function with a high degree of reliability may qualify as Independent Protection Layers (IPL). The criteria to qualify protection Layer (PL) as an IPL are:

- The protection provided reduces the identified risk by a large amount, that is, a minimum of a 10-fold reduction.
- The protective function is provided with a high degree of availability (90% or greater.

It has the following important characteristics:

a) Specificity: An IPL is designed solely to prevent or to mitigate the consequences of one potentially hazardous event (e.g., a runaway reaction, release of toxic material, or a fire). Multiple causes may lead to the same hazardous event; and, therefore, multiple event scenarios may initiate action of one IPL.

b) Independence: An IPL must be independent of all the other protection layers associated with the identified potentially hazardous event, the performance must not be affected by the failure of another protection layer, or by the conditions that caused another protection to fail. Most importantly, the protection layer is independent of the initiation cause.

c) Dependability: It can be counted on to do what it was designed to do. Both random and systematic failures modes are addressed in the design.

d) Auditability: It is designed to facilitate regular validation of the protective functions. Proof testing and maintenance of the safety system is necessary.

Only those protection layers that meet the tests of availability, specificity, independence, dependability, and auditability are classified as Independent Protection Layers.

Process design to reduce the likelihood of an Impact Event from occurring, when an Initiating Cause occurs. An example of this would be a jacketed pipeline or vessel. This jacket would prevent the release of process material if the vessel is compromised.

The next item is the Basic Process Control System (BPCS). If a control loop in the BPCS prevents the impacted event from occurring when the Initiating Cause occurs, credit is given based on its PFD avg. The last item credit for alarms that alert theoperator and utilize operator intervention. Typical protection layer PFD average values are listed in table.

The LOPA described here is a method that can be applied to an existing plant by a multi-disciplined team to determine the required safety instrumented functions and the SIL for each. The team should consist of:

- Operator with experience operating the process under consideration
- Engineer with expertise in the process
- Manufacturing management
- Process Control Engineer
- Instrument/Electrical maintenance person with experience in the process under consideration
- Risk analysis specialist

At least one person on the team should be trained in the LOPA methodology. The information required for the LOPA is contained in the data collected and developed in the Hazard and Operability analysis (HAZOP).

LOPA is a risk quantification method normally used when the process is too complete or used at any point of the life cycle or process and is a cost-effective method when implemented during the front-end loading when probability of failure on demand (PFD) are complete and process and instrumentation diagram are under development. For an existing process, LOPA should be used during or after hazard identification and operability study (HAZOP) review or any other hazard identification method like preliminary hazard analysis or HAZAN (Hazard).

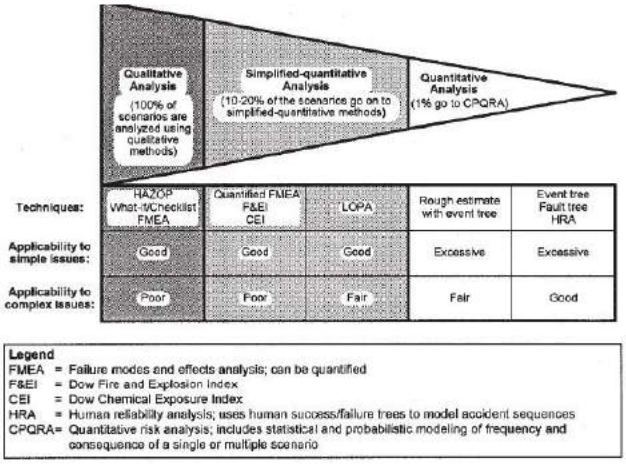
LOPA is typically applied after qualitative hazards analysis has been completed, which provides the LOPA team with a listing of hazard scenarios with associated consequence description and potential safeguards for consideration. A LOPA program is most successful when the procedure is well developed for which LOPA is used. For LOPA to be used, getting the scenario frequency from the industry is necessary ie, the release of lpg causing an emergency situation has occurred how many times is the basis on which the calculation of initiating event frequency. Then with the help of the probability of failure on demand value, we can estimate the total risk due to fire. Probability of failure on demand (PFD) is the probability of dangerous failure of an instrument. PFD depends on failure rate, failure mode & test interval. The development of these criteria takes time, but this cost is rapidly offset by the increased speed at which LOPA can be implemented on specific projects.

LOPA can also be applied when a hazard evaluation team (or other entity):

- Believes a scenario is too complex for the team to make a reasonable risk judgment using purely qualitative judgment, or
- The consequences are too severe to rely solely on qualitative risk judgment. The hazard evaluation team may judge the “scenario as too complex” if they do not understand the initiating event well enough,
- do not understand the sequence of events well enough, or
- do not understand whether safeguards are truly IPLs.

LOPA can also be used as a screening tool prior to a more rigorous quantitative risk assessment (CPQRA) method. When used as a screening tool, each scenario above a specified consequence or risk level will first go through LOPA analysis, and then certain scenarios will be targeted for a higher level of risk assessment. The decision to proceed to CPQRA is typically based on the risk level determined by LOPA or based on the opinion of the LOPA analyst (i.e., the scenario is too critical or complex to rely on LOPA for risk assessment). Figure below shows the spectrum of risk assessment tools: from purely qualitative to rigorous application of quantitative methods. At the far left are qualitative tools; these are typically used to identify the scenarios and qualitatively the risk is tolerable. In the middle are semi-quantitative tools (or simplified quantitative tools); these include LOPA and are used to provide an order-of-magnitude estimate of risk. Finally at the far right are quantitative tools; these allow analysis of more complex scenarios and provide risk estimates for comparison and risk judgment. The percentages are for illustration purposes only. Typically, all scenarios are identified and evaluated qualitatively, and some that are too onerous or complex proceed to semi quantitative risk assessment, and a few scenarios may need more rigorous evaluation than is than possible with LOPA.

Thus, LOPA can be applied to evaluate scenarios that are too complex or consequential for only qualitative review and LOPA can screen which scenarios need more quantitative scrutiny (which need to go beyond LOPA to CPQRA). Later chapters provide examples of how companies have incorporated LOPA into their risk assessment approaches. In general, the writers believe that if the analyst or team can make a reasonable risk decision using only qualitative methods, then LOPA may be overkill. However, LOPA can be much more efficient than qualitative methods for judging the sufficiency of IPLs; in a qualitative hazard review these decisions can quickly digress into shouting matches. LOPA should notbe used as a replacement for quantitative analysis. If complex human behaviour models or equipment failure models are required to understand the risk of a scenario, then quantitative analysis is more appropriate.



Techniques:	HAZOP What-if/Checklist FMEA	Quantified FMEA F&EI CEI	LOPA	Rough estimate with event tree	Event tree Fault tree HRA
Applicability to simple issues:	Good	Good	Good	Excessive	Excessive
Applicability to complex issues:	Poor	Poor	Fair	Fair	Good

Legend
FMEA = Failure modes and effects analysis; can be quantified
F&EI = Dow Fire and Explosion Index
CEI = Dow Chemical Exposure Index
HRA = Human reliability analysis; uses human success/failure trees to model accident sequences
CPQRA= Quantitative risk analysis; includes statistical and probabilistic modeling of frequency and consequence of a single or multiple scenario

Fig.4 Spectrum of Risk Assessment Tools

1. Each protection layer counted must be truly independent of the other protection layers. That is, there must be no failure that can deactivate two or more protection layers.
2. The frequency reduction for an IPL is two orders of magnitude, i.e., 10-2 PFD (that is, the availability is 99%).
- Exception: Risk reduction for Operator Response to Alarms is one order of magnitude, i.e., 10^{-1}.
- If an IPL is believed to be more reliable (lower value for PFD), a Quantitative method should be used to confirm the PFD. (For example, if the team desires to improve the unavailability of risk reduction logic in the BPCS (Basic Process Control System) by adding additional sensors or final elements, theimpact event should be reviewed by a quantitative method such as fault tree.)

3. The IPL is specifically designed to prevent or mitigate the consequences of a potentially hazardous event.
4. The IPL must be dependable; it can be counted on to do what it was intended to do.
5. The IPL will be designed so it can be audited and a system to audit and maintain it will be provided.
6. If the initiating event is caused by a failure in the Basic Process Control System (BPCS), the BPCS cannot be counted as an IPL.
7. Alarms that are annunciate on the BPCS are not independent of the BPCS; if the BPCS is counted as an IPL, then such alarms cannot be counted as an IPL.
8. A control loop (PID loop) in the BPCS whose normal action would compensate for the initiating event can be considered as an IPL. For example, an initiating cause for high reactor pressure could be failure of a local upstream pressure regulator; the normal action of the reactor pressure controller would be to close the inlet PV, thus providing protection against the impact event.

A well-developed procedure is needed to find out the risk involved in the LPG storage tank. The steps to be taken to carry out the process include:

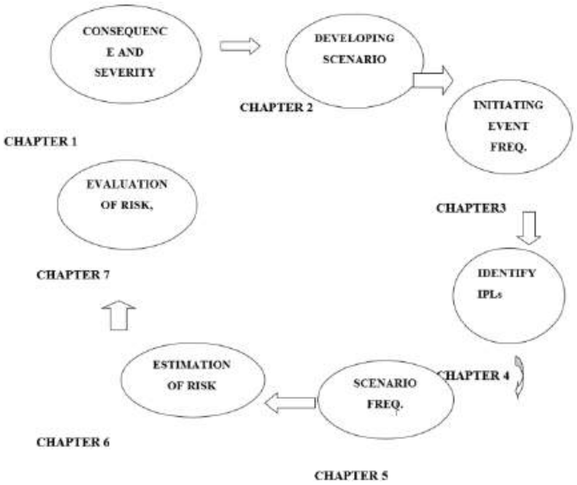


Fig.5 Steps of LOPA

Step 1: Identification of consequence to screen the scenarios
As LOPA evaluates typically the scenarios that have been developed in a prior study, a first step by the LOPA analyst is to screen these scenarios, and the most common screening method is based on consequence. The consequence is typically identified during a qualitative hazard review (such as a HAZOP study). HAZOP is a hazard identification technique to evaluate the consequence of an impact event and its possible failure modes. A typical HAZOP study is given in the Table. Some companies stop at the magnitude of a release (of material or energy), which implies,
but does not explicitly state, the impact to people, the environment, and the production system. Consequence class characteristics are classified in different ways from three levels to five levels as chosen by the study team members.

The basis for classification depends on local regulations and corporate safety and environment philosophy. Consequences are measured in terms of damage to people, property and environment. The extent of damage can be predicted by means of experimental values or simulated values available for the chemicals. The advantage of LOPA technique lies in the fact that it can be used even if no software simulation is available for quantification of consequences. To reduce the subjectivity, the guidelines for estimation of consequences have been developed by some experts based on the quantity of chemicals involved in the scenario. The guidelines suggested by Colin S. 'Chip' Howat Ph.D. are widely accepted for estimation purposes. Other companies will model the release and more explicitly estimate the risk to people, the environment, and production by accounting for the likelihood of harm resulting from a specific scenario, for instance by also accounting for the probability of operators being in harm's way during a release scenario.

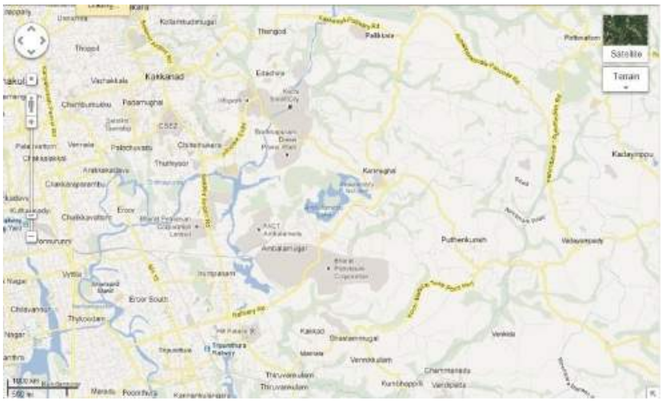


Fig.6 Consequence analysis result

Step 2: Select an accident scenario
LOPA is applied to one scenario at a time. Normally we select some scenario's which has the probability to cause highest consequence while doing LOPA. The scenario can come from other analyses (such as qualitative analyses), but the scenario describes a single cause–consequence pair (see Table). The severity level can be taken from Table

Impact Event Level	**Consequence**
Minor (M)	Impact initially limited to local area of event with potential for broader consequence, if corrective action not taken.
Serious (S)	Impact Event could cause any serious injury or fatality on site or off site
Extensive (E)	Impact Event that is five or more times severe than a Serious event.

Table 3 Impact Event Severity Levels

Step 3: Identify the initiating event of the scenario and determine the initiating event frequency (events per year)
The initiating event must lead to the consequence (given failure of all of the safeguards must be taken into account). The frequency must account for background aspects of the scenario, such as the frequency of the mode of operation for which the scenario is valid. The initiating likelihood can be taken from Table. Most companies provide guidance on estimating the frequency to achieve consistency in LOPA results. Chapter 3 provides guidance on selecting an appropriate initiating event and in determining a reasonable frequency in the context of the accident scenario being analysed. Table 3.4 provides various possible initiating event frequencies.

Low	A failure of failures with a very low probability of occurrence within the expected life time of the plant	$f<10^{-4}$, /year
Medium	A failure of failures with a very low probability of occurrence within the expected life time of the plant	$10^{-4}f<10^{-2}$, /year
High	A failure can be reasonably be expected to occur within the expected life time of the plant	$f<10^{-2}$, /year

Table 4 Initiation Likelihood

Initiating event	**Frequency Range from literature**	**Value chosen by the company for LOPA**
Pressure Vessel Residual Failure	10^{-5} to 10^{-7}	$1*10^{-6}$
Piping Residual Failure-100m-Full Breach	10^{-5} to 10^{-6}	$1*10^{-5}$
Piping Leak (10% Section)- 100m	10^{-2} to 10^{-4}	$1*10^{-2}$

DOI: 10.17148/IARJSET.2022.9571

Atmospheric Tank Failure	10^{-3} to 10^{-3}	$1*10^{-3}$
Gasket/Packing Blowout	10^{-2} to 10^{-6}	$1*10^{-2}$
Turbine/Diesel Engine Over-Speed with Casing Breach	10^{-3} to 10^{-4}	$1*10^{-4}$
3rd Party Intervention (External Impact by Backhoe, Vehicle)	10^{-2} to 10^{-4}	$1*10^{-2}$
Crane Load Drop	10^{-3} to 10^{-4}/Lift	$1*10^{-4}$/Lift
Lightning Strike	10^{-3} to 10^{-4}	$1*10^{-3}$
Safety Valve Opens Spuriously	10^{-2} to 10^{-4}	$1*10^{-2}$
Cooling Water Failure	1 to 10^{-2}	$1*10^{-1}$
Pump Failure	10^{-1} to 10^{-2}	$1*10^{-1}$
Unloading/Loading Hose Failure	1 to 10^{-2}	$1*10^{-1}$
BPCS Instrument Hose Failure	1 to 10^{-2}	$1*10^{-1}$
Regulator Failure	1 to 10^{-1}	$1*10^{-1}$
Small External Fire (Aggregate Causes)	10^{-1} to 10^{-2}	$1*10^{-1}$
Large External Fire (Aggregate Causes)	10^{-2} to 10^{-3}	$1*10^{-2}$
Lock Out Tag Out Procedure Failure	10^{-3} to $10^{4/}$ opportunity	$1*10^{-3}$
Operator Failure	10^{-1} to 10^{-3}/ opportunity	$1*10^{-2}$

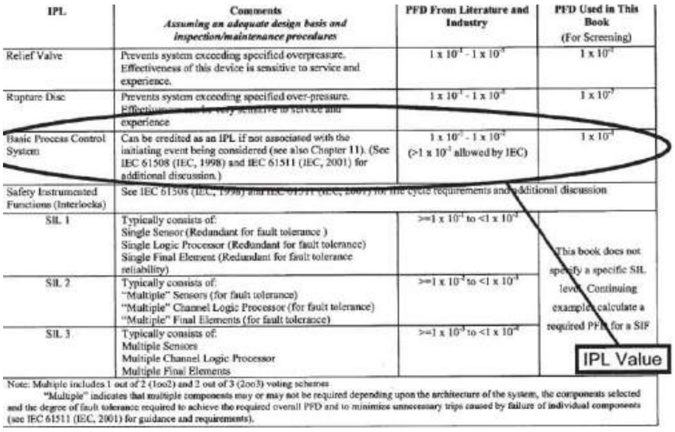
Table 5 Typical Frequency f^{-1} Assigned to Initiating Events

Step 4: Identify the IPLs and estimate the probability of failure on demand of each IPL.
Recall that LOPA is short for "layer of protection analysis." Some accident scenarios will require only one IPL, while other accident scenarios may require many IPLs, or IPLs of very low probability of failure on demand, to achieve a tolerable risk for the scenario. Recognizing the existing safeguards that meet the requirements of IPLs for a given scenario is the heart of LOPA. Most companies provide a predetermined set of IPL values for use by the analyst, so the analyst may pick the values that best fit the scenario being analysed. Chapter 4 provides the rules (requirements) that are applied to select existing IPLs and also describes how various companies estimate the effectiveness of existing and proposed IPLs

Table 6PFDs of various IPLs

INDEPENDENT PROTECTION & MITIGATION LAYERS	**PFD used**
Process design failure	**$1.0*10^{-1}$**
Alarms	**$2.0*10^{-1}$**
Valves	$2.0*10^{-1}$

Control loop	**1.0 x 10^{-1}**
Relief valve	1.0 x 10^{-2}
Human performance (trained, no stress)	1.0 x 10^{-2}
Deluge/Hydrants	**1.0*10-1**
Vulnerability	**10% of the day**
Human performance (under stress)	0.5 to 0.1
Operator Response to Alarms	1.0 x 10^{-1}
Restricted Access	1.0 x 10^{-1}
Occupancy	**5.0*10^{-1}**
Vessel pressure rating above maximum challenge from internal and external pressure sources	10^{-4} or better, if vessel integrity is maintained (i.e., corrosion understood, inspections and repairs in place)



IPL	Comments *Assuming an adequate design basis and inspection/maintenance procedures*	PFD From Literature and Industry	PFD Used in This Book (For Screening)
Relief Valve	Prevents system exceeding specified overpressure. Effectiveness of this device is sensitive to service and experience.	1 x 10^{-1} - 1 x 10^{-5}	1 x 10^{-2}
Rupture Disc	Prevents system exceeding specified over-pressure. Effectiveness can be very sensitive to service and experience	1 x 10^{-1} - 1 x 10^{-5}	1 x 10^{-2}
Basic Process Control System	Can be credited as an IPL if not associated with the initiating event being considered (see also Chapter 11). (See IEC 61508 (IEC, 1998) and IEC 61511 (IEC, 2001) for additional discussion.)	1 x 10^{-1} - 1 x 10^{-2} (>1 x 10^{-1} allowed by IEC)	1 x 10^{-1}
Safety Instrumented Functions (Interlocks)	See IEC 61508 (IEC, 1998) and IEC 61511 (IEC, 2001) for life cycle requirements and additional discussion		
SIL 1	Typically consists of: Single Sensor (Redundant for fault tolerance) Single Logic Processor (Redundant for fault tolerance) Single Final Element (Redundant for fault tolerance reliability)	>=1 x 10^{-2} to <1 x 10^{-1}	This book does not specify a specific SIL level. Continuing examples calculate a required PFD for a SIF
SIL 2	Typically consists of: "Multiple" Sensors (for fault tolerance) "Multiple" Channel Logic Processor (for fault tolerance) "Multiple" Final Elements (for fault tolerance)	>=1 x 10^{-3} to <1 x 10^{-2}	
SIL 3	Typically consists of: Multiple Sensors Multiple Channel Logic Processor Multiple Final Elements	>=1 x 10^{-4} to <1 x 10^{-3}	

Note: Multiple includes 1 out of 2 (1oo2) and 2 out of 3 (2oo3) voting schemes

"Multiple" indicates that multiple components may or may not be required depending upon the architecture of the system, the components selected and the degree of fault tolerance required to achieve the required overall PFD and to minimize unnecessary trips caused by failure of individual components (see IEC 61511 (IEC, 2001) for guidance and requirements).

Figure 7: Choosing IPL values

Step 5: Estimate the risk of the scenario by mathematically combining the consequence, initiating event, and IPL data. Other factors may be includedduring the calculation, depending on the definition of consequence (impact event). Approaches include arithmetic formulae and graphical methods.

Loss magnitude Chara. of consequence	Spared or non-essential equipment	Plant outage < 1 month	Plant outage 1-3 month	Plant outage >3 month	Vessel rupture 3000-10000gal, 100-300 psig	Vessel rupture >10000 gal >200 psig
Mech.Damage to large main plant	Category 2	Category 3	Category 4	Category 4	Category 4	Category 5

Table 7(a)Consequence Severity Categorization

Release Size Release Chara.	1-10 Pound release	10-100 Pound release	100-1000 Pound release	1000-10000 Pound release	10000-100000 Pound release	>100000 Pound release

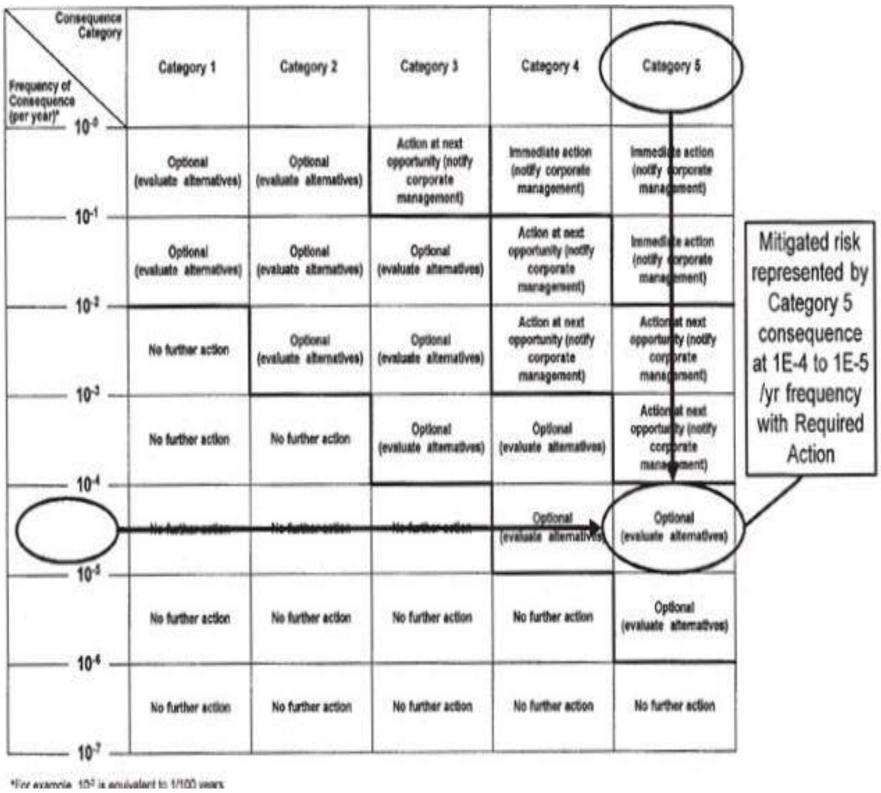
Extremelytoxic above BP	Category 3	Category 4	Category 5	Category 5	Category 5	Category 5
Extremely Toxic below BPOrHighly toxic above BP	Category 2	Category 3	Category 4	Category 5	Category 5	Category 5
Highly toxic below BP or Flammable above BP	Category 2	Category 2	Category 3	Category 4	Category 5	Category 5
Flammable below BP	Category 1	Category 2	Category 2	Category 3	Category 4	Category 5
Combustible liquid	Category 1	Category 1	Category 1	Category 2	Category 2	Category 3

Table 7(b)-Consequence Severity Categorization

This describes how to use LOPA data to estimate risk, using the initiating event frequency (discussed in Chapter 3), the IPL values (discussed in Chapter 4), and the consequence value (discussed in Chapter 1). Chapter 7 also discusses how to include the probability of reaching the impact event, given the stated consequence (such as a release of a hazardous substance) occurs; and how to estimate the frequency of the scenario (by factoring the probability of the presence of people in the vicinity, probability of escape, probability of ignition, etc.). As we know that from the amount of LPG released this can be classified under category 5 type . We will get the characteristic of release and the overall cost for the damage associated with it.

The risk can be calculated by the following equation,

Risk = (Frequency of the initiating event) * (PFDs of all IPLs) * (Vulnerability) * (Occupancy)



Frequency of Consequence (per year)* \ Consequence Category	Category 1	Category 2	Category 3	Category 4	Category 5
10^{0} 10^{-1}	Optional (evaluate alternatives)	Optional (evaluate alternatives)	Action at next opportunity (notify corporate management)	Immediate action (notify corporate management)	Immediate action (notify corporate management)
10^{-1} 10^{-2}	Optional (evaluate alternatives)	Optional (evaluate alternatives)	Optional (evaluate alternatives)	Action at next opportunity (notify corporate management)	Immediate action (notify corporate management)
10^{-2} 10^{-3}	No further action	Optional (evaluate alternatives)	Optional (evaluate alternatives)	Action at next opportunity (notify corporate management)	Action at next opportunity (notify corporate management)
10^{-3} 10^{-4}	No further action	No further action	Optional (evaluate alternatives)	Optional (evaluate alternatives)	Action at next opportunity (notify corporate management)
10^{-4} 10^{-5}	No further action	No further action	No further action	Optional (evaluate alternatives)	Optional (evaluate alternatives)
10^{-5} 10^{-6}	No further action	No further action	No further action	No further action	Optional (evaluate alternatives)
10^{-6} 10^{-7}	No further action	No further action	No further action	No further action	No further action

Mitigated risk represented by Category 5 consequence at 1E-4 to 1E-5 /yr frequency with Required Action

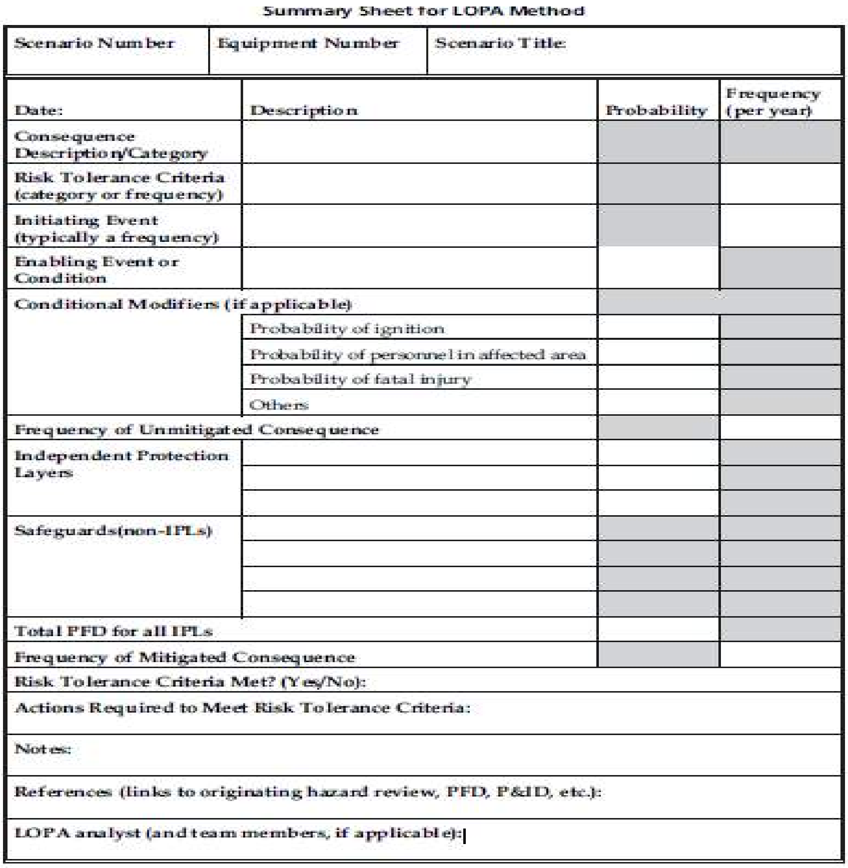
*For example, 10^{-2} is equivalent to 1/100 years

Table 8 Estimating the risk and required action

Step 6: Compare the risk with tolerable and make suggestions.

Above data describes how to make risk decisions with LOPA.As we know the LPG release would come under category

5, we will find out the tolerable risk from the risk matrix. (See Table 7) And after diving the obtained risk with tolerable we will get to know whether any additional protection is needed or not.



Summary Sheet for LOPA Method

Scenario Number	Equipment Number	Scenario Title:	
Date:	Description	Probability	Frequency (per year)
Consequence Description/Category		▨	▨
Risk Tolerance Criteria (category or frequency)		▨	
Initiating Event (typically a frequency)		▨	
Enabling Event or Condition			▨
Conditional Modifiers (if applicable)		▨	▨
	Probability of ignition		▨
	Probability of personnel in affected area		▨
	Probability of fatal injury		▨
	Others		▨
Frequency of Unmitigated Consequence		▨	
Independent Protection Layers			▨
			▨
			▨
Safeguards(non-IPLs)		▨	▨
		▨	▨
		▨	▨
		▨	▨
Total PFD for all IPLs			▨
Frequency of Mitigated Consequence		▨	
Risk Tolerance Criteria Met? (Yes/No):			
Actions Required to Meet Risk Tolerance Criteria:			
Notes:			
References (links to originating hazard review, PFD, P&ID, etc.):			
LOPA analyst (and team members, if applicable):			

Fig.8 LOPA Worksheet

LOPA has numerous advantages compared to other qualitative risk assessment tools and combines the advantage of qualitative and quantitative tools. Some of the advantages are summarized below:

- Is a simple risk assessment tool and requires less time and resources than for a QRA but is more rigorous than HAZOP. It can be used a screening tool for QRA.
- Improves scenario identification by pairing of the cause and consequence from PHA studies
- Identifies operations, practices, systems and processes that do not have adequate safeguards and helps in deciding the layers of protection required for process operations and thereby focuses on the most critical safety systems.
- It helps to determine the need for Safety Instrumented Systems (SIS) and Safety Integrity Levels (SIL) for SIS.
- Can be used as a Cost Benefit Analysis tool while selecting process safety instrumentation
- Is useful for making risk-based decisions during stages like design, management of change, preparation of Safety Operating Procedures for operators, incident investigation emergency response planning, bypassing a safety system etc.
- LOPA can improve the efficiency of hazard evaluation meetings by providing a tool to help reach risk judgments quicker.
- LOPA facilitates the determination of more precise cause–consequence pairs, and therefore improves scenario identification.
- LOPA provides a means of comparing risk from unit to unit or plant to plant, if the same approach is used throughout the company.
- Provides due credit to all protective layers and helps in estimating the specific risk level of the unit/ equipment.
- Removes subjectivity while providing clarity and consistency to risk assessment and helps to compare risks based on a common ground if it is used throughout a plant.
- Can be regarded as good to identify whether any additional mitigation layer is needed, if so, of what kind of probability of failure on demand.

DOI: 10.17148/IARJSET.2022.9571

- Can be used as a tool in place of Quantitative Risk Analysis for substances for which standard damage distances or effects are not known. In such cases it helps decide if the risk is As Low as Reasonably Possible (ALARP) for compliance to regulatory requirements or standards.

LOPA is just another risk analysis tool that must be applied correctly. The limitations imposed on LOPA result in a work process that is much less complex than quantitative risk analysis, while generating useful, somewhat conservative, estimates of risk. LOPA is subject to the following limitations: While using this technique, its limitations should also be kept in mind for deriving better results:

- Risk tolerance criteria must be established for LOPA exercise before the process starts.
- For countries where such criteria have not been specified by statutes it will be difficult to decide which standards are to be adopted.
- LOPA offers flexibility to the user in the areas of selecting IPLs and PFDs associated with the IPLs though the general industry data is available for the purpose. This brings in subjectivity in the assessment process and depends on the expertise of the user.
- It does not decide what specific IPLs should be used and decision depends on the experience and expertise of the user.
- LOPA is a simplified approach and should not be applied to all scenarios. The amount of effort required to implement LOPA may be excessive for some risk-based decisions and is overly simplistic for other decisions.
- LOPA requires more time to reach a risk-based decision than qualitative methods such as HAZOP and What-if. This extra time is offset by the improved risk decision compared to using only qualitative methods for moderately complex scenarios. For simple decisions, the value of LOPA is minimal. For more complex scenarios and decisions, LOPA may actually save time compared to using only qualitative methods, because LOPA brings focus to the decision making.

identification procedure) is done first. HAZOP tables usually list Deviations, Causes, Consequences, Safeguards, and Recommendations. The HAZOP table may also include estimates of the Frequency for each Cause and Severity for each Consequence. With these estimates a risk matrix can be used to estimate Risk for a Cause- Consequence pair (Fryman, 1996). Figure 1 shows the HAZOP information and the LOPA information in graphical form. The solid lines show the sequence of the HAZOP or LOPA development. The dotted lines show how HAZOP information is transferred to the LOPA.

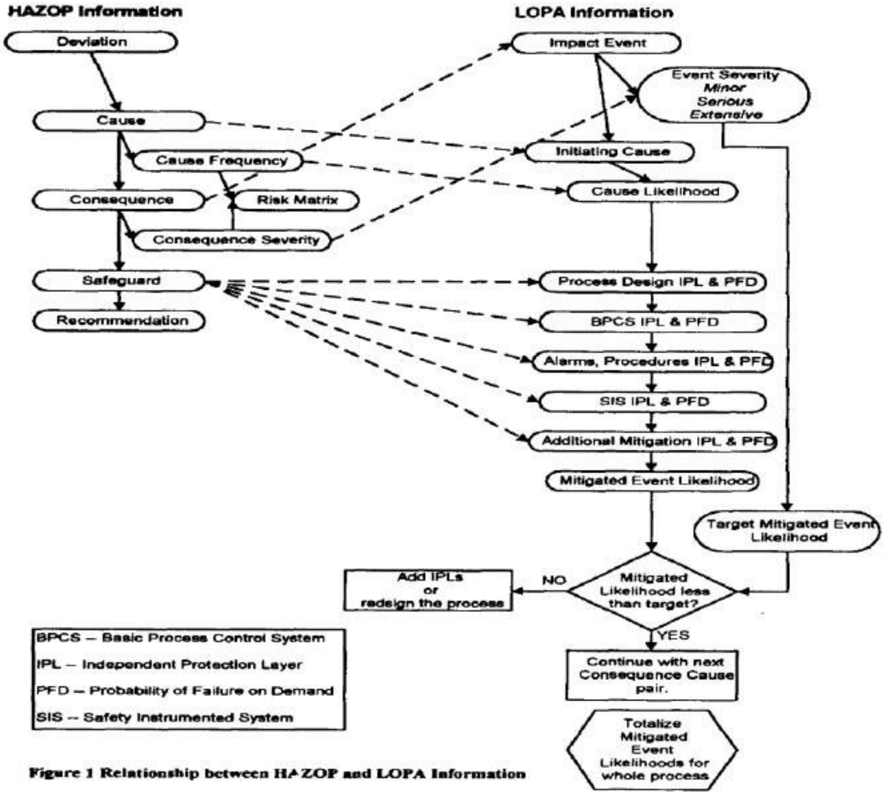


Figure 1 Relationship between HAZOP and LOPA Information

Fig 9Relationship between HAZOP and LOPA

If additional risk reduction measures are proposed:

- LOPA identifies the additional risk reduction that is required as a numerical value.
- If the additional risk reduction is to be a Safety Instrumented System (SIS):
- The IEC 61508 relationship between SIL and Probability of Failure on Demand (PFD) is USED to provide the SIS design objective.

Safety Integrity Level (SIL)	Low Demand Mode of Operation (Avg. Prob. Of Failure to Perform Its Design Function On Demand)	Risk Reduction Factor
4	$\geq 10^{-5}$ TO $< 10^{-4}$	> 10,000 to ≤ 100,000 Times
3	$\geq 10^{-4}$ TO $< 10^{-3}$	> 1000 to ≤ 10,000 Times
2	$\geq 10^{-3}$ TO $< 10^{-2}$	> 100 to ≤ 1000 Times
1	$\geq 10^{-2}$ TO $< 10^{-1}$	> 10 to ≤ 100 Times

Table.9 SIL LEVELS

Is defined as a relative level of risk-reduction provided by a safety function, or to specify a target level of risk reduction. In simple terms, SIL is a measurement of performance required for a Safety Instrumented Function (SIF). The term safety interlock function was replaced with the term safety instrumented function after the release of the ISA 84.01, IEC 61508 and IEC 61511 standards

The requirements for a given SIL are not consistent among all of the functional safety standards. In the European Functional Safety standards based on the IEC 61508 standard four SILs are defined, with SIL 4 being the most dependable and SIL 1 being the least. A SIL is determined based on a number of quantitative factors in combination with qualitative factors such as development process and safety life cycle management.

There are several methods used to assign a SIL. These are normally used in combination, and may include:

- Risk Matrices
- Risk Graphs
- Layers Of Protection Analysis (LOPA)

The assignment may be tested using both pragmatic and controllability approaches, applying guidance on SIL assignment published by the UK HSE.[1] SIL assignment processes that use the HSE guidance to ratify assignments developed from Risk Matrices have been certified to meet IEC EN 61508.

There are several problems inherent in the use of Safety Integrity Levels. These can be summarized as follows:

- Poor harmonization of definition across the different standards bodies which utilize SIL
- Process-oriented metrics for derivation of SIL
- Estimation of SIL based on reliability estimates
- System complexity, particularly in software systems, making SIL estimation difficult to impossible

HAZOP study has identified that there is a risk of overfilling a tank containing volatile liquid from two causes such as pump failure (2 per year) and level control per year (.1 per year). The IPL found to this situation are:

IPL found	**PFD**
Process design	0.1
Process control	0.1
Independent alarm	0.5
Restricted access	0.5
closed drains	0.1

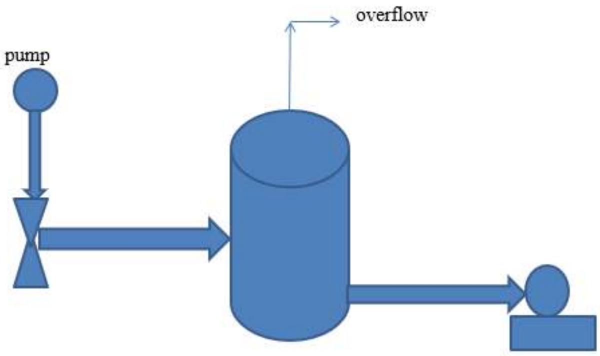


Fig 10

The ipl founded in this case are process design, process control, alarm, restricted access and closed drains. the pfd values are taken from the ccps. the initiating events for the consequence overflow of tank are pump failure (2 per year) and level control per year (.1 per year).
Typical Lopa worksheet for the above question is

Table.10LOPA WORKSHEET

	Impact event	**Overfilloftank**	**Overfill of tank**
	Severity level	S	S
	Initiating causes	Pump failure	Level control failure
	Event freq./year	2	0.1
Protection and mitigation layer	Process design	0.1	0.1
	Process control	0.1	
	Independent alarm	0.5	0.5
	Restricted access closed drains	0.5 0.1	0.5 0.1
	Intermediate event freq.	5E-4	2.5E-4
	Total mitigated event freq.	7.5E-4	
	Tolerable event freq.	1E-4	
	reqd. SIS risk reduction	1.33E-3(SIL=2)	

4. CASE STUDY

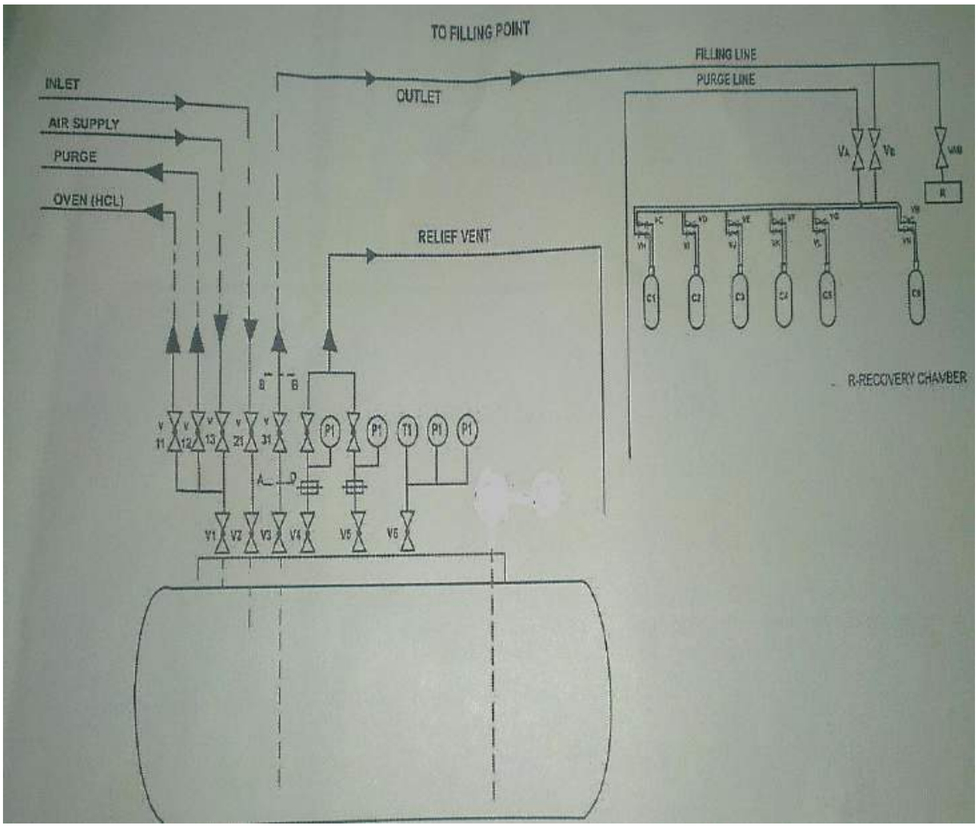


Fig11. process flow diagram of the chlorine storage and filling station

The chlorine gas which is produced in the membrane cell plant is coming to the storage tank through the inlet and then it passes through the outlet to the filling station, both lines employ non return valves to prevent the re-entry of the chlorine gas. Line for air supply and purge are also provided for the purpose of purging. a separate line is provided to the oven where chlorine is used to produce HCl. if overfilling results in excess pressure, it is relieved through the relief vents. In the chlorine filling station chlorine is filled in the tonners, a recovery chamber is provided to purge the leaky tonners. principle of redundancy is applied in the relief vent line of the storage tank, as the employment of two valves in the relief vent will reduce the chances of failure. Pressure gauges are added to monitor the pressure inside the storage tank continuously.

Design specifications of the storage tank
Pressure -1551 kPa (min.)- 2586kPa(max.)
Temperature - ambient temp.

Specification of Chlorine Tonner	
Water Capacity (approx.) Kg.	780
Chlorine Capacity (approx.) Kg.	930
Design Pressure, Kg/cm^2	19.9
Inside Diameter (approx.) mm	760
Shell Thickness, mm	10
Dished Ends Thickness, mm	9.6 (Min.)
Overall Length (approx.) mm	2085
Tare Weight (approx.) Kg.	620
Valve Outlet	5/8”
Thread	14 tpi

Table.11 Chlorine tonner specifications

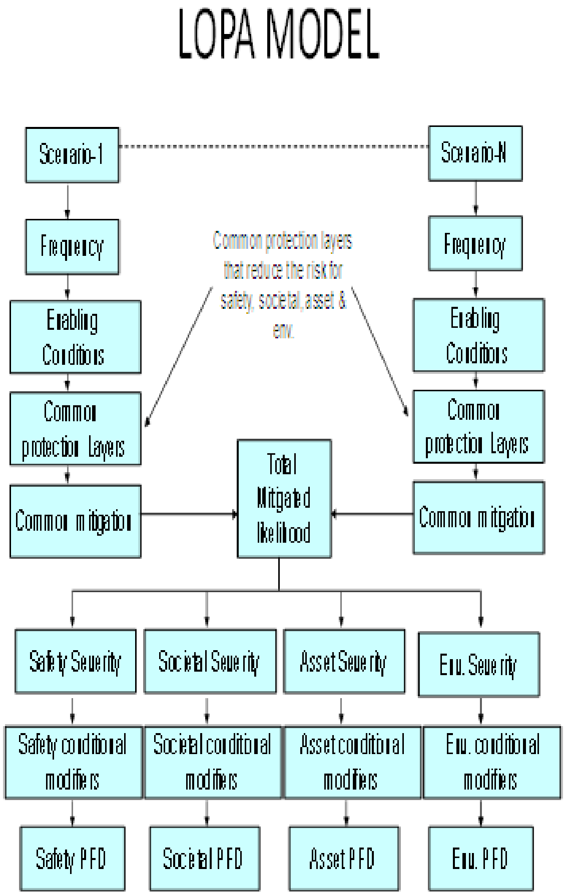


Fig12: **lopa model**

For doing this analysis it is necessary to take certain number of initiating causes that would cause the impact event. Here we are only taking 4 initiating events whose impact severity is 'E' (Extensive) or 'S' (Serious). This doesn't mean that there is no 5th way of causing the impact event, we are restricted it to 4 because the impact severity of the fifth may not be appreciable to cause a deviation from the Total Mitigated Event Frequency. The 4 initiating causes are

1. Tank Leakage
2. Joint Failure
3. Pump Failure
4. NRV Failure

And for the calculation of the Total Mitigated Event Frequency, we have to add all the intermediate Event Frequency arising out of the 4 initiating causes. From the risk matrix we have found the tolerable risk. We then have to divide that with the Total Mitigated Event Frequency to find the required SIS reduction.

Here we have not only to take care of the impact associated to the safety of human beings; we have to take care of the impact associated with the same to the assets and environment. The Total Mitigated Event Frequency for Safety, Assets & Environment would be different because occupancy and vulnerability etc. has to no goods while its value is

Impact event	**Chlorine release**	**Initiating Cause 1**	**Initiating Cause 2**	**Initiating Cause 3**	**Initiating Cause 4**
	Cause	Tank Leakage	Joint Failure	Pump failure	NRVs failure

DOI: 10.17148/IARJSET.2022.9571

	Event freq./year	0.1	0.1	0.2	0.1
	Severity level	E	E	S	S
Protection & Mitigation layers	Process design	0.1	0.1	0.1	0.1
	Process control – Alarm	0.2	-	-	0.2
	Control valve	0.2	-	0.2	0.2
	Operator response to alarm	0.1	0.1	0.1	0.1
	Restricted Acess	-	-	-	-
	Vulnerability	-	-	-	-
	Occupancy	-	-	-	
	Any other ipl	-	-	-	-
	Intermediate Event Frequency	4.0*E-5	1.0*E-3	4.0E-4	4 .0E-5
	Total Mitigated Event Frequency(c)	1.48* E-3			
	Tolerable Event Frequency (d)	1.0*E-4			
	Required SIS Reduction (PFD) (e)=(d)/(c)	0.64*E-1(SIL Required – 1)			

considered while calculating Total Mitigated Event Frequency for Safety of human beings.

Process design: Process design to reduce the likelihood of an Impact Event from occurring, when an Initiating Cause occurs, an example of this would be a jacketed pipeline or vessel. The full 750 meters of pipeline is jacketed with glass wool. This jacket would prevent the release of process material if the integrity of the primary pipe or vessel is compromised.

Process control systems: Process control systems are essentially acting on the principle that if a parameter exceeds the pre-set values it works to reduce the exceeded parameter. This is done with the assistance of safety instrumented systems. It includes process alarms.

flow control valve: Used to regulate fluid pressure and flow rate, flow control valves are used in a wide range of systems. A basic flow control valve consists of a changeable aperture that opens to increase flow rate or closes to slow flow rate

DOI: 10.17148/IARJSET.2022.9571

operator response against alarm: It is the human intervention or human protective layer.it is the response of human or the operator against a particular alarm. the failure rate can be high in this case.

Occupancy: It is assumed that occupancy of the LPG storage area is 50%. It means that persons are present there only for 50% of the time we are considering. If we are considering 24 hours area will be occupied only for 12 hours.

Vulnerability: Vulnerability refers to the inability to withstand the effects of a hostile environment.

Table.12 Asset- Solution

Impact event	**Chlorine release**	**Initiating Cause 1**	**Initiating Cause 3**	**Initiating Cause 4**	**Initiating Cause 5**
	Cause	Tank Leakage	Joint Failure	Pump failure	NRVs failure
	Event freq./year	0.1	0.1	0.2	0.1
	Severity level	E	E	S	S
Protection & Mitigation layers	Process design	0.1	0.1	0.1	0.1
	Process control – Alarm	0.2	-	-	0.2
	Control valve	0.2	-	0.2	0.2
	Operator response to alarm	0.1	0.1	0.1	0.1
	Restricted Acess	0.1	0.1	0.1	0.1
	Vulnerability	-	-	-	-
	Occupancy	-	-	-	
	Any other ipl	-	-	-	-
	Intermediate Event Frequency	4.0*E-6	1.0*E-4	4.0E-5	4.0E-6
	Total Mitigated Event Frequency (c)	1.48* E-4			
	Tolerable Event Frequency (d)	1.0*E-6			

DOI: 10.17148/IARJSET.2022.9571

	Required SIS Reduction (PFD) (e)=(d)/(c)	0.68* E -2 (SIL Required – 2)

5. CONCLUSION

Table.12 Environment- Solution

SAFETY INTEGRITY LEVEL (SIL)	**PFD avg**
1	10^{-1} to 10^{-2}
2	10^{-2} to 10^{-3}
3	10^{-3} to 10^{-4}

6. RESULT

- SIL Levels of the Safety, Asset and Environment have been identified.
- Required Safety Instrumented Systems are as follows

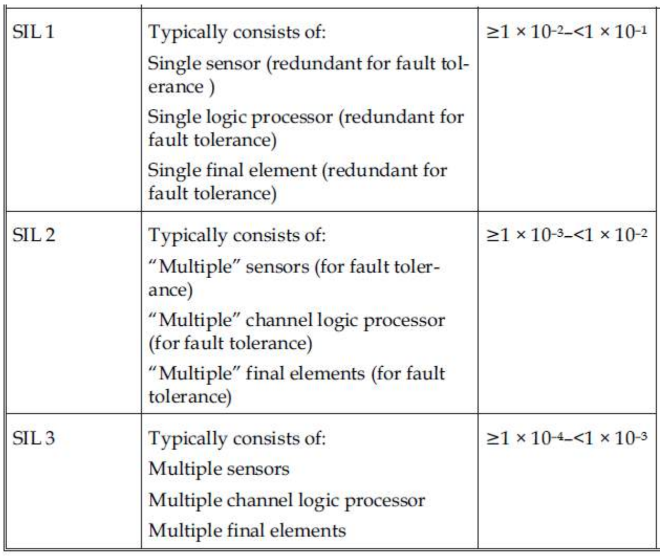
1. For Safety, it is 0.3*E-1, i.e., SIL 1 is required.
2. For Asset, required SIS reduction is 0.64*E-1 and SIL is 1.
3. For Environment, required SIS reduction is 0.68* E -2 and the SIL is 2.
4. For increasing the SIL level more IPL can be implemented such as pressure rupture disk,independentalarm, emergencyresponse, external emergency plan etc.by adding these the risk can be brought under control or into tolerable limit and we can increase the sil level required to a safer level.
5. For each sil level specific type of technology and equipment's are made into action for the controlling of the particular risk

SIL 1: PFD ≥ 1 × 10–2 to <1 × 10–1 [IEC 61511 (IEC, 2001)]. These SIFs are normally implemented with a single sensor, a single SIS logic solver and a single final control element.

SIL 2 :PFD ≥ 1 × 10–3 to <1 × 10–2 These SIFs are typically fully redundant from the sensor through the SIS logic solver to the final control element.

SIL 3: PFD ≥ 1×10–4 to <1 × 10–3 These SIFs are typically fully redundant from sensor through the SIS logic solver to the final control element and require careful design and frequent proof tests to achieve low PFD figures. Many companies find that they have a limited number of SIL 3 SIFs due to the high cost normally associated with this architecture.

SIL 4: PFD ≥ 1×10–5 to <1 × 10–4 These SIFs are included in the IEC 61508 and 61511 standards, but such SIFs are difficult to design and maintain and are not used in LOPA



SIL 1	Typically consists of: Single sensor (redundant for fault tolerance) Single logic processor (redundant for fault tolerance) Single final element (redundant for fault tolerance)	$\geq 1 \times 10^{-2}$–$<1 \times 10^{-1}$
SIL 2	Typically consists of: "Multiple" sensors (for fault tolerance) "Multiple" channel logic processor (for fault tolerance) "Multiple" final elements (for fault tolerance)	$\geq 1 \times 10^{-3}$–$<1 \times 10^{-2}$
SIL 3	Typically consists of: Multiple sensors Multiple channel logic processor Multiple final elements	$\geq 1 \times 10^{-4}$–$<1 \times 10^{-3}$

Fig.13

6.FUTURE WORK

The right now created framework is completely working what not the fundamental functionalities are met effectively relying on the prerequisites. In any case, so as to be utilized as an item in the certifiable certain adjustments must be done since it has to work and register progressively. Those progressions include:

- The focal server can be redesigned from Thing speak to a particular devoted server for this reason.
- Multi-threading must be accomplished all the more viably for expanding the framework responsiveness
- Additional security layers must be introduced. There can't be any odds of a security escape clause in a genuine time traffic framework like this.
- The circumstance of different ambulances moving toward a common traffic signal point must be considered with additional number of integral factors with the goal that the circumstance could be taken care of in the best and most effortless manner.
- The framework ought to have the option to fuse other emergency vehicles like police, fire and salvage and so forth with distinctive need levels.

7.ACKNOWLEDGEMENT

The satisfaction that the one gets on completion of a task cannot be fully enjoyed without mentioning the people who made it possible. I am very much grateful to the almighty, who helped us all the way and who moulded me into what I am today. I am remaining indebted to my parents who have sacrificed many things for my success. I submit my heartfelt regards and sincere thanks to them.

I express my sincere thanks and I gratitude to my honourable Chairman **Prof. Dr. A.K. NATESAN, M.Com. MBA., M.Phil., Ph.D., FTA, PHF** for all the help he has provided in accomplishing this task.

I convey my kind regards and thanks to my beloved Principal **Dr.R. NALLUSAMY, M.E., Ph.D.,** who motivated me to take up this seminar work for having provided the suitable environment to work with.

I express my sense of gratitude and sincere thanks to the Head of the Department **Mr. NITHIYANAND, M.E.,** of mechanical engineering for his valuable guidance in the preparation and presentation of this internship work.

I express my profound sense of thanks with deepest respect and gratitude to my supervisor **Mr.S SARAVANAKUMAR, M.E.,** Department of Mechanical Engineering for his valuable and precious guidance throughout the period of work.

My sincere thanks are due to my Friends, Teaching, Non-Teaching Staff members and the well-wishers for their constant support all the time.

8. REFERENCES

1. P Nithiyanand, A Krishnan, B Baby, D Baby, M Sufaid " Design of LPG used Refrigeration system using Nozzle Expansion” International Research Journal on Advanced Science Hub, 2020, Volume 2, Issue 4, Pages 46-53
2. S.Anandakumar, D.Alagesan , P.Nithiyanand “INVESTIGATIONS ON THE MACHINING OF MAGNESIUM MATRIX COMPOSITES”,IJARAS, vol 6, issue VII, pages 138-154
3. Bridges, William G. (2000a), Course 209, Layer of Protection Analysis. Knoxville, TN: Risk Consulting Division, ABS Consulting.
4. Application of Safety Instrumented Systems for the Process Industries (1996), ANSI/ISA-ISA 84.01-1996, ISA, Research Triangle Park, NC.
5. Angela.e.summer, Introduction to layer of protection analysis
6. V.R.Renjith,G.Madhu,A.B.Bhasi,two dimensional fuzzy fault tree analysis for chlorine release from chlor alkali industry using expert alicitation