Risk Assessment in Refinery by Various Quantitative Methods and their Comparison

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Declaration

This is to certify that

i) The thesis comprises my original work towards the degree of Master of Technology in Chemical Engineering - Environmental Process Design at Nirma University and has not been submitted elsewhere for a degree.

ii) Due acknowledgment has been made in the text to all other material used.

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Undertaking for Originality of the Work

I Suraj Sinha, 12MCHE17, give undertaking that the major project entitled "Risk Assessment in Refinery by Various Quantitative Methods and their Comparison" submitted by me, towards the partial fulfillment of the requirements for the degree of Master of Technology in Chemical Engineering (Environmetal Process Design) of Nirma University, Ahmedabad is the original work carried out by me and I give assurance that no attempt of plagiarism had been made. Due acknowledgement has been made in the text to all other material used.

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This is to certify that the Major Project entitled "**Risk Assessment in Refinery by various Quantitative methods and their comparison**" submitted by **Mr. Suraj Sinha** (12MCHE17), towards the partial fulfillment of the requirements for the award of **Degree of Master of Technology in Chemical Engineering (Environmental Process Design)** of Nirma University, Ahmedabad is the record of work carried out by him under my supervision and guidance. In my opinion, the submitted work has reached a level required for being accepted for examination. The results embodied in this major project, to the best of my knowledge, have not been submitted to any other University or Institution for award of any degree or diploma.

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Abstract

The hazardous chemical accidents in past remain a matter of major concern. Therefore, in order to provide more accurate management plan, risk assessment has become a critical issue in chemical process industry. Risk assessments in particular have been used in the chemical industry for many years to support decision-making on the choice of arrangements and measures associated with chemical processes, transportation and storage of dangerous substances. The assessments are on risk perspective which is measured in terms of economic loss, human injury and environmental loss which is product of frequency and consequences. There are various risk assessment methods based on the techniques like qualitative, semi-quantitative and/or quantitative approaches. High level of accuracy in terms of risk analysis is obtained from the quantitative method as compared with other two techniques. Literature survey concluded that in the field of chemical process industries risk assessment are mainly done by quantitative methods to achieve high accuracy.

The Event Tree Analysis, Fault Tree Analysis, F-N (Frequency-Number of Fatality) curve, Location Specific Individual Risk (LSIR) and consequence contour are the quantitative risk assessment methods by which the frequency and consequences are combined to give risk. The F-N curve is product of frequency F of events causing N number of fatalities. For F-N curve, LSIR and consequence contour method the practical case study of the chemical process industries has been analyzed.

For the analysis of the F-N curve, LSIR and consequence contour the Phast and Phast Risk software are utilized. The accidental scenario input as source model to the software is identified from the major consequences of HAZOP study. Various models in Phast for discharge, dispersion as well as flammable, explosive and toxic effects has been studied. Based on calculated estimates of consequence (software modeling) from Phast is imported to Phast Risk and likelihood (failure rate data), local population distribution, source ignition and local prevailing weather conditions are input in Phast risk to obtain risk which is presented in terms of individual risk and societal risk . This provides a calculated value of risk. The risk estimated is compared with the risk criteria whether it is in Intolerable or ALARP or Tolerable based on the fatality rate. If the risk is intolerable then risk measures controls are identified to bring down the risk levels into ALARP or Broadly Acceptable range. In this way, the objective is to analyze Hydro Cracker Unit by applying Quantitative Risk Assessment method. The risk found after the study for the Hydro Cracker Unit was in ALARP region.

Keywords: Frequency, Consequences, LSIR, Individual Risk, Societal Risk.

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Acronyms

AIChE	American Institute of Chemical Engineers
ALARP	As Low As Reasonable Practicable
BLEVE	Boiling Liquid Expanding Vapor Explosion
CCPS	Center for chemical Process Safety
DNV	Det Norske Veritas
ERPG	Emergency Response Planning Guidelines
ESD	Emergency Shutdown Device
ETA	Event Tree Analysis
F/N	Frequency / Number of Fatalities
FAR	Fatal Accident Rate
FMEA	Failure Mode and Effect Analysis
FTA	Fault Tree Analysis
HAZAN	Hazard Analysis
HAZID	Hazard Identification
HAZOP	Hazard and Operability study
HSE	Health, Safety & Environment
IDLH	Immediately Dangerous to Life and Health
IRPA	Individual Risk Per Annum
KW/m^2	Radiation Unit
LC	Lethal Concentration
LD	Lethal Dose
LFL	Lower Flammable Limit
LPG	Liquefied Petroleum Gas
LSIR	Location Specified Individual Risk
MCLS	Maximum Credible Loss Scenarios
MSDS	Material Safety Data Sheet
NIOSH	National Institute for Occupational Safety and Health
QRA	Quantitative Risk Assessment

Terminology

Accident — A specific unplanned event or sequence of events that has undesirable consequences.

Basic Event — A fault tree event that is sufficiently basic that no further development is necessary.

Consequence — A measure of the expected effects of an incident.

Explosion — A sudden release of energy characterized by accompaniment of a blast wave.

External Event — An event caused by a natural hazard (earthquake, flood, etc) or man-induced events (aircraft crash, sabotage, etc).

Fire — process of combustion characterized by heat or smoke or flame or any combination of these.

Frequency — The number of occurrences of an event per unit of time.

Hazard — A characteristic of the system/plant process that represents a potential for an accident causing damage to people, property or the environment.

Mitigation System — Equipment and/or procedures designed to respond to an accident event sequence by interfering with accident propagation and/or reducing the accident consequence.

Probability — An expression for the likelihood of occurrence of an event or an event sequence during an interval of time or the likelihood of the success or failure of an event on test or on demand.

Risk — A measure of potential economic loss or human injury in terms of the probability of the loss or injury occurring and the magnitude of the loss or injury if it occurs.

Worst Case Consequence — A conservative (high) estimate of the consequences of the most severe accident identified.

Accident A specific unplanned event or sequence of events that has undesirable consequences.

BLEVE Boiling Liquid Expanding Vapor Explosion, which occurs from the sudden of the large mass of pressurized liquid to the atmosphere. A primary cause is an external flame impinging on the shell of the vessel above the liquid level, weakening the shell and resulting the sudden rupture.

Fire Ball The atmospheric burning of a fuel-air cloud in which the energy is mostly emitted in the form of radiant heat. The inner core of the fuel .

Individual Risk The term Individual Risk is used for the calculations of the risk of fatality for someone at a specific location, assuming that the person is always present at the location, i.e. is continuously exposed to the risk at that location.

Societal Risk The societal risk is a measure of the risk that the events pose to the local population, taking into account the distribution of the population in the local area.

FN curve FN curve defines the societal risk. It represents the relationship between the frequency and the number of people suffering a given level of harm from the realization of specified hazards. It is usually taken to refer to the risk of death and usually, expressed as a risk per year.

PPL Societal risk can be presented as Potential Loss of Life (PLL). The PLL represents the potentially expected number of fatalities, usually presented on an annual basis.

Risk Contour It defines the risk to a hypothetical individual assumed to be continuously present at a specific location, i.e. in the vicinity of the hazard. It includes the nature of the injury to the individual, the likelihood of the injury occurring and the time period over which the injury might occur at that particular location.

Flash Fire The Combustion of a flammable vapor and air mixture in which flame passes through that mixture at less than sonic velocity, such that negligible damaging overpressure is generated.

Pool Fire The combustion of material evaporating from a layer of liquid at the base of the fire.

Accident A specific unplanned event or sequence of events that has undesirable consequences.

Jet Fire Fire type resulting from fires from pressurized release of gas and/or liquid.

Detonation A release of energy caused by the extremely rapid chemical reaction of a substance in reaction front advances into the unreacted substance greater than sonic velocity.

Chapter 1

Introduction

1.1 Background of work

The increasing variety of products manufactured by chemical process industries has made industries to use reactors, conduits and storage vessels in which hazardous material are stored, processed and transferred at high temperatures and/or pressures. Accidents in such units caused either by equipment failure (piping (25%), reactors and storage tanks (both 14%) and process vessels (10%)) [1], operational manual error (such as raising the pressures temperature/flow-rate beyond limits), or design error (poor layout (17%), insufficient consideration of chemical reactivity and mismatch (16%) and incorrectly chosen process conditions (16%)) [1, 2]. The most shocking example of an accidents which drives us for risk assessment like Texas city disaster (USA) April 1947 (576 dead), Ludwigshafen (Germany) July 1948 (207 dead), Flixborough (England) June 1974 (28 dead), Romeoville (USA) July 1984 (14 dead), Pemex (Mexico) November 1984 (542 dead), Bhopal (India) December 1984 (15000 dead), Chernobyl (Ukraine) April 1986 (31 dead and 75000 cancers cases), Pasadena (USA) October 1989 (31 dead) and Visakhapatham (India) September 1997 (50 dead) [2, 3].

Due steady increase in industrialization and population risk also keeps on increasing. Further it is common to find industrial areas or industrial complexes where groups of industries are situated in close proximity to one another. The growth in the number of such industrial areas and in the number of industries contained in each of the areas gives rise to increasing probabilities of chain of accidents or cascading/domino effects wherein an accident in one industry may cause another accident in a neighboring industry which in turn may trigger another accident and so on. So it is necessary to each industries to know the risk in there facility. Some of past accidents experiences like Pemex (Mexico), Pasadena (USA) and recently Vishakhapatnam (India) are examples of such disasters [2, 3]. In order to decrease or reduce the frequency of occurrences of accidents, efforts are needed to increase the level of safety, hazard management and emergency preparedness. This has been realized and the public awareness has been increased towards this issue, has demanded new technique development for new processes for identifying risk assessment and safety evaluation of chemical process industries, singly or in combinations.

The resulting science of risk assessment deals with the following key aspects of accidents in chemical process industries:

- Development of techniques and tools to forecast accidents.
- Development of techniques and tools to analyze consequences of likely accidents.
- Development of management strategies for emergency preparedness planning and damage reduction'.

Risk assessment is utilized for the decision-making process in industries. All the options are viewed, it is very important to analyze the level of risk in each level with all option. The analysis can address financial risks, health risks, safety risks, environmental risks and other types of business risks. An proper analysis of these risks will help us to provide information which is critical for good decision making, and will often clarify the decision to be made. The information generated through risk assessment should be communicated to the organization to understand the risk factors, which influenced the decision.

Risk assessment is a legal requirement in India:

- Section 7A of the Factories Act, 1948.
- Section 41 B of the Factories Act 1948.
- Section 7 of the Environment Protection Act 1986.
- Rules 12-C & 68-O of the Gujarat Factories Rules 1963 (GFR) and Form No. 37 u/r 12-B.
- Schedule 19 on Chemical Works u/r 102 GFR.

Internationally there are many other guidelines and standards.

1.2 Scope of work

Refinery industries possess high amount of risk as compared to other chemical industries. So it is selected for risk identification, risk analysis and risk assessment. Risk is identified by qualitative and quantitative. But risk output by qualitative is not in numerical value and it is subjective judgment so a higher potential for uncertainty.

So the risk evaluation in the selected case study will be done quantitatively. Quantitative risk assessment based on calculated estimates of consequence by software modeling and likelihood by failure data of site or industry. Provides a calculated value of risk. Better suited for more complex decision making or where risks are relatively high.Quantitative techniques can provide a more detailed knowledge of the causal chain of events and the influence of controls.More rigorous, detailed and objective than other methods and can better assist choice between different control options. The risk estimated is compared with the risk criteria whether it is in Intolerable or ALARP or Tolerable based on the fatality rate. If the risk is intolerable then Risk measures controls are identified to bring down the risk levels into ALARP or Broadly Acceptable range.

1.3 Objective of project

Refinerys are exposed to high amount of risk during different operational stages. It therefore becomes necessary to make the process/ operations easier and safer by applying different safety tools available. Safety tools in current time can be different qualitative, semi-quantitative and quantitative methods aiming at risk minimization. HAZOP, LOPA, Risk Matrix, Fault Tree Analysis, Safety Integrity Level (SIL), Quantitative risk assessment etc., are the concepts/ tools which have shown the necessary risk reduction and increase in safety level in a chemical industry. They have provided the necessary improvement from the very foundation i.e design to the plant start-up. Statistics have shown that having a safety management programs and other risk minimization techniques reduces the chances of any unwanted/ undesired event.The study focuses on such safety tools and provides a methodology with a case study to carry out the industrial audit.

Hence, the sole aim of the study is too:

- Apply this study as a reference for Hydro cracker unit to analyze hazards in process conditions.
- To identify the hazards and dangers associated in the particular industry through HAZOP analysis.
- To identify the accidental scenarios from HAZOP study for QRA study.
- To apply the QRA study for quantitative analysis.
- To understand Phast and Phast Risk software models and use the same for study.
- To identify the risk for the particular accidental scenarios by the application of the software of Phast and Phast Risk and plot the contours.
- To recommend safeguards for the scenarios to bring risk in broadly acceptable zone by reducing frequency of failure and mitigating consequences.

1.4 Organization of Thesis

The Thesis has been classified into various chapters.

- Chapter 2 will discuss about the Introduction of risk assessment, risk assessment process, risk assessment methods/ techniques with examples, frequency assessment, consequences assessment and research paper citation.
- Chapter 3 will discuss about the methodology of HAZOP, QRA and case study with HAZOP study.
- Chapter 4 will discuss about the introduction of phast as well as phast risk software and there models.
- Chapter 5 will discuss about the QRA of case study.
- Chapter 6 and 7 will discuss the result and summary.

Chapter 2

Literature Survey

The process, environmental engineer and safety personnel sometimes use the terms hazard and risk interchangeably. However, hazard relates to the source of harm, while risk is the likelihood of the harm being experienced. Risk is analyzed in terms of economic loss, environmental loss and human injury which is a function of frequency and the magnitude of the loss or injury, where hazard is defined as the degree of harm or damage to human beings, property, society and environment [4, 5]. In other words, the risk is product of frequency and consequence as shown in figure 2.1. The frequency is number of occurrence of an event per unit time. Event is the release of a material or energy that has the potential for causing harmful effects or it is associated with the incident. The consequences are measure of the expected effects of an incident outcome case.

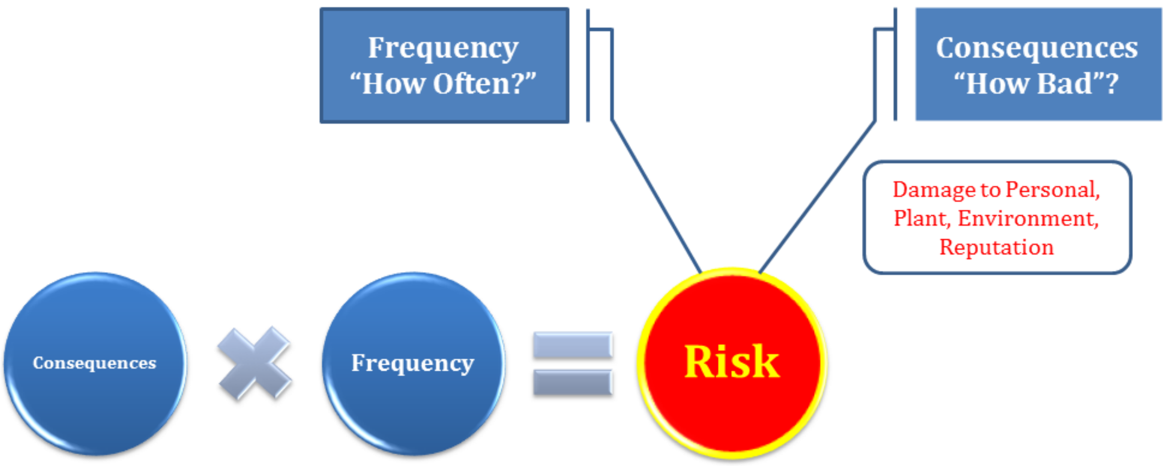

Figure 2.1: Risk function of frequency and consequences [4].

2.1 Basis of Risk Assessment

Risk assessment is the process of collecting data and combining information for analysis, assessment and quantification of risk for particular industry. To explain and understanding of the risk of an facility, one must answer the following three questions [5]:

- What can go wrong?
- How likely it is?
- What are the impacts?

The answers of all above questions are often sufficient for making good decisions for the facility as shown in the Figure 2.2. However operator/ safety offices/ managers seek more detailed cost/ benefit information which help their decisions, they may wish to use various risk assessment method depending on their need in terms of cost.

Figure 2.2: Elements of Risk Assessment [5].

2.2 The Risk Assessment Process

To use a systematic method to determine risk levels, the Risk Assessment Process is applied as shown in Figure 2.3. This process consists of four basic steps:

(i) Hazard Identification

(ii) Frequency Assessment

(iii) Consequence Assessment, and

(iv) Risk Evaluation.

The first step for the risk assessment begins with the hazard identification. Because hazards are the source of events (release of material or energy) that lead to uninvited consequences or damage, analysis to understand risk exposed must begin by understanding and explaining the hazards present in the facility. Hazard identification provides the overview information so it is rarely utilized directly for implementing in the decision making, it is a most important and critical step. Sometimes hazard identification is clearly performed using planned techniques. Overall, hazard identification focuses a risk analysis on key hazards present in the facility and the types of casualties depending on these hazards may create [6].

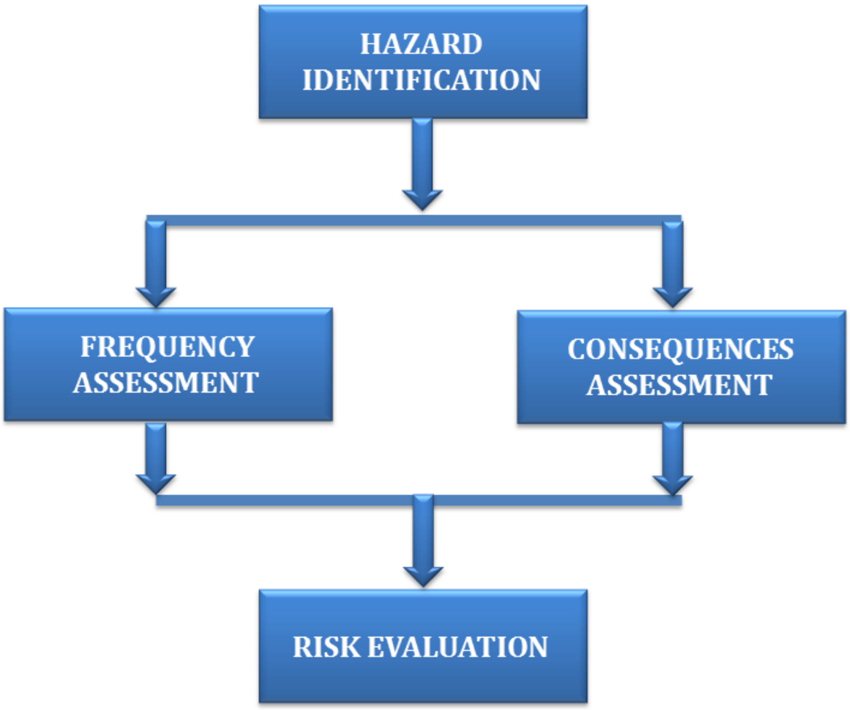

Figure 2.3: Risk Assessment Process [6].

After the identification of the hazard in the system or process of the facility, the next step in performing a risk assessment is to identify the frequency at which the initiating event of hazard will occur per unit time.

Consequence modeling involves the use of software's analytical models to predict the damage or loss of a particular initiating event of concern for the facility. Use of these analytical software's models in the performance of a risk analysis and its assessment typically involves four activities:

(i) Characterization of the source of the material, energy and loss for the event with the hazard being analyzed.

(ii) Analyzing by the experiments or software model's and its correlations the transport of material and its propagation in the environment.

(iii) For the target interest effects of the propagation of energy or material.

(iv) Quantifying the health, safety, environmental, or economic impacts on the target of interest.

Objective and scope of study should estimate the consequences effects for the facility. Consequences results are always stated in terms of the equipment damage, number of injuries, exposure for particular energy level for the material released. These estimates average meteorological conditions and population distribution and may include mitigating factors, such as evacuation and sheltering. In some cases, simply assessing the quantity of material or energy released will provide an adequate basis for decision-making.

After the estimation of the consequences and the frequency of for the events, this both are combined to give the risk for the facility. So the risk is the product of the consequences and the frequency. There are variety methods for the risk estimation like qualitative, quantitative and semi quantitative techniques.

2.3 Risk Assessment Methods/ Techniques

There are various different analysis methods and models that have been developed to aid in conducting risk assessments as shown in Figure 2.4. A key to any successful risk analysis is choosing the right method (or combination of methods) for the situation at hand[7].

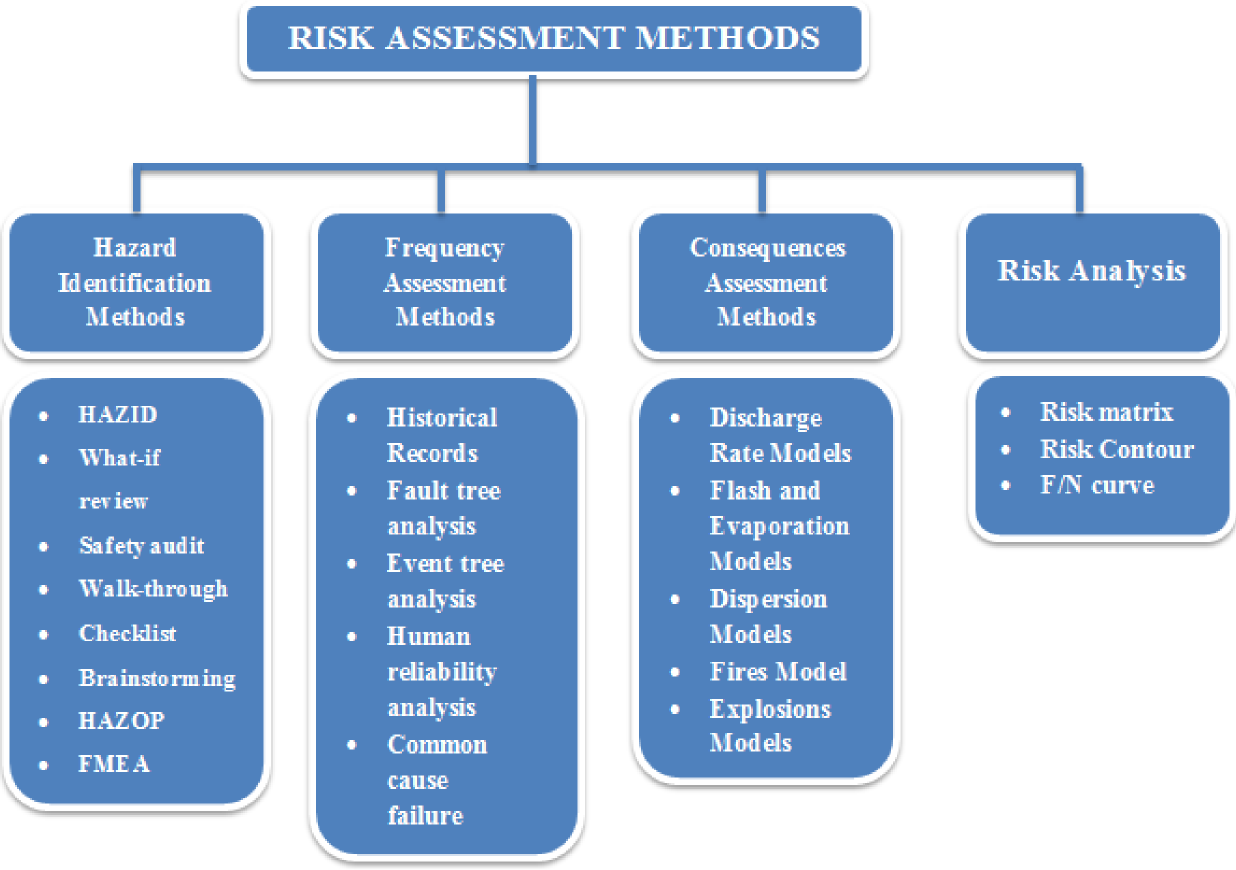

Figure 2.4: Overview of Risk Assessment Methods

Risk analysis may be done using qualitative, semi-quantitative and/or quantitative approaches. Qualitative risk assessment methods can be used to identify assets to be detailed and bear a simple and rapid assessment. In this case, a single person or team can gather information. This assessment is used often when numerical data are inadequate or unavailable, resources are limited (budget or expertise) and time allowed is less. Semi-quantitative methods are used to describe the relative risk scale. For example, risk can be classified into categories like "low", "medium", "high" or "very high". In a semi-quantitative approach, different scales are used to characterize the likelihood of adverse events and their consequences. Analyzed frequency and their consequences do not require accurate mathematical data. The objective is to develop a hierarchy of risks against a quantification, which reflects the order that should be reviewed and no real relationship between them. In Quantitative techniques risk is considered as quantity that is estimated by the mathematical models, by taking the frequency from the data record from the standard guidelines.

In selecting a risk assessment process, the operator should consider the objective of the risk assessment and the level of risk, as well as the detail needed in the assessment results. All three approaches involve the same steps and a variety of

Safety Assessment techniques may be applied that correspond with these approaches. The common Safety Assessment techniques and the key points of each approach are listed in Table 2.1 [8].

Table 2.1: Key Aspects of Risk Analysis Technique [8]

Technique	**Safety Assessment Techniques**	**Aspects of the risk assessment technique**
Qualitative	HAZID	Low cost.
	What-if review	Risk output is not expressed as a numerical value.
	Safety audit	Based on the relative ranking of hazardous event from highest to lowest.
	Walk-through	Participants estimates the risk which can result higher ownership of the risk results for particular site.
	Checklist	It is subjective judgment, so a higher chances for uncertainty.
	Brainstorming	Lower level of risk estimation in general with lower risk ranking capacity.
	HAZOP	Cummulative risk analysis is very difficult.
	FMEA	This all methods are preliminary risk assessment tool or screening tools.
		It is task based risk assessments methods.
		It is generally for the facility where risk exposure is low.
		This is fast and quick assessment methods for the risk.
		It is easy to use.
		This takes into account of issues such as public outrage and company reputation.
Semi-Quantitative	Risk matrix method	Describes the relative risk scale.
		Describes the likelihood and consequence on a scale which is described in words.
	Fault Tree Analysis	Numerical risk value is generated though this value is not absolute.
		This provide higher capacity to differentiate between the hazards

Table 2.2: Key Aspects of Risk Analysis Technique [8]

Technique	**Safety Assessment Techniques**	**Aspects of the risk assessment technique**
Semi-Quantitative	Event Tree Analysis	Cumulative risk assessment can be done but difficult for the large sites. Caution should be taken to combining the data.
		Few methods provide a more structured techniques for taking and understanding the control.
Quantitative	Risk Contour	It is based on the calculated value of the consequences by software modeling and frequency is measured based on the data.
	F-N Curve	Give a calculated value of risk from the software.
		Suited for the complex decision making or the facility which have high risk.
	Fault Tree Analysis	Quantitative techniques provide a detailed knowledge of chains of event occuring.
	Event Tree Analysis	Detailed study and objective than other methods and gives the better selection between the diferent contol options.
		These consumes lots of time and expensive than other methods.
		QRA provides the risk contours on the plot plant of the facility for demonstrating the off-site risk for land use planning.

For the decision making level of information needed is different methods. As the level of knowledge needed in the qualitative risk assessment is less. The quantitative method is detailed risk assessment procedure, so level of accuracy is high. The level of accuracy is increases from the qualitative to quantitative as shown in the Figure 2.5 which helps in the decision making [8].

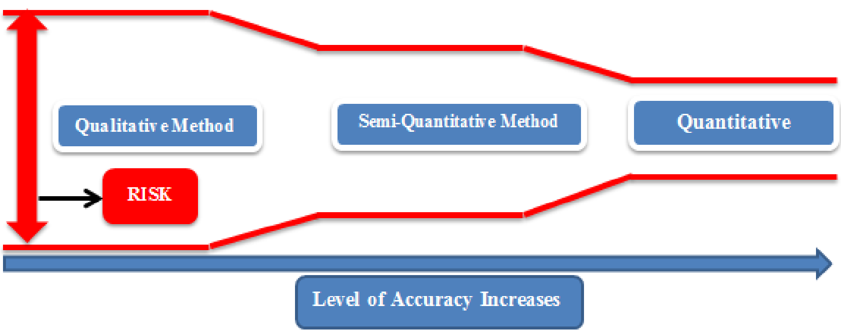

Figure 2.5: Spectrum of decision making [8].

2.4 Hazard Identification

2.4.1 HAZID (Hazard Identification)

HAZID is the term utilized for the identification of the external hazard associated events that have the potential to result in significant consequences. For example, a HAZID of refinery shall be conducted to identify the major hazard, which can result to the injuries and fatality of the individual. This technique can be applied to all or part of a facility or vessel or it can be applied to analyze operational procedures. Depending on the source of the resource and data availability the procedure can vary to great extent. System to be evaluated are divided into small parts according to the process or system wise, and then team people will led a brainstorming session which utilized checklists to identify the major hazards present in the facility or in each part of the system. This is done by the team of experienced persons involved in the field of design and operation facility, and the hazards that are considered significant are prioritized for further evaluation [9].

2.4.2 What-if Analysis

What-if analysis is a brainstorming approach that uses broad, loosely structured questioning to (1) postulate potential upsets that may result in mishaps or system performance problems and (2) ensure that appropriate safeguards against those problems are in place. This technique relies upon a team of experts brainstorming to generate a comprehensive review and can be used for any activity or system. What-if analysis generates qualitative descriptions of potential problems (in the form of questions and responses) as well as lists of recommendations for preventing problems. It is applicable for almost every type of analysis application, especially those dominated by relatively simple failure scenarios. It can occasionally be used alone, but most often is used to supplement other, more structured techniques (especially checklist analysis) [10].

2.4.3 Checklist Analysis

Checklist analysis is method which evaluates the system from per-establised criteria in the form of more then one checklists. It is utilized to achieve detailed and vigorous study and is used primarily to provide structure for documentation reviews, field inspections and interviews of the system being analyzed. This analysis generated the list of recommendations which are qualitative. Checklist analysis can be integrated with the other methods like what-if analysis to identify the specific requirements of the facility.

2.4.4 Hazard and Operability (HAZOP)

HAZOP technique is a very well structured and systematic method with the objective with the identifying the hazards and operability problems in the system. The guide words are utilized by the experienced group of individuals to find out the major hazard and the operability problems related to the equipment and systems. Guide words describing potential deviation from the intended design by application of the particular words (i.e high, low, no, etc.) to the process parameters (composition, flow, pressure, temperature etc). The experienced group have brainstorms sessions for the consequences of the deviations and they provide the appropriate safeguards to prevent the deviation for the intended purpose. This generates the qualitative results. The HAZOP analysis can also be used to review procedures and sequential operations [11].

2.4.5 Failure Modes and Effects Analysis (FMEA)

FMEA is an inductive reasoning approach that is best suited for reviews of mechanical and electrical hardware systems. The FMEA (1) technique considers how the failure mode of each component of the system may lead to performance problems in the system and (2) ensures that appropriate action against such problems safeguards are in place. This technique is applicable to any well-defined system, but the main use is for reviews of the mechanical and electrical systems. It is also used as the basis for defining and maintenance of equipment because the method focuses on direct and individual equipment failure modes. FMEA generates qualitative descriptions of potential performance problems (failure modes, root causes, effects and safeguards) and can be extended to include quantitative failure frequency and / or impact estimates [12].

2.5 Frequency Assessment Methods

2.5.1 Analysis of Historical Data

The frequency assessment is done from the research industry database and historical frequency data which relates to the same event. Before using this database good analysis should be performed to determine its applicability for the particular events. The analyst should consider the data from the source and quality or the data should also checked. When the frequency data base for the particular event is not present it is necessary to found out the frequency from the methods shown below.

2.5.2 Event Tree Analysis (ETA)

Event tree analysis shows the graphical models and the possible outcome of the initial event to the end event of interest. By this method we can identify the qualitative detailed description and it measures the event frequency of particular initiating events. Event tree analysis is used to determine the possible outcome of the of the initiating events for which the possible multiple safeguards are in line as protective features [13].

Example for event tree in Figure 2.6 illustrate the Leakage of LPG storage bullet.

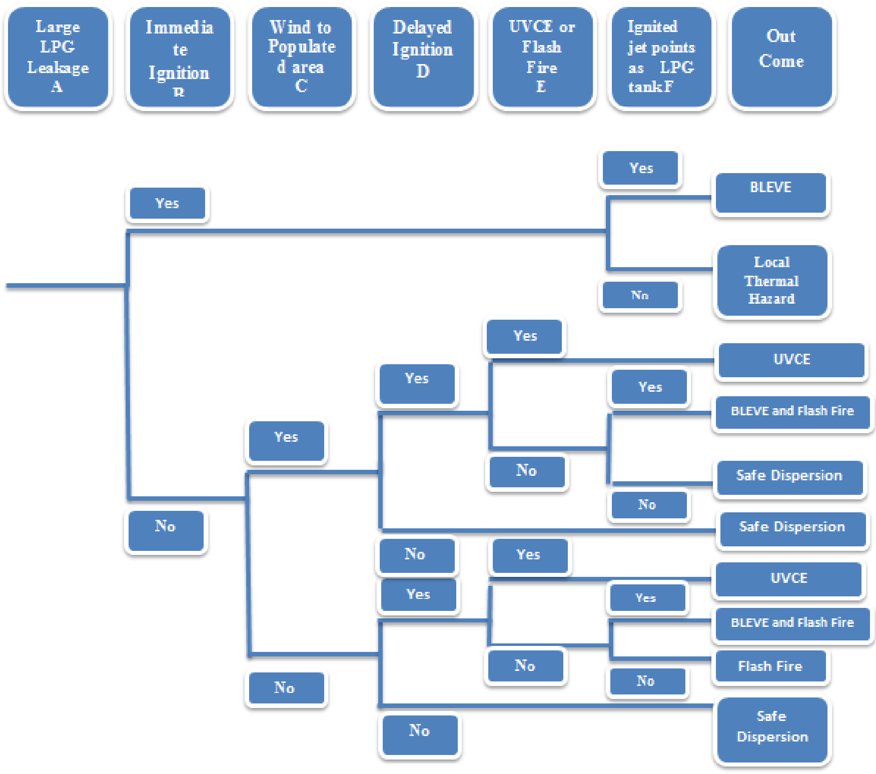

Figure 2.6: Event tree outcomes for sample problem [13].

2.5.3 Fault Tree Analysis (FTA)

Fault Tree Analysis (FTA) is a deductive analysis opposite of Event Tree Analysis. Logical relationship between the external events, human errors and equipment failure are combined to cause specific mishap interest. This is also similar to the Event Tree Analysis method we can identify the qualitative detailed description of the problems and it measures the event frequency of particular initiating events. This is most widely applied for the complex combination of the events. Following example of Fault tree Figure 2.7. Illustrates the failure of the lamp to light [14].

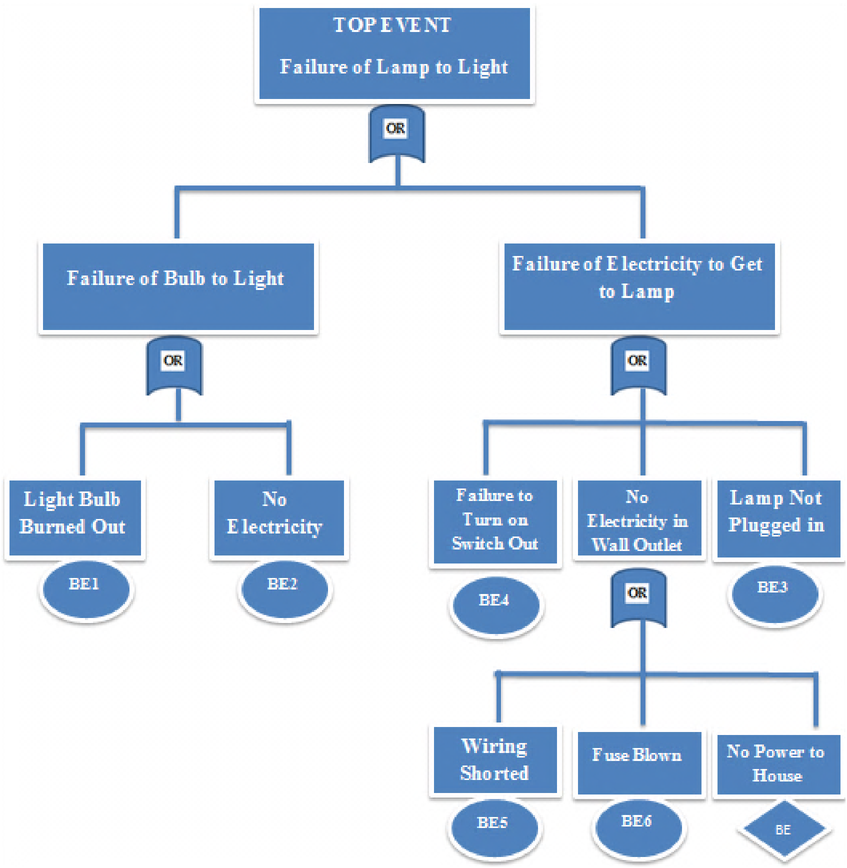

Figure 2.7: Fault tree for failure of lamp to light [14].

2.6 Consequence Assessment Methods

2.6.1 Discharge Rate Models

Hazardous event propagate from the discharge of the flammable or toxic material form the normal vessel. Discharge can take place from the vessel, pipe, vent and relief valves. The release phase can be in the form of gas, liquid or two phase. This model provide the basic input for the flash and dispersion model [15].

2.6.2 Flash and Evaporation Models

Main purpose of the flash and evaporation models is to found out the total vapor that forms a cloud. Liquid stored under the high pressure above the normal boiling point, will flash when released to the atmosphere. Vapor produced can be entrained into the liquid as droplets. The flashed vapor and liquid can be calculated by the thermodynamics considerations [15].

2.6.3 Dispersion Models

- **Neutral/Positively Buoyant Plume and Puff-Models**: This model is utilized to determine the concentration and time profile of the flammable and toxic material downwind by the Gaussian dispersion. Diffusion in the atmosphere is totally depended on the turbulence in the air. Gaussian model predicts the turbulence of the material in the atmosphere.

- **Dense Gas Dispersion Models**: This mechanism is different from the neutral and buoyant experienced by many different fields. Two different approach for the dense gas dispersion has been made one is mathematical and other is physical.

2.6.4 Fires and Explosions Models

- **Vapor Cloud Explosions (UVCE) and Flash Fire**: When gaseous flammable material is released a vapor cloud forms and if it is ignited before it is diluted below its lower explosive limit, a vapor cloud explosion Figure 2.8a and a flash fire may occur if the gas cloud reaches a source of ignition and rapidly burns back to the source of release Figure 2.8b. Insignificant level of confinement will result in flash fire. The vapor cloud explosion will result in overpressure.[15].

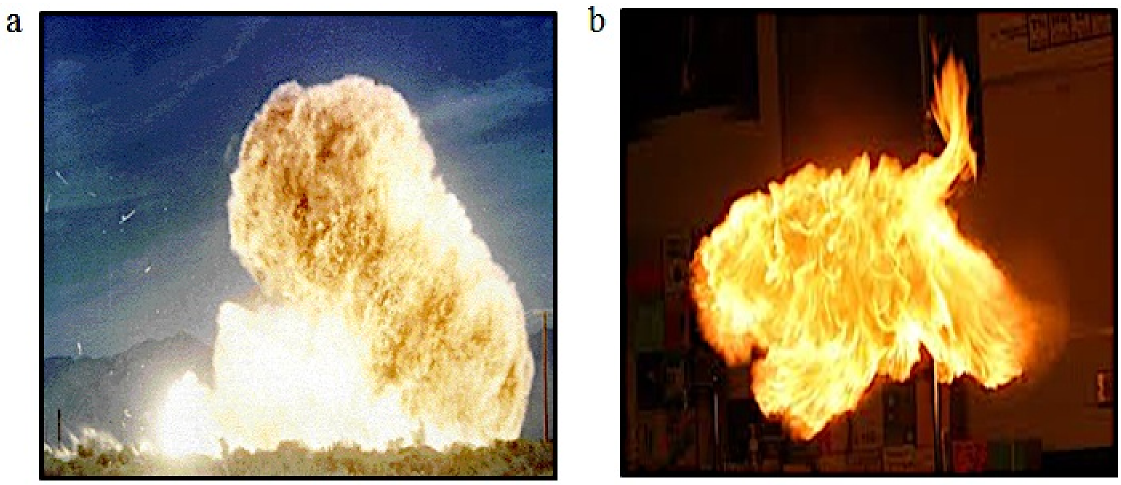

Figure 2.8: a) Example for Vapor Cloud Explosion; b) Example for Flash Fire

- **Physical Explosion**: Vessel containing a pressurized liquid/ gas ruptures and this resulting storage in the vessel energy is released as shown in Figure 2.9. This destroy the whole vessel produces a shock wave and accelerated vessel fragments. If the flammable material released and in the contact of ignition source results in the fire and explosion.

Figure 2.9: Example for Explosion

- **BLEVE and Fireball**: A Boiling Liquid Expanding Vapor Explosion (BLEVE) occures when there is sudden loss of containment if there is sudden increase in the pressure and temperature which contain the superheated liquid or liquified gas. This causes sudden release of the whole pressurized heated mass in the vessel into the atmosphere. Main cause of this BLEVE is the external fire impinging on the vessel surface which weakens the material of vessel and led to shell rupture [15].

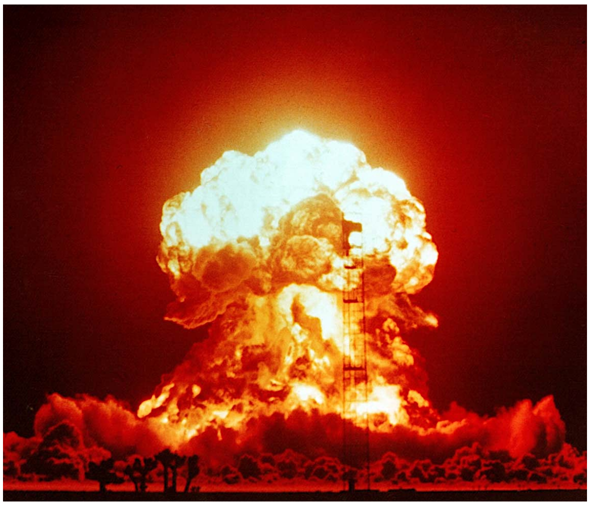

Figure 2.10: Example for Fire Ball

- **Pool Fire and Jet Fire:** Pool fires and jet fires are common fire types resulting from fires over pools of liquid or from pressurized releases or gas and/or liquid Figure 2.11. They tend to be localized in effect and are mainly of concern in establishing potential for domino effects and employee safety. Models are available to calculate various components - burning rate, pool size, flame height, flame tilt and drag, flame surface emitted power, atmospheric transmissive, thermal flux, etc.

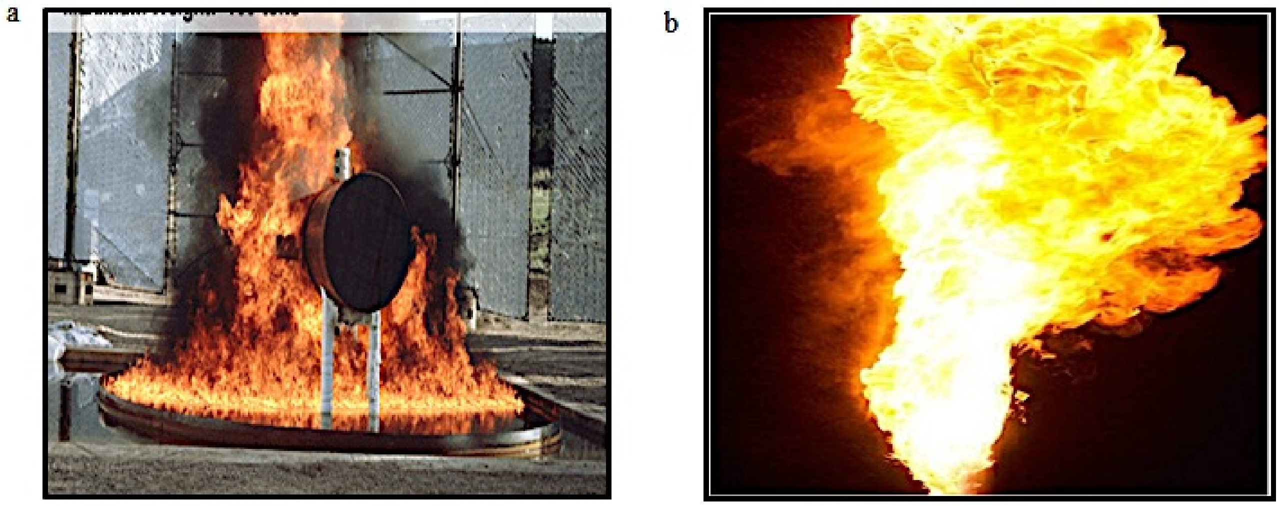

Figure 2.11: a) Example for Pool fire; b) Example for Jet fire

2.7 Methods for Determining Consequence Effects

2.7.1 Effect of Fire

The effect of fire on human beings causes a burn. There are basically three categories for the burns such as 'first degree', 'second degree' and 'third degree' burn. Major role in calculating the fire depends on the clothing, escape time, duration of exposure, however the primary considerations are duration of exposure and the thermal intensity level [15].

The heat radiation levels of interest are:

- 4 kW/m^2: Causes pain if unable to reach cover within 20 s.
- 4.7 kW/m^2: Accepted value to represent injury.
- 10 kW/m^2: Second degree bum after 25 s.
- 12.5 kW /m^2: Minimum energy required for melting of plastic.
- 25 kw/m^2: Minimum energy required to ignite wood.
- 37.5 kW/m^2 : Sufficient to cause damage to the equipment.
- 125 KJ/m^2: causing first degree bum.

- 250 KJ/m^2: causing second degree bum.
- 375 KJ/m^2: causing third degree bum.

2.7.2 Effect of Explosion

The effect of overpressure on human beings is twofold: a) Direct effect of overpressure on human organs, and b) Effect of debris from structure affecting human.

When there is sudden change in the pressure difference will damage the human organ. The damage to the human will depent mainly on the duration of overpressure, body weight, position of person and protection inside a shelter. The main organs which will most effected are the ear drum and lung.

The explosion overpressure of interest are:
a) 1.7 bar: Bursting of lung.
b) 0.3 bar: Major damage to plant equipment structure.
c) 0.2 bar: Minor damage to steel frames.
d) 0.1 bar: Repairable damage to plant equipment and structure.
e) 0.07 bar: Shattering of glass.
f) 0.01 bar: Crack in glass.

2.7.3 Toxic Effect

Toxicity values which shall be considered for evaluating its effect on the human for the release of the chemical are: a) Lethal dose levels. b) Emergency response planning guidelines. c)Permissible exposure limits.

- **Threshold Limit Values (TLV)**: Short Term Exposure Limit Values (STEL) these are the limits on exposure excursions lasting up to 15 min and should not be used to evaluate the toxic potential or exposure lasting up to 30 min. TLV-STEL limits is used in evolving measures to protect workers from acute effects such as irritation and narcosis resulting from exposure to chemicals. Use of STEL may be considered if the study is based on injury.
- **Immediately Dangerous to Life and Death (IDLH)**: The maximum air borne concentration of a substance to which a worker is exposed for as long as 30 min or any condition that poses an immediate or delayed threat to life or that would cause irreversible adverse health effects after 30min exposure [15].
- **Short Term Public Emergency Guidance Levels (SPEGL)**: These are defined as the acceptable concentration for exposures of members of general public. SPEGLs are generally set at 10 - 50 percent of EEGL (Emergency and Continuous Exposure Guidance Limit). Substances for which IDLH values are unavailable an estimated level of concern can be estimated for median

lethal concentration (LC50) or median lethal dose (LD50) levels reported for mammalian species. The LC50 and LD50 are concentrations or the dose that kill 50 percent of the exposed laboratory animals in controlled experiments. Lowest reported lethal concentration (LCLO) or lethal dose level (LDLO) can also be used as levels of concern [15].

2.8 Risk Analysis Methods

After the identification of the frequencies and consequences for the hazardous event for the process or system. We can able to identify the risk associated for the facility for the particular event.

2.8.1 Risk Matrix

Once generation of the consequences and the frequency is done, the risk matrix mechanism can be utilized for the identification of the risk. Matrix contains the cells which corresponds to a specific and unique combination of the likelihood on the x-axis and consequences on the y-axis. The priority of the risk will depend on the organization for acceptance of the particular risk value. [16].

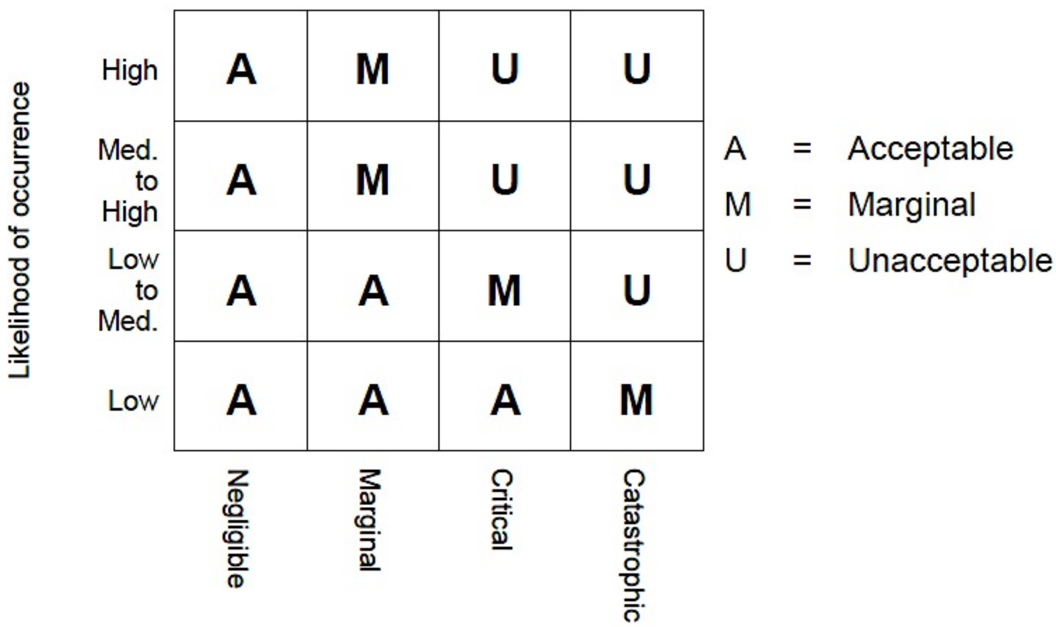

Figure 2.12: Example for Risk Matrix [16]

2.8.2 Risk Contour

Risk contour on the plot plan shows the nature of injury to the individual, likelihood of the injury per unit time and the distance of the hazard form the source point. The below figure indicates the location specific individual risk (LSIR) on the map. Contour shown in the figure connects points of equal risk around the whole facility.

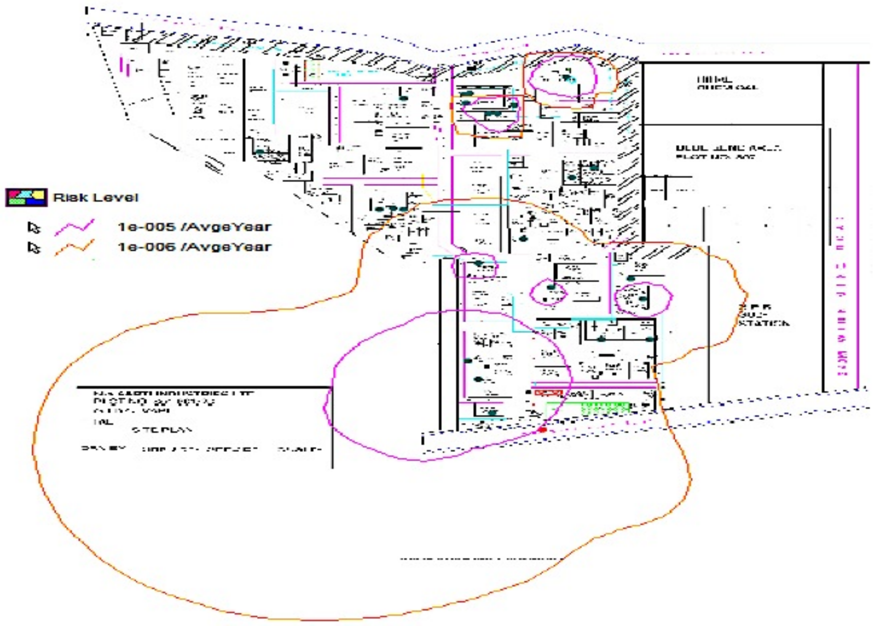

Figure 2.13: Example for Example for Location Specific Individual Risk

The various consequences outcome from the hazard like jet fire, flash fire, pool fire, vapor cloud explosion and dispersion of toxic gases is estimated and the contour for all the individual can be shown on the plot. There is the linearity between the distance from the point of hazard source and the concentration from the hazard source point. As we move away from the source of hazard the concentration of hazard decrease.

2.8.3 F/N Curve

A common form of risk assessment tolerability criteria for societal risk is on an FN-diagram, where two criteria lines divide the space into three regions where risk is intolerable, where it is broadly acceptable and where it requires further assessment and risk reduction as far as is reasonably practicable, as shown in Figure 2.14. Societal risk is a measure of risk to a group of people. An F-N curve is a plot of cumulative frequency of incident plotted on y-axis versus consequences expressed as number of fatalities on x-axis. A logarithmic plot is usually used because the frequency and consequences range over several orders of magnitude[17].

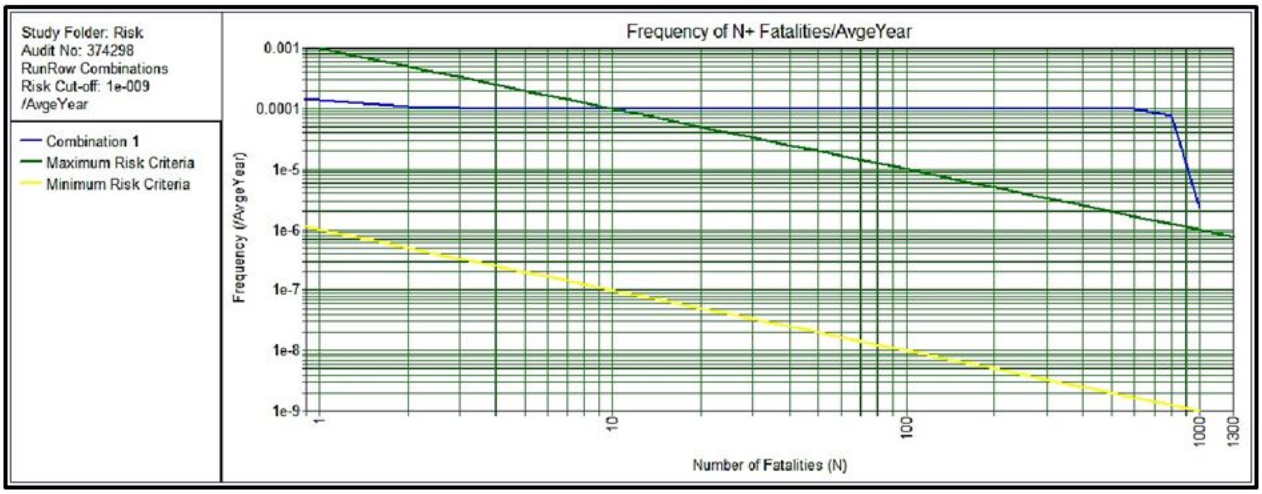

Figure 2.14: Example for F/N Curve [17].

2.9 Research Paper Citation

The objective of this work is to analyze and classify the main risk analysis and assessment (RAA) methods by the scientific/ Research literature as shown in below Table.

Table 2.3: Research Paper Citation for Literature Survey on Risk Assessment

Sr. No.	No. Field of application	Paper Citation	Techniques name	Methods
1	The relationship between culture and safety on offshore supply vessels (Antonsen, 2009)[18]	Checklists/ Safety Audits	Qualitative	Empirical data
2	Accident prevention in railway systems: Application of a safety approach (Rådbo, Svedung, & Andersson, 2010)[19]	FTA	Semi-Quantitative	Empirical data
3	Indicators to compare risk expressions, grouping, and relative ranking of risk for energy systems: Application with some accidental events from fossil fuels (Colli, Arellano, Kirchsteiger, & Ale, 2009; Colli, Serbanescu, & Ale, 2009) [20]	Probabilistic Risk Analysis (PRA)	Quantitative	Accidents data

Table 2.4: Research Paper Citation for Literature Survey on Risk Assessment

Sr. No.	No. Field of application	Paper Citation	Techniques name	Methods
4	Toward an evaluation of accident investigation methods in terms of their alignment with accident causation models (Katsakiori, Sakellaropoulos, & Manatakis, 2009) [21]	FTA	Quantitative	Empirical data (Case study)
5	Early hazard identification of chemical plants with state chart modeling techniques (Graf & Schmidt-Traub, 2000) [22]	HAZOP	Qualitative	Empirical data
6	Criticality evaluation of petrochemical equipment based on fuzzy comprehensive evaluation and a BP neural network (Guo, Gao, Yang, & Kang, 2009) [23]	Failure mode and effects analysis (FMEA)	Quantitative	Theoretical foundations
7	Applications of 3D QRA technique to the fire/explosion simulation and hazard mitigation within a naphtha cracking plant (Yet-Pole, Shu, & Chong, 2009) [24]	QRA	Quantitative	Empirical data
8	Comprehensive risk assessment and management of petrochemical feed and product transportation pipelines (Gharabagh et al., 2009) [25]	QRA	Quantitative	Empirical data
9	A quantitative risk-assessment tool for the external safety of industrial plants with a dust explosion hazard (van der Voort et al., 2007) [26]	QRA	Quantitative	Facts
10	A framework for understanding the development of organizational safety culture (Parker, Lawrie, & Hudson, 2006) [27]	Safety audits	Qualitative	Empirical data
11	Qualitative models of equipment units and their use in automatic HAZOP analysis (Bartolozzi, Castiglione, Picciotto, & Galluzzo, 2000) [28]	HAZOP	Qualitative	Theoretical foundations

Table 2.5: Research Paper Citation for Literature Survey on Risk Assessment

Sr. No.	Field of application	Paper Citation	Techniques name	Methods
12	Risk assessment of LPG automotive refueling facilities (Melchers & Feutrill, 2001) [29]	Quantified risk analysis (QRA)	Quantitative	Theoretical foundations & Empirical data
13	Risk assessment in maritime transportation (Guedes Soares & Teixeira, 2001) [30]	Quantified risk assessment	Quantitative	Theoretical foundations
14	A dynamic fault tree (Cepin & Mavko, 2002) [31]	FTA	Semi-Quantitative	Theoretical foundations Chemical
15	Quantifying uncertainty under a predictive, epistemic approach to risk analysis (Apeland, Aven, & Nilsen, 2002) [32]	Quantified risk analysis (QRA)	Quantitative	Theoretical foundations &
16	Accident sequence analysis of humane computer interface design (Fan & Chen, 2000) [33]	FTA, ETA	Semi-Quantitative	Theoretical foundations
17	Prioritizing and quantifying the risk of outstanding corrective actions (Burns & Turcotte, 2000) [34]	Probabilistic Risk Analysis (PRA)	Quantitative	Theoretical foundations
18	On the ALARP approach to risk management (Melchers, 2001) [35]	ALARP approach	Qualitative	Theoretical foundations
19	A case study in the integration of accident reports and Constructive design documents (Johnson, 2010) [36]	Accident reports	Qualitative	Theoretical foundations
20	Risk assessment of LPG automotive refueling facilities (Melchers & Feutrill, 2009) [37]	Quantified risk analysis (QRA)	Quantitative	Theoretical foundations &
21	Automated multiple failure FMEA (Price & Taylor, 2010) [38]	Failure mode and effects analysis (FMEA)	Qualitative	Theoretical foundations
22	Quantifying uncertainty under a predictive, epistemic approach to risk analysis (Apeland, Aven, & Nilsen, 2011) [39]	Quantified risk analysis (QRA)	Quantitative	Theoretical foundations & Empirical data

Table 2.6: Research Paper Citation for Literature Survey on Risk Assessment

Sr. No.	**No. Field of application**	**Paper Citation**	**Techniques name**	**Methods**
23	Integration of interlock system analysis with automated HAZOP analysis (Cocchiara, Bartolozzi, Picciotto, & Galluzzo, 2011) [40]	HAZOP	Qualitative	Theoretical foundations
24	Identification of reference accident scenarios in SEVESO establishments (Delvosalle et al., 2012) [41]	FTA, ETA & Identification of Major Accident Hazards (MIMAH) methodology	Qualitative Accident data	Empirical data
25	Condition-based fault-tree analysis (CBFTA): A new method for improved fault-tree analysis (FTA), reliability and safety calculations (Shalev & Tiran, 2012) [42]	Condition-Based FTA (CBFTA)	Quantitative	Statistical data
26	Quantitative risk assessment model of hazardous chemicals leakage and application (Hu Si a,b,., Hong Ji a,b, Xiaohong Zeng b, 2012)[43]	QRA	Quantitative	Empirical data
27	An extended risk assessment approach for chemical plants applied to a study related to pipe ruptures (Maria Francesca Milazzo a, Terje Aven b,n) [44]	QRA	Quantitative	Empirical data
28	Comparison study on qualitative and quantitative risk assessment methods for urban natural gas pipeline network (Z.Y. Han, W.G. Weng) [45]	QRA	Qulatitative	Empirical data

Main results and conclusions of this work are summarized to the following points:

- The reviewing of this scientific research paper, shows that published technical research on risk assessment for many different fields like mechanics, engineering, chemical industry, computer science, transportation, Engineering etc.

- Three major risk assessment techniques are: a) qualitative, b) semi-quantitative and c) quantitative.

- After referring these research paper it was clear that quantitative methods has the highest application as compared to the qualitative which as lower application. And the semi-quantative methods has very low application.
- According to quantitative techniques, the risk can be considered as a quantity, which can be estimated and expressed by a mathematical relation, under the help of real accidents data recorded in a work site. This method serves high accuracy as compared to other techniques.
- The field of Chemical Industry concentrates on greatest number of risk assessment and that particular Quantitative methods, while other fields with significant percentages low.
- This shows the quantitative risk assessment application is high because of its detailed analysis, accuracy and applicability to complex process.

Chapter 3

Methodology and Case Study

3.1 HAZOP method

HAZOP is the method used for the identification of hazards, which is important step in Risk Assessment as it leads to the generation of accidental scenarios for QRA study. The merits of including the hazard for further investigation are subsequently determined by its significance, normally using a cut-off or threshold quantity. Once a hazard has been identified, it is necessary to evaluate it in terms of the risk it presents to the employees and the neighboring community.

During the hazard identification component, the following considerations are taken into account as follows:

- Chemical identities.
- Location of process unit facilities for hazardous materials.
- The types and design of process units
- The quantity of material that could be involved in an airborne release
- The nature of the hazard (e.g. airborne toxic vapors or mists, fire, explosion, large quantities stored or processed handling conditions) most likely to accompany hazardous materials spills or releases.

HAZOP technique is a very well structured and systematic method with the objective of:

- Identifying the hazards involved in the system, and
- Identifying operability problems in the system.

British Standard IEC (International Electrotechincal Commission) 61882[46] is generally followed worldwide for HAZOP study methodology. A simple flowchart deduced from IEC 61822 [46] summarizing the HAZOP method is shown in Figure 3.1.

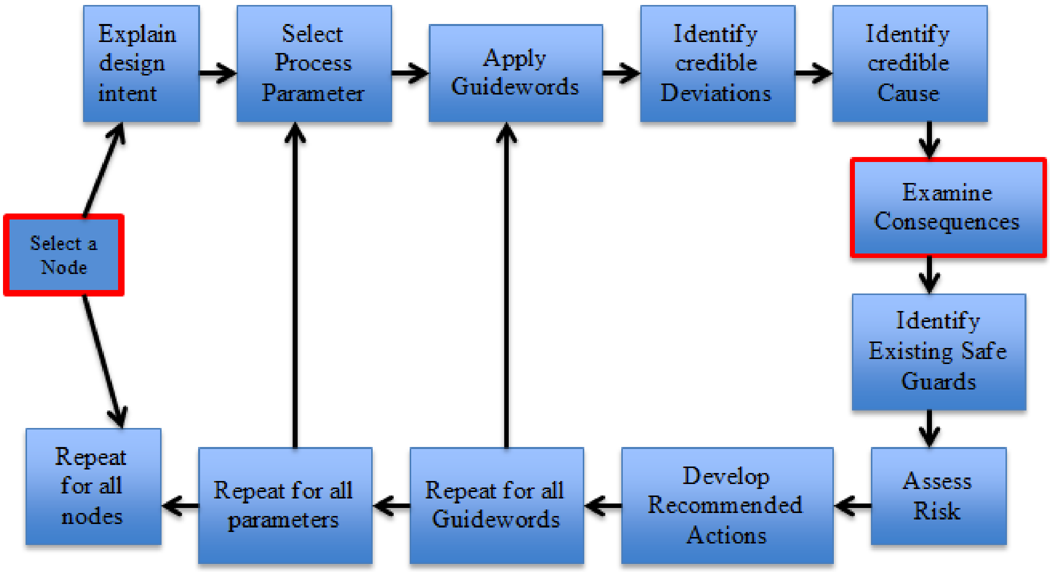

Figure 3.1: Flowchart of HAZOP study Methodology [46].

The HAZOP study begins with the selection of the node and it moves clock wise as shown in flowchart Figure 3.2 and ends with repeat for all nodes. Examining major consequence from HAZOP will be important step for the determination of the accidental scenario for the QRA study.

		HAZOP STUDY							
		HAZOP WORKSHEET							
NODE NO: 12	Description: Design Intention:				P & ID No.:				
PARAMETER	DEVIATIONS / GUIDE WORDS	CAUSES	CONSEQUENCES	EXISTING SAFE GUARDS/ COMMENTS	N-	RECOMMENDATION / ACTION	TYPE	ACTION BY	
Flow	More flow of								
	Less flow of								
	No flow of								
	Reverse flow of								
Pressure	High pressure in								
	Low pressure in								
Temperature	High temperature in								
	Low tempreture in								
Level	High level in								
	Low level in								
Concentration	High concentration of								

Figure 3.2: Sample HAZOP Worksheet.

Step 1: Node

The system is broken down into small parts, which is known as the node. If this contain to many small nodes, this will consume lots of time. If the node selected is too large there is chances that things can be missed while study. There is no such procedure for the node selection but this totally depends on the experience of the chairperson. The typical boundaries between nodes can be process or module boundaries, Pressure, temperature, Connections into headers, points at which streams converge or diverge and battery limits.

Step 2: Parameters

The physical parameters such as flow, temperature, pressure, level and concentration are changed or deviated from their normal operation conditions by use of guide words. These guide words with their meaning are given in the table 3.1 shown below.

Table 3.1: Guide word and their physical significance [46]

Guide Words	**Meaning**	**Parameter**	**Deviation**
MORE	Quantitative Increase	Flow	High Flow rate
		Level	High Level
		Temperature	High Temperature
		Pressure	High Pressure
LESS	Quantitative Decrease	Flow	Low Flow rate
		Level	Low Level
		Temperature	Low Temperature
		Pressure	Low Pressure
		Concentration	Low Concentration
AS WELL AS	Qualitative modification/increase	Concentration of impurity	Concentration increase
		Temperature of substance	Temperature increase
		Level of impurity	Level increase
		Flow of impurity	Flow increase
PART OF	Qualitative modification/decrease	Concentration	Concentration decrease
		Flow	Flow decrease
		Level	Level decrease
REVERSE	Logical opposite of the design intent	Flow	Reverse flow rate
		Pressure	Reverse pressure

Table 3.2: Guide word and their physical significance [46]

Guide Words	Meaning	Parameter	Deviation
OTHER THAN	Complete substitution	Concentration of desired substance	Concentration Zero
		Level of desired substance	Level Zero
		Flow of desired substance	Flow rate zero
HIGH	Quantitative increase	Temperature	High Temperature
		Pressure	Low Pressure
LOW	Quantitative decrease	Temperature	High Temperature
		Pressure	Low Pressure

Step 3: Cause

The third step of HAZOP study involves determination of cause for a particular deviation occurring. These causes are usually, because of the malfunctioning of control valve, pump VFD malfunctions, strainer choking, siphoning, manual human error etc., to avoid repetition during the analysis causes applicable to the particular node should only be listed. Majority of the causes found in an industry are due to human error. Hence care should be taken to account for all those human errors to make study practicable and accurate. Once the causes for the deviation have been determined the next step in the HAZOP process involves determination of consequences.

Step 4: Consequences

Consequences are the effects that would be produce due to the cause determined in step 3. Consequences are identified for each cause. There may be more than one consequence resulting from a single cause. These consequences can lead to deterioration in product quality, process upset, explosion or release of chemicals, production stoppage or plant shutdown. The main aim of the HAZOP process is to mitigate these consequences by addition of safeguards. Step 3 and step 4 are important steps in HAZOP process as they bring out different kinds of hazards that can occur in a particular industry.

Step 5 & 6: Safeguards & Recommendations

Once the consequences have been determined, existing safeguards are reviewed to make sure whether provided safeguards are adequate to stop the event from occurring. If the safeguards provided are not sufficient, recommendations are given to improve the process. The loop then continues till all the guide words, parameters and nodes are addressed. This methodology is used during the HAZOP study for Hydro Cracker Unit in Refinery. Appendix B shows the HAZOP worksheets of Hydro cracker Unit.

3.2 QRA Methodology

Quantitative Risk Assessment (QRA) in particular have been used in the chemical industry for many years to support decision-making on the choice of arrangements and measures associated with chemical processes, transportation and storage of dangerous substances. The quantitative method consists of a probability assessment, a consequences analysis and a risk evaluation. The outcome of the qualitative method is a qualitative risk value, and for quantitative method the outcomes are individual risk and social risk.

A simple flowchart deduced from IS 15656[6] summarizing the QRA method as shown in Figure 3.3. This methodology begins with the system definition and ends with the risk comparison with the acceptance criteria.

Step 1: System Definition

The potential hazards associated with a facility or the activities are analyzed. The scope of work for a QRA is defined like the boundaries for the study, identifying which activities are to be included and which are excluded, and which phases of the facilitys life are to be assessed.

Step 2: Hazard Identification

There are various methods for the hazard identification. Here the HAZOP study was done for identifying the major hazard in the facility and for generation of the accidental scenario, which is the most important step for the Quantitative Risk Assessment study.

Step 3: Accidental Scenario

The accidental scenario is developed from the HAZOP study from above step. The various accidental scenario like Catastrophic Rupture, Leak, Vent from Vapor Space, Line Rupture, Long Pipeline Leak and Rupture, Disk Rupture, Relief Valve Failure, Tank roof Failure is been considered for the study.

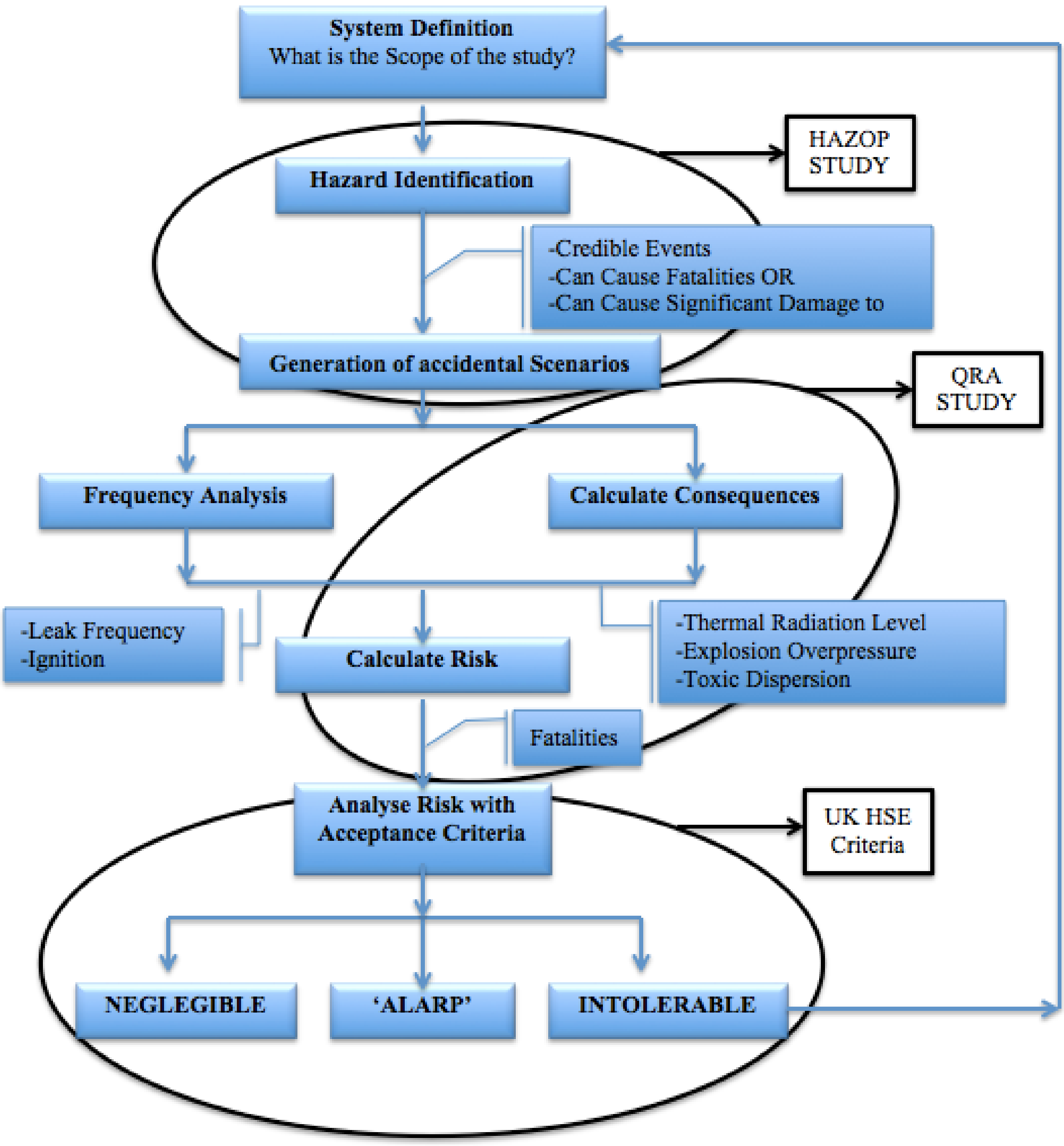

Figure 3.3: QRA Methodology [6].

Step 4: Frequency Calculation .

Once the potential hazards have been identified, failure frequency estimates how likely it is for the accidents scenario developed from HAZOP study to occur. The component failure frequencies to be used is usually derived from an analysis of historical accident experience (Failure databases), or by some form of theoretical modeling UK HSE Failure Frequencies Database and TNO Purple book.

Step 5: Consequences Calculation

In parallel with the frequency analysis, consequence modeling evaluates the resulting effects if the accidents occur, and their impact on people, equipment and structures, the environment or business, depending on the defined scope of the QRA study. This Estimation of the consequences of each possible event is done by the computer modeling software which is Phast and Phast Risk. Consequence analysis requires the modeling of a number of distinctive phases, i.e. discharge, dispersion, fires and explosions (for flammable materials). The consequences are classified as toxic gas release, fire leading to injury, fatality or property damage and explosion either mechanical or chemical.

Step: 6 Risk Calculations

When the frequencies and consequences / impact of each modeled event have been estimated, they can be combined to produce risk results by the software utilized. The output of the software is in the form of risk contour or LSIR (Location specific individual risk), commonly known as Individual risk - the risk experienced by an individual person and in the form of graph commonly known as Group/Societal risk - the risk experienced by a group of people exposed to the hazard.

Step: 7 Risk Assessment with criteria

Risk Assessment is the process of comparing the level of risk against a set criteria as well as the identification of major risk contributors. The criteria are set either by the regulator or the operator. For the Individual risk levels above 1 x 10-3 per year will be considered unacceptable and will be reduced, irrespective of cost. Individual risk levels below 1 x 10-6 per year will be broadly acceptable. Risk levels between 1 x 10-3 and 1 x 10-6 per year will be reduced to levels as low as reasonably practicable (ALARP) as per UK HSE standard [47].

Step: 8 Tolerable/ ALARP/ Intolerable

The risk for the facility comes under the tolerable limits then the existing safeguard is sufficient for the facility. If the risk comes under the ALARP region that is the risk within this region is tolerable only of further risk reduction is considered impracticable because the cost required to reduce the risk is grossly disproportionate to the improved gain. And if the risk fall under the intolerable region then the various risk mitigation measures is to be taken to reduce the risk to ALARP region or in tolerable region.

3.3 Hydro Cracker Unit

Cracking is the process whereby the complex organic molecules such as heavy hydrocarbon are broken down into simpler molecules such as a light hydrocarbon. The breaking of C-C bonds occur which depend on the temperature and the presence of the catalyst. The cracking is the breakdown of the large alkane into smaller, more useful alkanes and alkenes.

The Hydro cracking is the catalytic cracking process assisted by the presence of an elevated partial pressure of the Hydrogen gas. Feed to the unit consists of a blend of vacuum gas oil (VGO) from a vacuum distillation unit (VDU) and coker distillates from a delayed coker unit (DCU). The objective of the Hydro cracking Unit is to produce middle distillate fuel of superior quality.

The primary products from the unit are:

- LPG
- Stabilized Light Naphtha
- Heavy Naphtha
- Kerosene (Aviation Turbine Fuel)
- High Speed Diesel

3.3.1 Process Description

The process flow description of the Hydro cracker for operation is divided into the following sections [48]:

- **Make-Up Hydrogen Compression Section:**The make-up hydrogen compression section supplies high purity, high pressure hydrogen from an off plot pressure swing adsorption (PSA) unit to the reaction section.
- **Reactor Feed System:** The feed system preheats and filters the fresh oil feed before it enters the filtered feed surge drum. It also prepares the feed to the second-stage reactor. The oil feeds are then pumped to system pressure before they are mixed with high pressure, hydrogen-rich recycle gas.

These systems are discussed in the following sections:

Feed Filter System

Reactor Feed Pumps

- **Reactor Feed Heating System:**The reactor feed heating system consisting of the feed/effluent exchangers and feed furnaces heats the first and second stage reactor oil and gas feeds to the desired reactor inlet temperatures.

- **Reactor System:** The reactor system hydro treats and hydro cracks the oil to the desired products.

- **Reactor Effluent Cooling:** The reactor effluent cooling system cools the reactor effluent from both stages before they are combined.

- **High Pressure Reactor Effluent Separation:**The reactor effluent separation system separates the oil and gas in the combined reactor effluent at high pressure and high temperature, cools the reactor effluent vapor, removes ammonium bi-sulfide from the condensing vapor, and separates additional oil from the gas at low temperature and high pressure to form a hydrogen-rich recycle gas stream.

Subsections are:

Hot High Pressure Separator

Effluent Vapor Cooling

Fouling and Corrosion Control in Effluent Vapor Cooling

Water and Poly-sulfide Injection Facilities

Effluent Vapor Air Cooler

Cold High Pressure Separator

- **Recycle Gas Compressor:** The recycle gas compressor compresses the recycle gas stream to near reactor inlet pressure. Some of the gas is sent to the reactor as quench. The rest is combined with make-up hydrogen, heated, and mixed with first and second stage reactor oil feeds.

- **Low Pressure Separators:** The low-pressure separators recover any remaining hydrogen-rich gas from the reactor effluent liquid stream produced from the initial high-pressure flashes. Liquid streams from the low-pressure separators are combined to form the product fractionator feed.

- **Fractionation Section:** The fractionation system separates the reactor effluent liquid into the desired product streams, provides preheat for the reactor oil feeds, and provides feed to the light ends section. Subsections are: -Product Fractionator Feed Heating -Product Fractionator -Overhead System -Product Fractionator Side cut Strippers.

- **Light Ends Recovery and LPG Treating:** The light ends section separates un-stabilized light naphtha to recover sour fuel gas, stabilized light naphtha, and LPG. The LPG is then treated to meet sales specifications. Subsections are: -Light Ends Compression Section -De-ethanizer -Stabilizer -LPG Treating Section.

Hazards associated with this Hydro Cracker units are summarized in the following table:

Table 3.3: Hazards associated with Hydro Cracker Unit

Category	**Material**	**Associated Hazard**
Flammable Liquid	Crude Oil, Naptha, HSD, SKO	JF, FF, PF, EX
Flammable Gas Under Pressure	Hydrogen	JF, FF, FB, BLEVE, VCE
Toxic Gas	Sour Gas, Hydrogen Sulfide	Toxic Dispersion
Toxic Liquid	Sour Water	Toxic Dispersion

3.4 HAZOP of Hydrocracker Unit

The HAZOP study was conducted at the refinery for Hydrocracker unit. The study involved a team of experienced engineers in diverse discipline. Before the study, a total of 26 nodes were created based on the criteria's mentioned in step 1 of HAZOP method. Table 3.4 provides detail on the number of nodes created for the analysis. The HAZOP study was carried out for 41 different P & IDs shown in Appendix A. The main reason for the HAZOP study was to extract data for the accidental scenario for QRA method. Figure shows the required QRA data, which will be made available from the HAZOP method.

Table 3.4: Node description of HAZOP study

Node No.	**Node Description**
01	Liquid feed preparation system up to feed surge drum (VV-001)
02	Feed preparation system from feed surge drum VV-001 to filter feed surge drum (VV-002).
03	First stage reactor feed stream from filtered feed surge drum VV-002 to first stage heater outlet.
04	First stage lead & main reactor and first stage reactor effluent.
05	High pressure reactor effluent separation circuit
06	Recycle gas loop
07	Low pressure separator and fractionator feed system.
08	CLPS treatment section
09	Fractionator feed furnace (FF-003) fuel and firing system
10	Fractionator overhead, cooling systems, overhead accumulator and reflux systems
11	Off gas compressor system up to de-ethanizer feed
12	De-ethanizer overhead section and bottom section up to

Table 3.5: Node description of HAZOP study

Node No.	Node Description
13	Stabilizer feed Stabilizer circuit
14	LPG wash section
15	Heavy naphtha stripper and product rundown system
16	Kerosene stripper and product rundown stream
17	Diesel product section
18	Fractionator bottom system and 2nd stage reactor feed
19	Second stage reactor and effluent system
20	Make up hydrogen section
21	MP steam generation and super heating system
22	MP steam generation and super heating system
23	Tempered water system
24	Flare KOD
25	CBD system
26	Start-up circuit

The objective of HAZOP study was to identify the major consequence, which can lead to unwanted events. And this will help for the generation of accidental scenario for the QRA study. Although worksheet shows recommendations given to the facility, for the purpose of this project only the consequence factors will be considered for analysis. Complete HAZOP worksheets of the facility are shown in Appendix B and node marked P&ID in appendix A.

3.5 Results and Discussion of HAZOP Study

The study was conducted at their facility for a total of 12 days. 26 Nodes as discussed earlier were addressed and suitable recommendations where required were given. The team comprised of total of 7 different disciplines consisting of process engineer, instrument engineer, HAZOP chairman, safety engineer, technical scribe, project engineer and operation representative.

3.5.1 QRA Scenario

There are many ways for determining accidental scenario for risk assessment for QRA study. Some of the most common ways scenarios are developed for QRA study are:

- Location of process unit facilities for hazardous materials.
- Recent incidents in the process.

- The nature of the hazard (e.g. airborne toxic vapors or mists, fire, explosion, large quantities stored or processed handling conditions) most likely to accompany hazardous materials spills or releases.
- Suggested interlocks for safer operations in the process.
- By determining major consequences in the HAZOP study for the scenario for QRA study.

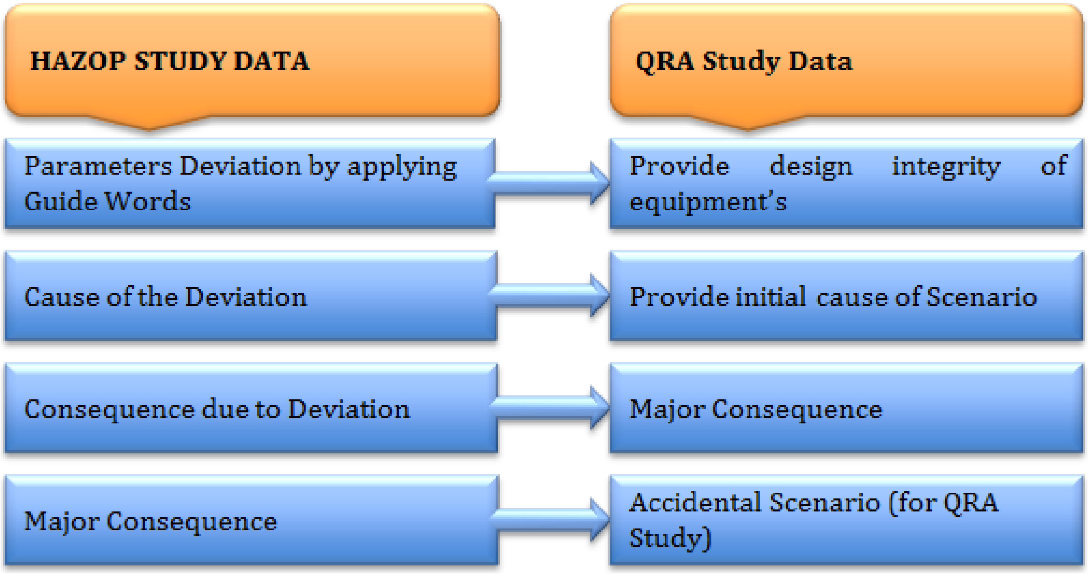

Figure 3.4: Utilization HAZOP study in QRA study

This report considers the method for determining the scenarios through HAZOP method. The advantage of this method over other is, while analysis the analysts get friendlier to plant operations and the operating problems faced by them. The major consequences identified during the HAZOP analysis are listed in Table 5.5 below. The consequences listed in the table, which leads for the generation of the accidental scenario for the QRA study. The main aim of the first part of the project was to conduct HAZOP study on a selected industry and to generate accidental scenario for QRA study.

Table 3.6: Major Consequences of HAZOP for Accidental Scenario Identification

Major Consequences from HAZOP	**Equipment**	**Accident Scenario**
High pressure in the Lead reactor 04-RB-001 and it may damage.	First Stage Lead Reactor 04-RB-001	Leak-Small, Medium & Catastrophic Rupture

Table 3.7: Major Consequences of HAZOP for Accidental Scenario Identification

Major Consequences from HAZOP	**Equipment**	**Accident Scenario**
High pressure in the reactor 04-RB-002 and it may damage.	First Stage Main Reactor 04-RB-002	Leak-Small, Medium & Catastrophic Rupture
High pressure in the reactor 04-RB-003 and it may damage.	Second Stage Reactor 04-RB-003	Leak-Small, Medium & Catastrophic Rupture
Liquid carry over to the compressor 04-KA-001 and it will damage it.	Recycle Gas Compressor 04-KA-001	Leak-Small, Medium
High Temperature in reactor effluent which will cause Possibility of material damage due to Hydrogen embritlement.	Cold High Pressure Separator (CHPS) 04-VV-004	Leak-Small, Medium & Catastrophic Rupture
High Pressure in the Cold Low Pressure, due to high liquid flow from CHPS and vapour from HLPS.	Cold Low Pressure Separator (CLPS) 04-VV-006	Leak-Small, Medium & Catastrophic Rupture
High Pressure in Hot Low Pressure Separator (HLPS) 04-VV-005	Hot Low Pressure Separator (HLPS) 04-VV-005.	Leak-Small, Medium & Catastrophic Rupture
High Temperature in the separator 04-VV-003, material damage due to Hydrogen embritlement.	Hot High Pressure Separator (HHPS) 04-VV-003	Leak-Small, Medium & Catastrophic Rupture
High Pressure in Product Fractionator 04-CC-001	Product Fractionator 04-CC-001	Leak-Small, Medium & Catastrophic Rupture
Due to Low/ no flow at the pump 04-PA-007 suction it will run dry which will lead to pump seal damage.	Fractionator bottom pump 04-PA-007 suction line	Leak-Small, Medium
High Pressure in Heavy Naptha stripper 04-CC-002	Heavy Naptha Stripper 04-CC-002	Leak-Small, Medium & Catastrophic Rupture
Due to Low/ no flow at the pump 04-PA-010 suction it will run dry which will lead to pump seal damage.	Heavy Naptha Product Pump 04-PA-010 suction line	Leak-Small, Medium

Table 3.8: Major Consequences of HAZOP for Accidental Scenario Identification

Major Consequences from HAZOP	**Equipment**	**Accident Scenario**
High Pressure in Kerosene Stripper 04-CC-003	Kerosene Stripper 04-CC-003	Leak-Small, Medium & Catastrophic Rupture
Due to Low/ no flow at the kerosene pump 04-PA-009 suction it will run dry which will lead to pump seal damage.	Kerosene Product Pump 04-PA-009 suction line	Leak-Small, Medium
High Pressure in Kerosene Stripper 04-CC-004	Diesel Stripper 04-CC-004	Leak-Small, Medium & Catastrophic Rupture
Due to Low/ no flow at the pump 04-PA-010 suction it will run dry which will lead to pump seal damage.	Diesel Product Pump 04-PA-008 suction line	Leak-Small, Medium
High Pressure in Deethanizer 04-CC-005	Deethanizer 04-CC-005	Leak-Small, Medium & Catastrophic Rupture
Due to Low/ no flow at the Deethanizer pump 04-PA-016 suction it will run dry which will lead to pump seal damage.	Deethanizer Bottom Pumps 04-PA-016 suction line	Leak-Small, Medium
Liquid carry over to first stage compressor 04-KA-002 and it will damage it.	First Stage off gas compressor 04-KA-002	Leak-Small, Medium
Liquid carry over to the 2nd stage compressor 04-KA-002 and it will damage it.	2nd Stage Off gas Compressor 04-KA-002	Leak-Small, Medium
High Pressure in KO Drum 04-VV-013	KO Drum 04-VV-013	Leak-Small, Medium & Catastrophic Rupture

3.5.2 Safeguard and Recommendation

HAZOP of Hydrocracker Unit where the results is shown in Appendix B. The facility is well engineered with sufficient safeguards provided as shown in the worksheet Appendix B. Some of the very specific safeguards provided at the facility were:

- Transmitters with high and low alarms.
- Interlocks for abnormal conditions.
- Updating and correct the P&ID to show the changes in the Plant.
- SOP for the particular operations.
- Providing the isolation valve.

However, for further improvement with respect to the safeguards against possible causes and the consequences total of 84 recommendations were provided. These recommendations can be categorized into engineering, hardware, software and operation. For the sake of this report, recommendations part will not be explained in detail as the main objective of HAZOP was to identify accidental scenarios for the Hydro cracker unit for the QRA study.

Chapter 4

Risk software

HAZOP study has identified the major consequences which helped for the generation of the accidental scenario for the QRA study. This all accidental scenarios are source model for the Phast and Phast Risk software for identification of the major risk in the selected facility. This will let us know the consequence by radiation, explosion and toxicity of the material as well as the distance affected from the source point around the selected facility.

4.1 Why QRA?

There are many reasons for performing a QRA and equally as many benefits. QRA can be used as a way of maximizing safety at minimum cost, it can be used as part of developing safety cases, or it may be a requirement of the particular legislative regime within which a plant operates. There may also be risk exposure criteria which are acceptable for insurance purposes which have to be satisfied or it may be useful purely from a decision making standpoint. QRA combined with an effective safety management system can act to both improve safety and reduce costs. It is of particular benefit when identifying the most effective risk reduction measures. By clearly identifying the areas of highest risk, it allows effort to be focused on them. When a risk reduction measure is proposed, its effect can be clearly illustrated by modifying the QRA model and recalculating the risk levels to assess how effective this measure has been. Using this methodology the benefits of a variety of risk reduction measures can be compared and the most effective combination can be implemented. Also, by including cost estimation for each suggested risk reduction measure, a cost benefit element can be included in the QRA to determine which measure, or combination of measures, will be most cost effective.

4.2 Why Software?

In order to perform an effective QRA it is essential that all possible accident scenarios are taken account of so that potential sources of high risk are not omitted from the overall risk picture. This means that QRAs rely on large quantities of accurate data and the performance of many repetitive calculations and risk summations. Also, in order for the QRA results to be as accurate as possible, well developed state-of-the-art mathematical models must be used to calculate the consequences of each scenario and feed into the overall risk calculations. In the past, computer technology was such that expensive mainframes or workstations were required to perform these calculations. However, as technology has moved forward, hardware has become much more powerful at much lower cost. Also, system software such as operating systems, databases and development environments has become much more powerful, enabling software developers to provide far more user friendly solutions. It has become possible over the last few years to make consequence modeling tools, such as Phast, and full QRA packages, such as SAFETI, accessible on hardware and operating systems that are available to far more analysts. Also, as models become better validated and evolve to give more accurate results and tools become more user friendly and robust, they no longer necessarily need expert users. That is not to say users no longer need to understand consequence and risk. However, they no longer need to understand how the data is handled, the variety of operating systems under which they run and the architectural and navigational anomalies previously necessary to shoe-horn the applications into the available hardware and software platforms.

4.3 Phast introduction

The Phast stands for Process Hazard Analysis Software Tool. Phast is a complete software package for consequence analysis in the process industry. As shown in the figure 4.1 Phast lies within the Risk Assessment process. Phast runs discharge, dispersion and effects calculation all from one interface with seamless data movement between the stages. This architecture enables rapid and transparent data entry and flexible modification to fully support the risk management cycle. An integrated system provides consistent look and supports a rapid learning curve[49].

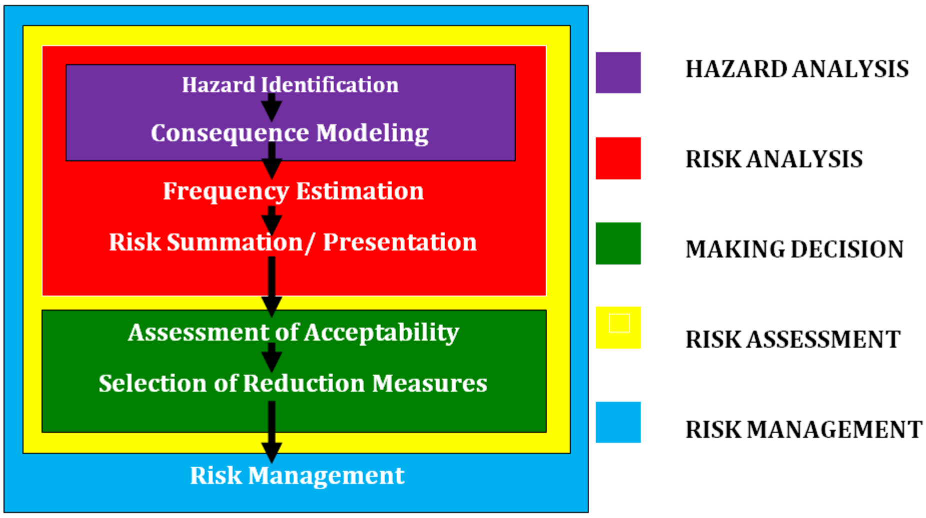

Figure 4.1: Phast Risk with in Risk Assessment process [49].

For the QRA study the Phast software is utilized for consequences analysis [49]. As shown in the figure 4.2.

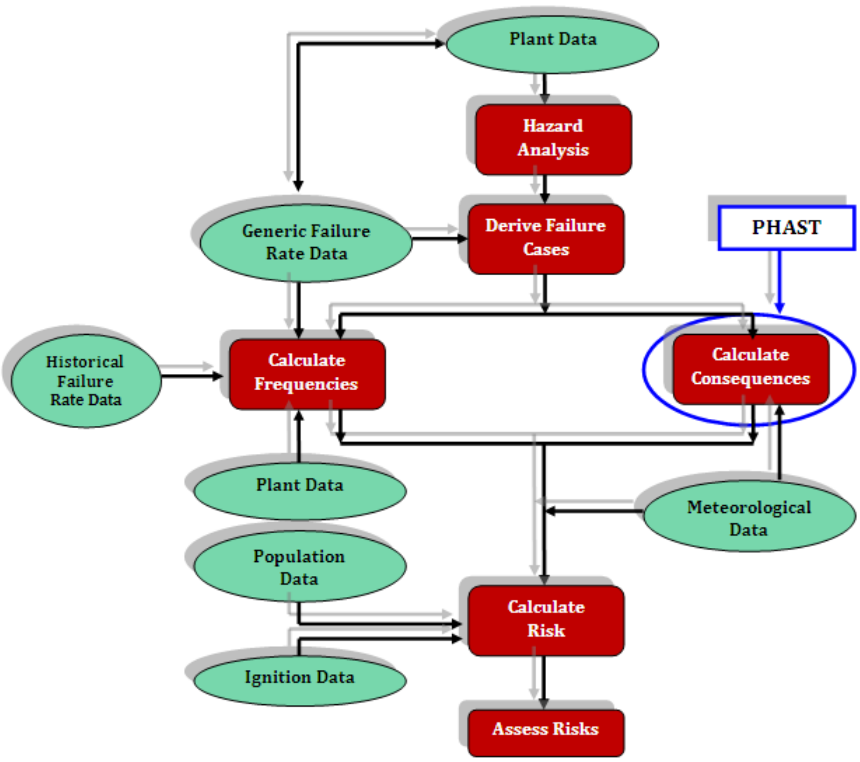

Figure 4.2: Phast application in QRA study [49].

4.4 Phast Models:

The Phast software runs on the various models for discharge, dispersion, toxic, flammable and explosion as shown in the figure 4.3. The various models will be explained in detail.

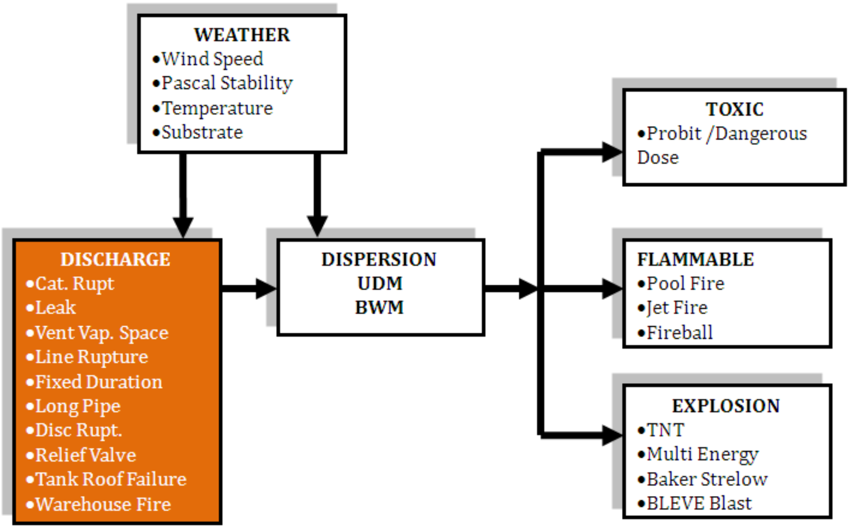

Figure 4.3: Phast models which calculates consequences [49].

4.4.1 Discharge Model

- **Catastrophic Rupture**: Designed to model an incident in which the vessel is destroyed by an impact, a crack, some other failure which propagates very quickly. Entire inventory is released for this case. No release direction, material is released in every direction. Expands to atmospheric pressure and discharge is instantaneous [49].

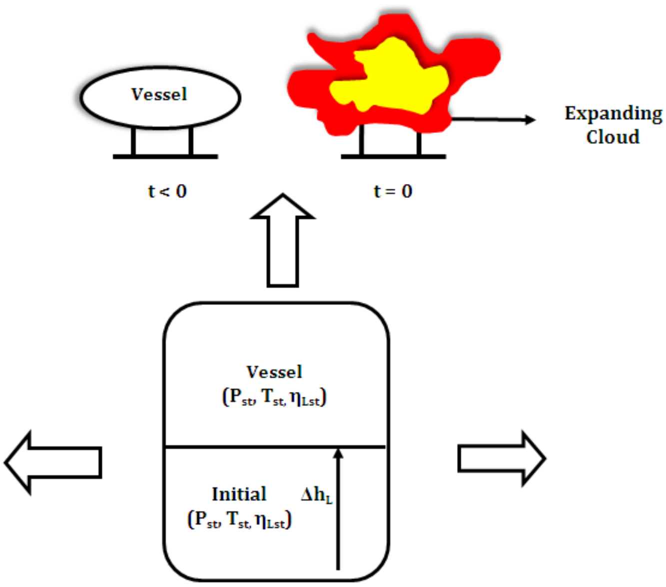

Figure 4.4: Catastrophic Rupture Model [49].

- **Leak:** Designed to model the hole in the body vessel, or a small hole in a large pipe. This discharge has duration and the release direction also. Here tank and pump head is specified. For 2-phase storage, the material can be released from the vessel as either liquid (hole below the liquid level) or vapor (hole above liquid level) [49].

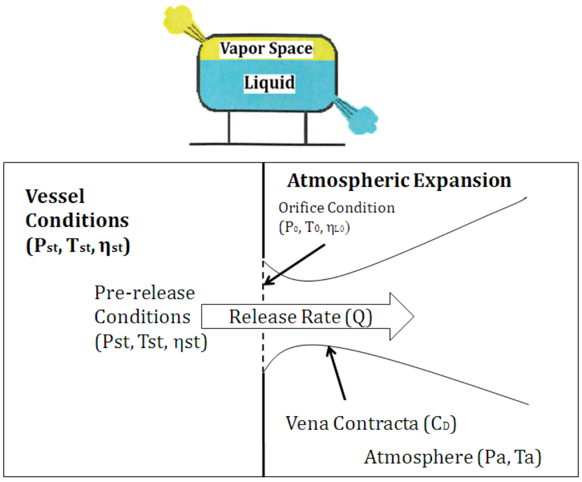

Figure 4.5: Leak Model [49].

- **Vent form the vapor space**: Designed for venting of material from the vapor space of an unpressurized vessel. The vapor volume flow out is equal to the liquid volume flow in. The outgoing vapor is the mixture of the air and the saturate vapor of the component present the vessel of the storage tank [49].

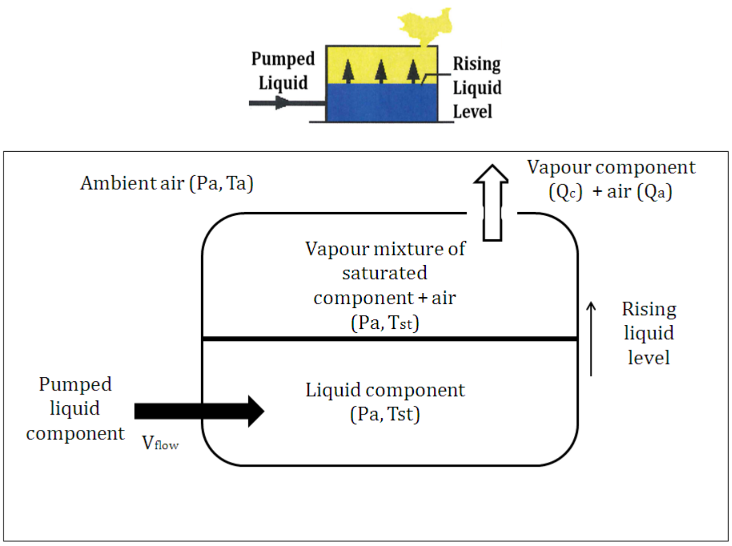

Figure 4.6: Vent from vapor space Model [49].

- **Line Rupture:** Designed for a full-bore rupture of a short length of pipe work attached to a vessel. The discharge has a duration and direction. For 2-phase storage, the material can be released from the vessel as either liquid (Pipe entrance below the liquid level) or vapor (Pipe entrance above the liquid entrance). Here also tank and pump head is defined [49].

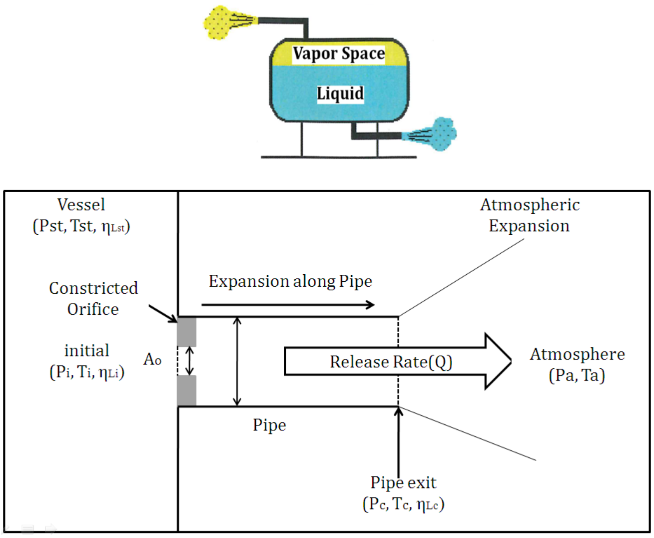

Figure 4.7: Leak Model [49].

- **Long Pipeline** This is applicable when pipe length >> 300 D [49].

Phast support the following arrangement:
Pumped inflow
Valve defined distance to break
User define distance to break
User defined release apertur

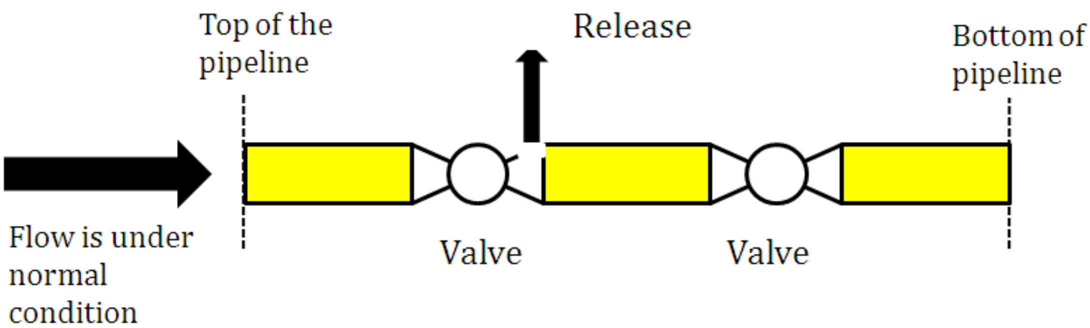

Figure 4.8: Long Pipeline Model [49].

- **Disk Rupture:** For over pressuring of a large vapor space vessel (storage disk rupture) or liquid swelling or over-filling of a small vapor space vessel (reactor disk rupture). Release through a burst rupture disk and along a short tailpipe. Discharge occurs through the disk seat. For 2-phase storage the leak occurs form the vessel as vapor or as a homogeneous 2-phase [49].

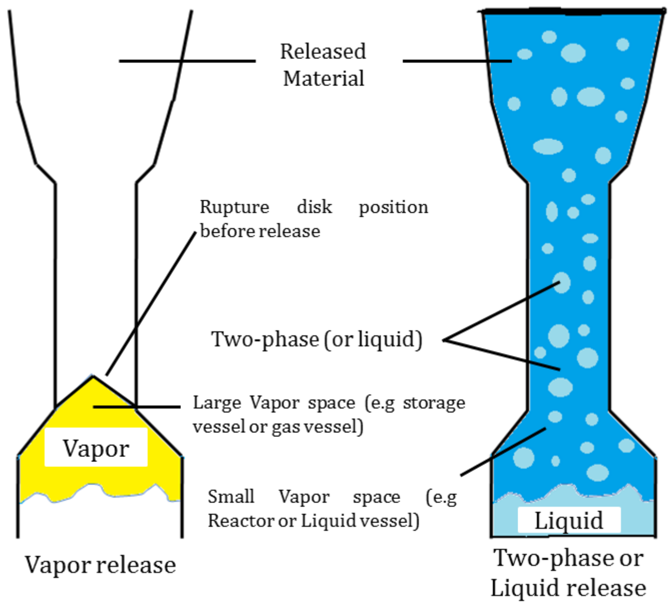

Figure 4.9: Disc Rupture Model [49].

- **Tank Roof Failure:** Designed for the release of vapor from a refrigerated, insulated tank under saturated conditions, in the event that the roof fails. Two types of failure: Roof removed and Roof collapsed. Two types of dispersion: initial instantaneous puff and continuous evaporation [49].

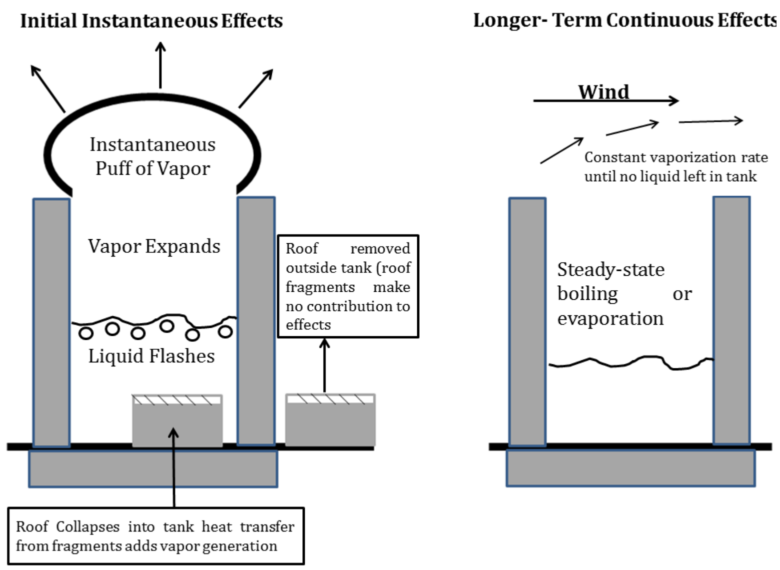

Figure 4.10: Tank Roof Failure Model [49].

- **Relief Valve:** Release due to over pressuring of a large vapor-space vessel, or liquid swelling of a small vapor-space vessel. The discharge occurs through the constricting relief valve at the entrance to the pipe and then along the length of a short tailpipe. For 2-phase storage, the material can be released from the vessel as either vapor or as a homogeneous 2-phase. Pressurized liquid vessels cannot use this scenario [49].

4.4.2 Dispersion Model

There are two dispersion models Unified Dispersion Model (UDM) and Building Wake Model (BMW). The Unified Dispersion Model (UDM) will be used in most situation in Phast as its is most sophisticated as it covers a wide range of conditions and well verified and validated. If user select a Building Wake Effect on scenario tab, the Building Wake Model will be used for the dispersion calculation and designed to handle to roof/ Lee and chimney releases [49].

UDM Dispersion Capabilities:

- **Types of clouds**

Continuous

Instantaneous

Short Duration (Quasi-Instantaneous)

Time-varying

- **Phast predicts the full range of expected dispersion stage:**

Initial turbulent expanding jet

Dense spreading and turbulent mixing

Slumping dense cloud

Passive dispersion

- **Effects considered**

Buoyancy or lack of buoyancy

Aerosol formation, rain out and pool vaporization

Touchdown, lift-off, and capping at the mixing layer

Air entrainment and cloud spreading

- **UDM also employs:**

Transition zones between phases

Interaction with substrate

Capping at mixing/ inversion layer

Ground level plume lift-off

4.4.3 Radiation Model

Fireball considers instantaneous releases and short duration continuous releases, jet fire considers the continuous releases and pool fire considers the delayed ignition after rain out.

- **Fireball:** In Phast fireball will be predicted by the vessel/ pipe source model if it is a vapor/ 2-phase catastrophic rupture with a flammable material stored. Fireballs will also be modeled for a continuous release if the discharge duration is less than the cut off time for short continuous releases found in the flammable parameters. Fireball is also available as a standalone model [49].

Three models available:

Roberts (HSE): Assume fireball is grounded and more conservative results at ground level.

TNO Yellow Book: Model fire ball as lift off.

DNV Recommended: Model fireball as lift off and utilize TNO Yellow Book to calculate radius, lift-off height and fireball duration. Surface emissive power calculated using Roberts (HSE) method.

- **Jet Fire:** A jet fire is a turbulent diffusion flame resulting from the combustion fuel continuously released with some significant momentum in a particular direction (UK HSE direction). In Phast a Jet Fire will be predicted by vessel/ pipe source model if it is a continuous release of a flammable material. It is also available as a standalone model. Jet fire models calculate the shape and intensity of a jet fire. Two available models: The cone model and API model [49].

- **Pool Fire:** Pool fire is the flame over a pool of flammable liquid. The combustion of the vaporized flammable material releases heat, which supplies energy to vaporize the liquid. In Phast, Pool Fires will be predicted by the vessel/ pipe source when there is release of flammable material that rains out to form a pool on the ground [49].

There are two types of pool fire:

Early Pool Fire: When burn rate and the liquid input to the pool (spill rate) are equal.

Late Pool Fire: When fire occurs after formation of the maximum pool radius and this is not applicable to standalone model.

4.4.4 Explosion Model

There are three models for calculating the explosion model [49]:

1. TNT Model
2. Multi Energy Model
3. Baker Strehlow Model

- **TNT Model:** This is the default model for linked models. It utilize an equivalent amount of TNT for the flammable mass calculated in the program and can be modeled as air or ground burst. It is a basic model, takes no account of congestion.

- **Multi Energy Model:** As presented in the Dutch yellow book this splits the cloud into up to 7 sub sources. This model defines the volume or fraction of confinement. Confinement strength between 3-10 is defined. Produced overpressure and impulse results based on results derived from CFD simulation.

- **Baker Strehlow Model:** This model uses blast chart to determine overpressure curve as well as the impulse. Possibility to estimate flame speed (mach number) from a number of inputs, similar to multi energy model and this is more popular in US. This is easy to use, but quite subjective.

4.4.5 Toxic Model

Two methods available for measuring dose-based toxic effects in phast [49]:

- Using Probit equation Methodology prescribed by dutch government

- Dangerous Dose (Load) Direct comparison with the calculated toxic load and ideal for UK SHE SLOT and SLOD values.

4.4.6 Phast layout

The main screen of the Phast Risk program structure is shown in Figure 7.11, with model, weather, parameters, material, Map functions are indicated.

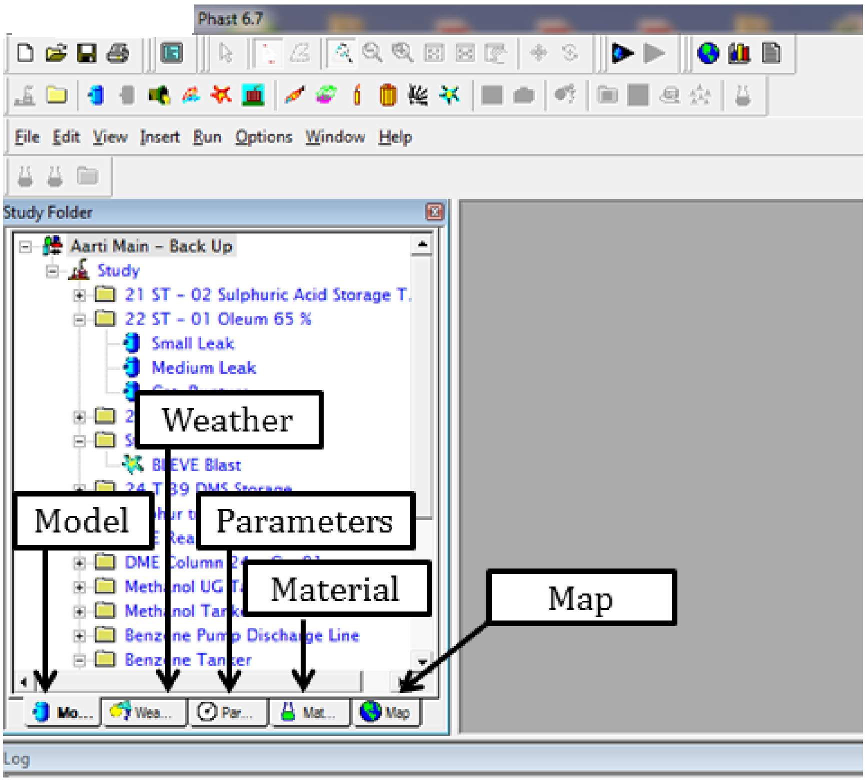

Figure 4.11: Phast main screen layout

4.4.7 Phast Output

- Radiation profiles and contours from a range of fire scenarios including pool fires, flash fire, jet fires and fire ball.
- Overpressure contours from Boiling Liquid Expanding Vapor Explosions.
- Graphs of toxic concentration profile.
- Indoor and outdoor toxic dose prediction.
- Reporting of distance to specific dose and concentration.
- Calculated exposure time.

4.5 Phast RISK Introduction

Software for the Assessment of Flammable, Explosive and Toxic Impact. This software combines the consequences (How Big?) and Frequencies (How often?) to determine the Risk. Phast Risk allows us to combine the flammable and toxic consequences from each scenario in QRA model with likelihood to quantify the risk of facilities.

Phast Risk also takes into account:

- Phast consequences modeling.
- Population density
- Ignition source
- Accidental frequency rate
- Wind rose data.

Phast Risk is utilized for the calculation of the risk by combining the consequences of the Phast results. Phast Risk allows us to quickly identify major risk contributors so that time and efforts can be directed to mitigate highest risk scenarios. A key benefit of Phast Risk is the ability to identify major risk contributors and differentiate these from incidents with worst case consequences which might otherwise dominate the safety reviews. Medium scale incidents have lesser consequences, they may have high a higher frequency, which when combined with their hazardous effected, generates a higher level of risk. Time and effort directed to mitigating high consequence but often low frequency events may not be well spent. Phast Risk helps you direct this effort more effectively.

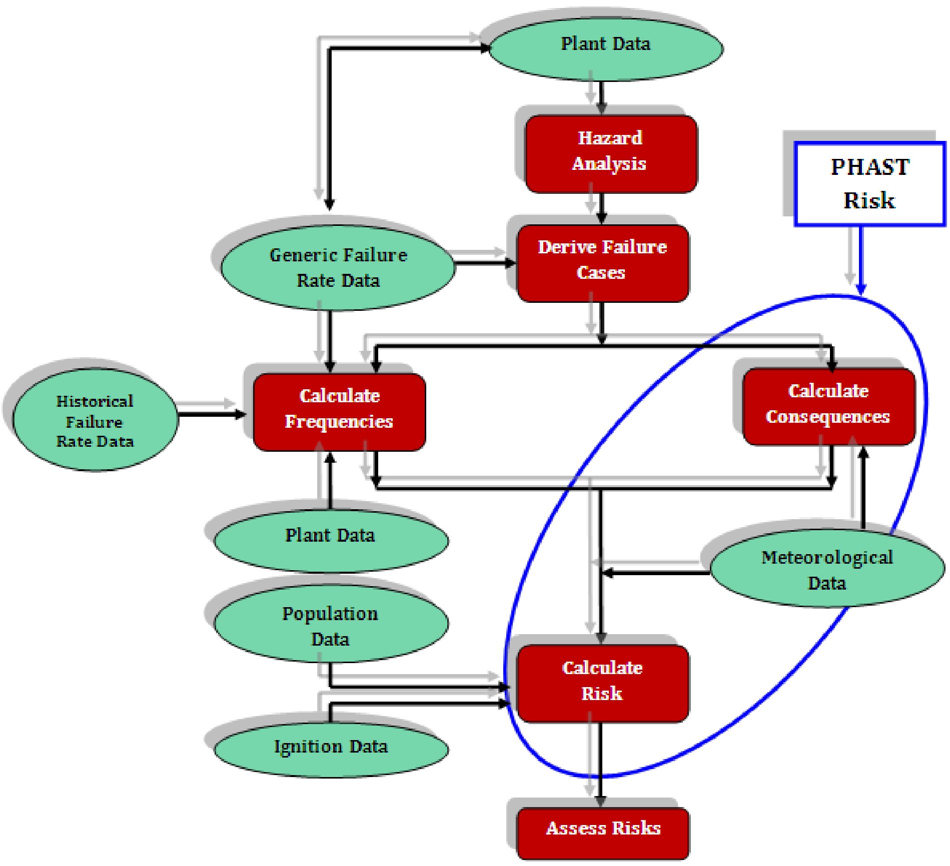

Figure 4.12: Phast Risk application in QRA

4.5.1 Phast Risk Layout

The main screen of the Phast Risk program structure is shown in Figure 7.13, with the key run row, model, weather, parameters, material, Map and risk functions are indicated.

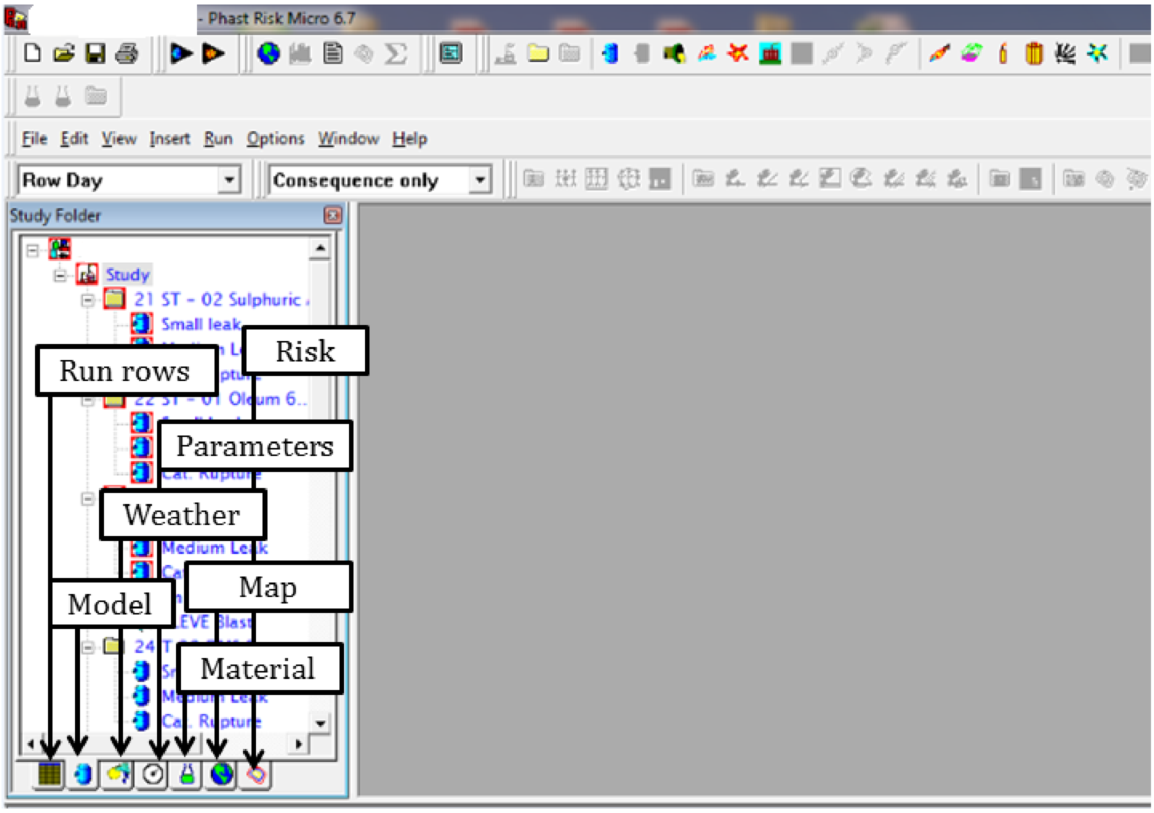

Figure 4.13: Phast Risk main screen layout

4.5.2 Phast Risk Output

- Its gives Location Specific Risk Contour(LSIR).
- Calculates the overall societal risk in the form of F/N(Frequency/ Number of fatality) curve.

Chapter 5

QRA for HydroCracker Unit

Quantitative Risk Assessment for HydroCracker Unit has been done by Phast 6.7 and Micro Risk software for risk quantification. Phast 6.7 software identifies the consequences and Micro Risk identifies risk by importing consequences data from phast 6.7 and combing it with frequency, ignition source as well as population data in Micro risk. Total 21 scenarios has been identified from the HAZOP study. All 21 scenarios has been taken as a study for their risk analysis and risk assessment. List of various failure scenarios identified from HAZOP study are shown below:

Table 5.1: Scenarios for QRA study

Unit	Equipment Name & Tag No.	Scenario	Material
HydroCracker Unit	First Stage Lead Reactor 04-RB-001	Leak-Small, Medium & Catastrophic	VGO,Vaccum Diesel,H2
	First Stage Main Reactor 04-RB-002	Rupture Leak-Small, Medium & Catastrophic	VGO, Coker Distillates, H2
	Second Stage Reactor 04-RB-003	Rupture Leak-Small, Medium & Catastrophic Rupture	Unconverted Oil, Diesel, H2
	Recycle Gas Compressor 04-KA-001	Leak-Small, Medium	Recycle Gas
	Cold High Pressure Seperator 04-VV-004	Leak-Small, Medium & Catastrophic Rupture	Recycle Gas & Sour Water
	Cold Low Pressure Seperator 04-VV-006	Leak-Small, Medium & Catastrophic Rupture	Sour Water, H2

Table 5.2: Failure Modes and frequencies of failure

Unit	Equipment Name & Tag No.	Scenario	Material
HydroCracker Unit	Hot Low Pressure Seperator 04-VV-005	Leak-Small, Medium & Catastrophic Rupture	Sour Water, H2
	Hot High Pressure Seperator 04-VV-003	Leak-Small, Medium & Catastrophic Rupture	Sour Water, Naptha, H2,
	Product Fractionator 04-CC-001	Leak-Small, Medium & Catastrophic Rupture	Naptha
	Fractionator bottoms pump 04-PA-007	Leak-Small, Medium	Unconverted Oil
	Heavy Naptha Stripper 04-CC-002	Leak-Small, Medium & Catastrophic Rupture	Naptha
	Heavy Naptha Product Pump 04-PA-010	Leak-Small, Medium	Naptha
	Kerosene Stripper 04-CC-003	Leak-Small, Medium & Catastrophic Rupture	Kerosene
	Kerosene Product Pump 04-PA-009	Leak-Small, Medium	Kerosene
	Diesel Stripper 04-CC-004	Leak-Small, Medium & Catastrophic Rupture	Diesel
	Diesel Product Pump 04-PA-008	Leak-Small, Medium	Diesel
	Deethanizer 04-CC-005	Leak-Small, Medium & Catastrophic Rupture	Hydrogen Sulfide, Naptha
	Deethanizer Bottom Pumps 04-PA-016	Leak-Small, Medium	Naptha
	First Stage off gas compressor 04-KA-002	Leak-Small, Medium	Hydrogen Sulfide, Naptha, H2
	2nd Stage Off gas Compressor 04-KA-002	Leak-Small, Medium	Hydrogen Sulfide, Naptha, H2
	KO Drum 04-VV-013	Leak-Small, Medium & Catastrophic Rupture	Hydrogen Sulfide, Naptha

5.1 Frequency Analysis

The frequencies have been obtained from OGP Risk Assessment Data Directory (Process Release Frequencies) [50] & Failure Rate and Event Data for use within Land Use Planning Risk Assessments published by Health and Safety Executive, UK (UK HSE). The failure scenarios with corresponding frequencies of failure are tabulated below.

Table 5.3: Failure Modes and frequencies of failure

Equipment Type	**Equivalent Hole Diameter**	**Frequency of failure per year**
Process Vessels	Small Leak (5mm)	2.0×10^{-4}
	Medium Leak (25mm)	1.0×10^{-4}
	Catastrophic Rupture	5.1×10^{-5}
Pressurized Tanks	Small Leak (6mm)	4×10^{-5}
	Medium Leak (25mm)	5×10^{-6}
	Catastrophic Rupture	2×10^{-6}
Reactors	Small Leak (5mm)	4×10^{-5}
	Medium Leak (25mm)	5×10^{-6}
	Catastrophic Rupture	1×10^{-5}
Pumps	Small Leak (5mm)	1×10^{-3}
	Medium Leak (25mm)	2.9×10^{-4}
Compressors	Small Leak (5mm)	6.8×10^{-4}
	Medium Leak (25mm)	1.3×10^{-4}

5.2 Assessment of Consequence Modeling Results

Results of Consequence Analysis for the release of various flammable materials at the facility are depicted. For the flammable chemicals, damage distances for Jet Fire, Fire ball, Flash Fire and Vapour Cloud Explosion are estimated.

5.2.1 Jet Fire/ Pool Fire/ Fire Ball

The extent of the consequence of a Jet Fire, Pool Fire and Flash Fire are represented by the thermal radiation envelope. Three levels of radiation are presented in this report, i.e.

- 4 kW/m2; this level is sufficient to cause pain if personnel is unable to reach cover within 20s; however blistering of the skin (second degree burn) is unlikely; 0% lethality.
- 12.5 kW/m2; this level will cause extreme pain within 20 seconds and movement to a safer place is instinctive. This level indicates around 6% fatality for 20 seconds exposure.

- 37.5 kW/m2; this level of radiation is assumed to give 100% fatality.

5.2.2 Flash Fire

The extent of the consequence of a Flash Fire is represented by the flash fire envelope, i.e. the maximum dispersion distance of the flammable cloud at LFL concentration.

5.2.3 Explosion Overpressure

The extent of the consequence of an explosion is represented by the maximum overpressure effect distance.Three levels of radiation are presented in this report, i.e.

- 0.0206 bar (0.3 psi); this overpressure range is sufficient to cause major glass breakage or damage. This includes the slight injury from the flying fragments of glass.
- 0.1 bar (2 psi); this overpressure range is sufficient to cause damage which is repairable. This includes 1% death, 1% eardrum damage, 1% serious wounds from the fragments of flying glass.
- 0.2068 bar (3 psi); this overpressure can cause the 100% fatality. This overpressure range is enough to cause the heavy damage to the plant and the structures.

5.2.4 Toxicity

The extent of the consequence of toxicity is represented by the toxicity envelope, i.e. the maximum dispersion distance of the toxic cloud at IDLH (Immediately Dangerous to Life and Health) concentration.

- Toxic effects from loss of containment of various chemicals have been analyzed.
- IDLH (Immediately Dangerous to Life and Health) concentrations for the chemicals as published by NIOSH have been used as a reference for the study.

5.3 Summary of Consequences Results

The summary of the consequence results has been compiled in the tables given below:

Table 5.4: Summary of Consequences for HydroCracker Unit

Equip. Name	Material Flowing	Temp. in deg. C	Pressure in bar	Accident Scenario	Release Rate in kg/s	Release Duration in s	Event	Impact Criteria	Consequence Distance Meters			
									Day		Night	
									A/B 2 m/s	D 5 m/s	F 2 m/s	D 5 m/s
First Stage Lead Reactor 04-RB-001	Stage 1 Feed	368	176.40	Small Top Leak	0.428	3600	Jet Fire	4 KW/m^2	NR	NR	NR	NR
								12.5 KW/m^2	NR	NR	NR	NR
								37.5 KW/m^2	NR	NR	NR	NR
							Flash fire	LFL	6.36	6.72	6.68	6.62
								LFL Fraction	11.59	12.61	12.80	12.42
							Explosion	0.02068 Bar	14.23	14.14	14.42	14.13
								0.1 Bar	11.10	11.07	11.14	11.07
								0.2068 Bar	10.85	10.83	10.89	10.83
							Toxic Dispersion	IDLH= 100ppm	NH	NH	NH	NH
				Medium leak	10.706	600.790	Jet Fire	4 KW/m^2	47.25	48.94	48.22	49.71
								12.5 KW/m^2	NR	NR	NR	NR
								37.5 KW/m^2	NR	NR	NR	NR
							Flash fire	LFL	28.80	30.0	30.93	29.43
								LFL Fraction	48.34	50.97	54.57	50.06
							Explosion	0.02068 Bar	60.12	70.06	71.45	69.94

Table 5.5: Summary of Consequences for HydroCracker Unit

Equip. Name	Material Flowing	Temp. in deg. C	Pressure in bar	Accident Scenario	Release Rate in kg/s	Release Duration in s	Event	Impact Criteria	Consequence Distance Meters			
									Day		Night	
									A/B 2 m/s	D 5 m/s	F 2 m/s	D 5 m/s
First Stage Lead Reactor 04-RB-001	Stage 1 Feed	368	176.40	Medium Leak	10.706	600.790	Explosion	0.1 Bar	45.21	55.19	55.56	55.16
								0.2068 Bar	44.03	54.02	54.30	53.99
							Toxic Dispersion	IDLH= 100ppm	NH	NH	NH	NH
	Stage 2 Feed	402	173.6	Small Top Leak	0.368	3600	Jet Fire	4 KW/m^2	4.06	3.94	4.03	3.90
								12.5 KW/m^2	2.23	2.03	2.25	2.09
								37.5 KW/m^2	NR	NR	NR	NR
							Flash fire	LFL	9.32	17.85	6.52	17.29
								LFL Fraction	11.37	28.43	8.44	27.63
							Toxic Dispersion	IDLH= 100ppm	8.11	23.32	4.27	22.69
				Medium Bottom Leak	9.200	526.060	Jet Fire	4 KW/m^2	33.94	33.80	34.60	34.43
								12.5 KW/m^2	18.73	18.62	19.15	18.96
								37.5 KW/m^2	12.46	13.49	12.35	13.32
							Flash fire	LFL	27.36	30.44	23.18	29.11
								LFL Fraction	34.35	39.43	31.35	38.07
							Explosion	0.02068 Bar	63.41	62.22	65.93	61.80

Table 5.6: Summary of Consequences for Hydro Cracker Unit

Equip. Name	Material Flowing	Temp. in deg. C	Pressure in bar	Accident Scenario	Release Rate in kg/s	Release Duration in s	Event	Impact Criteria	Consequence Distance Meters			
									Day		Night	
									A/B 2 m/s	D 5 m/s	F 2 m/s	D 5 m/s
First Stage Lead Reactor 04-RB-001	Stage 2 Feed	402	173.6	Medium Bottom Leak	9.200	526.060	Explosion	0.1 Bar	68.9	68.9	68.9	68.9
								0.2068 Bar	53.32	53.32	53.32	53.32
				Cat. Rupture	NA	NA	Flash Fire	LFL	42.91	48.38	43.59	47.77
								LFL Fraction	56.12	71.21	58.50	69.99
							Fire Ball	4 KW/m^2	433.46	433.46	450.30	450.30
								12.5 KW/m^2	237.90	237.90	247.16	247.16
								37.5 KW/m^2	103.04	103.04	109.55	109.55
							Toxic Dispersion	IDLH= 100ppm	49.73	59.51	51.14	58.66
							Explosion	0.02068 Bar	266.11	266.11	266.11	266.11
								0.1 Bar	68.90	69.90	68.90	68.90
								0.2068 Bar	53.31	53.31	53.31	53.31
Lead Reactor 04-RB-002	Stage 1 Eff	402.00	166.40	Small Bottom Leak	0.370	3600.000	Jet Fire	4KW/m^2	9.34	9.41	9.44	9.53
								12.5 KW/m^2	NR	4.79	NR	5.17
								37.5 KW/m^2	NR	NR	NR	NR

Table 5.7: Summary of Consequences for Hydro Cracker Unit

Equip. Name	Material Flowing	Temp. in deg. C	Pressure in bar	Accident Scenario	Release Rate in kg/s	Release Duration in s	Event	Impact Criteria	Consequence Distance Meters			
									Day		Night	
									A/B 2 m/s	D 5 m/s	F 2 m/s	D 5 m/s
First Stage Main Reactor 04-RB-002	Stage 1 Eff	402.00	166.40	Small Bottom Leak	0.370	3600.000	Flash Fire	LFL	3.32	2.76	3.65	2.71
								LFL Fraction	5.57	4.61	6.19	4.54
				Medium Bottom Leak	9.254	1368.980	Jet Fire	4KW/m^2	44.08	43.26	44.52	43.93
								12.5 KW/m^2	NR	27,19	NR	27.65
							Flash fire	LFL	15.44	13.01	16.18	12.79
								LFL Fraction	24.87	21.59	26.47	21.20
							Explosion	0.02068 Bar	37.77	36.36	38.97	36.32
								0.1 Bar	24.60	24.24	24.92	24.22
								0.2068 Bar	23.56	23.28	23.80	23.27
				Cat. Rupture	NA	NA	Flash Fire	LFL	46.38	52.38	47.29	51.80
								LFL Fraction	60.62	77.73	63.67	76.44
							Fire Ball	4 KW/m^2	469.09	469.09	487.76	487.76
								12.5 KW/m^2	257.43	257.43	267.7	267.7
								37.5 KW/m^2	110.85	110.85	118.10	118.10

Table 5.8: Summary of Consequences for HydroCracker Unit

Equip. Name	Material Flowing	Temp. in deg. C	Pressure in bar	Accident Scenario	Release Rate in kg/s	Release Duration in s	Event	Impact Criteria	Consequence Distance Meters			
									Day		Night	
									A/B 2 m/s	D 5 m/s	F 2 m/s	D 5 m/s
First Stage Main Reactor 04-RB-002	Stage 1 Eff	402.00	166.40	Cat. Rupture	NA	NA	Explosion	0.02068	289.7	289.7	289.7	289.7
								0.1 Bar	75.02	75.02	75.02	75.02
								0.2068 Bar	58.05	58.05	58.05	58.05
							Toxic Dispersion	IDLH= 100ppm	57.25	71.27	59.65	70.13
							Flash Fire	LFL	6.6	7.23	7.10	7.11
								LFL Fraction	12	13.69	13.6	13.47
							Explosion	0.02068 Bar	21.63	21.47	22.16	21.42
								0.1 Bar	13.01	12.97	13.15	12.96
								0.2068 Bar	12.33	12.30	12.44	12.29
							Toxic Dispersion	IDLH= 100ppm	NH	NH	NH	NH
				Medium Top Leak	9.893	667.080	Jet Fire	4 KW/m^2	NR	NR	NR	NR
								12.5 KW/m^2	NR	NR	NR	NR
								37.5 KW/m^2	NR	NR	NR	NR
							Flash Fire	LFL	29.81	32.07	32.36	31.52
								LFL Fraction	49.33	54.51	56.24	53.50

Table 5.9: Summary of Consequences for HydroCracker Unit

Equip. Name	**Material Flowing**	**Temp. in deg. C**	**Pressure in bar**	**Accident Scenario**	**Release Rate in kg/s**	**Release Duration in s**	**Event**	**Impact Criteria**	**Consequence Distance Meters**			
									Day		**Night**	
									A/B 2 m/s	**D 5 m/s**	**F 2 m/s**	**D 5 m/s**
First Stage Main Reactor	Stage 2 Feed	370	171.6	Medium Top Leak	9.893	667.080	Explosion	0.02068	95.37	105.42	108.59	105.18
								0.1 Bar	54.34	64.35	65.17	64.29
								0.2068 Bar	51.09	61.1	61.74	61.05
04-RB-003	Stage 2 Eff	386	166.4	Small Bottom Leak	.378	3600	Jet Fire	4 KW/m^2	9.45	9.52	9.55	9.63
								12.5 KW/m^2	NR	4.92	NR	5.27
								37.5 KW/m^2	NR	NR	NR	NR
							Flash Fire	LFL	3.36	2.8	3.69	2.75
								LFL Fraction	5.64	4.67	6.27	4.59
				Medium Bottom Leak	9.455	661.740	Jet Fire	4 KW/m^2	44.53	43.72	44.98	44.39
								12.5 KW/m^2	NR	27.49	NR	27.95
								37.5 KW/m^2	NR	NR	NR	NR
							Flash Fire	LFL	15.70	13.18	16.42	12.97
								LFL Fraction	25.23	21.89	26.84	21.5
							Explosion	0.02068 Bar	68.87	64.85	72.07	64.74

Table 5.10: Summary of Consequences for HydroCracker Unit

Equip. Name	**Material Flowing**	**Temp. in deg. C**	**Pressure in bar**	**Accident Scenario**	**Release Rate in kg/s**	**Release Duration in s**	**Event**	**Impact Criteria**	**Consequence Distance Meters**			
									Day		**Night**	
									A/B 2 m/s	**D 5 m/s**	**F 2 m/s**	**D 5 m/s**
First Stage Main Reactor 04-RB-003	Stage 2 Eff	386	166.4	Medium Bottom Leak	9.455	661.740	Explosion	0.1 Bar	32.65	31.61	33.48	21.58
								0.2068 Bar	29.79	28.99	30.43	28.96
							Toxic Dispersion	IDLH= 100ppm	NH	NH	NH	NH
				Cat. Rupture	NA	NA	Flash Fire	LFL	46.12	52.4	47.01	51.7
								LFL Fraction	60.39	77.86	63.49	76.6
							Fire Ball	$4 KW/m^2$	467.41	467.41	485.99	485.99
								$12.5 KW/m^2$	256.51	256.51	266.73	266.73
								$37.5 KW/m^2$	110.48	110.48	117.7	117.7
							Explosion	0.02068 Bar	783.61	783.61	783.61	763.61
								0.1 Bar	202.9	202.9	202.9	202.9
								0.2068 Bar	157	157	157	157
							Toxic Dispersion	IDLH= 100ppm	42.91	47.68	43.66	47.13

Table 5.11: Summary of Consequences for HydroCracker Unit

Equip. Name	**Material Flowing**	**Temp. in deg. C**	**Pressure in bar**	**Accident Scenario**	**Release Rate in kg/s**	**Release Duration in s**	**Event**	**Impact Criteria**	**Consequence Distance Meters**			
									Day		**Night**	
									A/B 2 m/s	**D 5 m/s**	**F 2 m/s**	**D 5 m/s**
Recycle Gas Compressor 04-KA-001	Reactors Recycle Gas	82	186.30	Small Leak	0.254	171.87	Jet Fire	$4 KW/m^2$	9.56	9.49	9.71	9.56
								$12.5 KW/m^2$	NR	NR	NR	NR
								$37.5 KW/m^2$	NR	NR	NR	NR
							Flash Fire	LFL	6.06	5.12	6.82	5.03
								LFL Fraction	9.52	8.56	10.72	8.42
				Medium Leak	6.361	68.71	Jet Fire	$4 KW/m^2$	45.80	44.09	46.32	44.86
								$12.5 KW/m^2$	NR	27.18	NR	27.79
								$37.5 KW/m^2$	NR	NR	NR	NR
							Flash Fire	LFL	25.70	23.52	28.33	23.14
								LFL Fraction	37.9	38.93	44.57	38.22
							Explosion	0.02068 Bar	58.78	55.81	70.52	55.73
								0.1 Bar	37.45	36.68	47.90	36.66
								0.2068 Bar	35.77	35.17	46.12	35.16

Table 5.12: Summary of Consequences for HydroCracker Unit

Equip. Name	Material Flowing	Temp. in deg. C	Pressure in bar	Accident Scenario	Release Rate in kg/s	Release Duration in s	Event	Impact Criteria	Consequence Distance Meters			
									Day		Night	
									A/B 2 m/s	D 5 m/s	F 2 m/s	D 5 m/s
Cold High Pressure Seperator 04-VV-004	Leaks	60	159.2	Small Top Leak	0.226	1786.05	Jet Fire	$4 KW/m^2$	NR	NR	NR	NR
								$12.5 KW/m^2$	NR	NR	NR	NR
								$37.5 KW/m^2$	NR	NR	NR	NR
							Flash Fire	LFL	5.91	5.22	6.25	5.13
								LFL Fraction	9.36	9.11	10.23	8.98
				Medium Top Leak	5.643	71.44	Jet Fire	$4 KW/m^2$	38.83	38.44	39.82	39.02
								$12.5 KW/m^2$	NR	NR	NR	NR
								$37.5 KW/m^2$	NR	NR	NR	NR
							Flash Fire	LFL	24.96	23.29	26.67	22.91
								LFL Fraction	36.84	38.98	43.08	38.31
							Explosion	0.0206Bar	57.38	54.44	68.28	54.35
								0.1 Bar	37.09	36.33	47.32	36.3
								0.2068 Bar	35.49	34.9	45.67	34.88
	SWS Sour Water	60	159.2	Small Bottom Leak	2.344	3600	Toxic Dispersion	IDLH= 100 ppm	NH	NH	NH	NH

Table 5.13: Summary of Consequences for HydroCracker Unit

Equip. Name	**Material Flowing**	**Temp. in deg. C**	**Pressure in bar**	**Accident Scenario**	**Release Rate in kg/s**	**Release Duration in s**	**Event**	**Impact Criteria**	**Consequence Distance Meters**			
									Day		**Night**	
									A/B 2 m/s	**D 5 m/s**	**F 2 m/s**	**D 5 m/s**
Cold High Pressure Seperator 04-VV-004	SWS Sour Water	60	159.2	Medium Bottom Leak	58.59	291.8	Toxic Dispersion	IDLH =100	190.23	NH	338.54	NH
				Cat. Rupture	NA	NA	Flash Fire	LFL	26.32	33.6	26.73	33
								LFL Fraction	36.6	55.51	37.86	54.15
							Fire Ball	$4 KW/m^2$	207.79	207.79	214.40	214.40
								$12 KW/m^2$	114.14	114.14	117.74	117.74
								$37.5 KW/m^2$	51.59	51.59	54	54
							Explosion	0.02068 Bar	134.32	134.32	134.32	134.32
								0.1 Bar	34.82	34.82	34.82	34.82
								0.2068 Bar	26.95	26.85	26.75	26.36
							Toxic Dispersion	IDLH= 100ppm	34.96	53.2	36.76	52.13
Seperator 04-VV-006	PSA unit CLPS Vap	44	35.2	Small Top Leak	.037	943.93	Jet Fire	$4 KW/m^2$	NR	NR	NR	NR
								$12.5 KW/m^2$	NR	NR	NR	NR
								$37.5 KW/m^2$	NR	NR	NR	NR

Table 5.14: Summary of Consequences for HydroCracker Unit

Equip. Name	Material Flowing	Temp. in deg. C	Pressure in bar	Accident Scenario	Release Rate in kg/s	Release Duration in s	Event	Impact Criteria	Consequence Distance Meters			
									Day		Night	
									A/B 2 m/s	D 5 m/s	F 2 m/s	D 5 m/s
Cold High Pressure Seperator 04-VV-004	PSA unit CLPS Vap	44	35.2	Small Top Leak	.037	943.93	FLash Fire	LFL	3.94	4.03	4.2	3.98
								LFL Fraction	6.37	7.44	7.2	7.34
				Medium Top Leak	0.916	37.76	Jet Fire	$4KW/m^2$	NR	NR	NR	NR
								$12.5 KW/m^2$	NR	NR	NR	NR
								37.5	NR	NR	NR	NR
							Flash Fire	LFL	15.46	16.50	16.78	16.18
								LFL Fraction	22.88	28.05	27.36	27.57
							Explosion	0.02068 Bar	66.66	61.20	67.45	60.96
								0.1 Bar	32.08	30.67	32.29	30.61
								0.2068 Bar	39.35	28.25	29.51	28.21
	SWS Sour Water	60	8.50	Small Bottom Leak	.54	3600	Toxic Dispersion	IDLH= 100ppm	NH	NH	54.33	NH
				Medium Bottom Leak	13.54	903.08	Toxic Dispersion	IDLH= 100ppm	162.13	173.18	201.53	163.26
				Cat. Rupture	NA	NA	Toxic Dispersion	IDLH= 100ppm	195.85	304.18	217.01	302.7
Hot Low Pressure Seperator 04-VV-005	HLPS Vap	204.00	36.10	Small Top Leak	0.689	3600	Jet Fire	$4KW/m^2$	NR	NR	NR	NR

Table 5.15: Summary of Consequences for HydroCracker Unit

Equip. Name	**Material Flowing**	**Temp. in deg. C**	**Pressure in bar**	**Accident Scenario**	**Release Rate in kg/s**	**Release Duration in s**	**Event**	**Impact Criteria**	**Consequence Distance Meters**			
									Day		**Night**	
									A/B 2 m/s	**D 5 m/s**	**F 2 m/s**	**D 5 m/s**
Hot Low Pressure Seperator 04-VV-005	HLPS Vap	204.00	36.10	Small Top Leak	0.689	3600	Jet Fire	12.5	NR	NR	NR	NR
								37.5 KW/m^2	NR	NR	NR	NR
							Flash Fire	LFL	4.7	4.02	4.66	3.95
								LFL Fraction	7.5	6.99	7.8	6.88
							Toxic Dispersion	IDLH= 100ppm	NH	NH	NH	NH
				Medium Top Leak	17.23	626.39	Jet Fire	4KW/m^2	56.78	58.36	58.98	59.47
								12.5 KW/m^2	NR	NR	NR	NR
								37.5 KW/m^2	NR	NR	NR	NR
							Flash Fire	LFL	21.97	19.22	22.16	18.87
								LFL Fraction	34.16	33.05	37.95	32.41
							Explosion	0.02068	107.74	98.72	108.4	98.42
								0.1 Bar	50.13	47.79	50.30	47.71
								0.2068 Bar	45.57	43.77	45.71	43.71
							Toxic Dispersion	IDLH= 100ppm	NH	NH	NH	NH
	HLPS Liquid	204	36.1	Small Bottom Leak	1.016	3600	Toxic Dispersion	IDLH= 100ppm	NH	NH	NH	NH

Table 5.16: Summary of Consequences for HydroCracker Unit

Equip. Name	**Material Flowing**	**Temp. in deg. C**	**Pressure in bar**	**Accident Scenario**	**Release Rate in kg/s**	**Release Duration in s**	**Event**	**Impact Criteria**	**Consequence Distance Meters**			
									Day		**Night**	
									A/B 2 m/s	**D 5 m/s**	**F 2 m/s**	**D 5 m/s**
Hot Low Pressure Seperator 04-VV-005	HLPS Liquid	204	36.1	Medium Bottom Leak	25.38	1051.6	Toxic Dispersion	IDLH= 100ppm	NH	NH	NH	NH
				Cat. Rupture	NA	NA	Flash Fire	LFL	38.79	60.29	41.41	58.92
								LFL Fraction	57.54	111.23	68.20	108.01
							Fire Ball	$4 KW/m^2$	432.97	432.97	449.9	449.9
								12.5	236.03	236.03	245.39	245.39
								37.5 KW/m^2	97.75	97.75	104.59	104.59
							Toxic Dispersion	IDLH= 100ppm	54.89	105.90	65.82	102.12
							Explosion	0.02068 Bar	720.75	720.75	720.75	720.75
								0.1 Bar	186.62	186.62	186.62	186.62
								0.2068 Bar	144.4	144.4	144.4	144.4
Hot High Pressure Seperator 04-VV-003	HHPS Vap.	206	161.6	Small top Leak	.230	1393.4	Jet Fire	$4 KW/m^2$	34.79	35.31	35.88	35.82
								12.5 KW/m^2	NR	NR	NR	NR
								37.5 KW/m^2	NR	NR	NR	NR
							Flash Fire	LFL	4.73	4.07	4.95	4.01
								LFL Fraction	7.65	7.17	8.24	7.05
							Toxic Dispersion	IDLH= 100ppm	NH	NH	NH	NH

Table 5.17: Summary of Consequences for HydroCracker Unit

Equipment Name	Material Flowing	Temp. in deg. C	Pressure in bar	Accident Scenario	Release Rate in kg/s	Release Duration in s	Event	Impact Criteria	Consequence Distance Meters			
									Day		Night	
									A/B 2 m/s	D 5 m/s	F 2 m/s	D 5 m/s
Hot High Pressure Seperator 04-VV-003	HHPS Vap.	206	161.6	Medium top Leak	5.743	55.74	Jet Fire	$4 KW/m^2$	34.79	35.31	35.88	35.82
								$12.5 KW/m^2$	NR	NR	NR	NR
								$37.5 KW/m^2$	NR	NR	NR	NR
							FLash Fire	LFL	20.54	18.40	21.39	18.06
								Fraction	31.05	30.98	34.57	30.39
							Explosion	0.02068 Bar	91.92	85.24	94.10	95.12
								0.1 Bar	46.03	44.35	46.60	44.27
								0.2068 Bar	42.41	41.10	42.84	41.04
							Toxic Dispersion	IDLH= 100ppm	NH	NH	NH	NH
	HHPS Liquid	206	161.6	Small Bottom Leak	1.681	3600	Jet Fire	$4 KW/m^2$	21.13	18.13	21.43	18.36
								$12.5 KW/m^2$	12.55	11.38	12.71	11.53
								$37.5 KW/m^2$	NR	6.54	NR	6.67
							Flash Fire	LFL	6.38	5.27	6.76	5.19
								LFL Fraction	10.05	8.45	10.88	8.32
							Toxic Dispersion	IDLH= 100ppm	NH	NH	NH	NH
				Medium Bottom Leak	42.03	178.67	Jet Fire	$4 KW/m^2$	81.57	69.88	83.15	71.13
								$12.5 KW/m^2$	50.26	43.94	51.07	44.72
								$37.5 KW/m^2$	27.62	27.92	28.83	28.43

Table 5.18: Summary of Consequences for HydroCracker Unit

Equipment Name	**Material Flowing**	**Temp. in deg. C**	**Pressure in bar**	**Accident Scenario**	**Release Rate in kg/s**	**Release Duration in s**	**Event**	**Impact Criteria**	**Consequence Distance Meters**			
									Day		**Night**	
									A/B 2 m/s	**D 5 m/s**	**F 2 m/s**	**D 5 m/s**
Hot High Pressure Seperator 04-VV-003	HHPS Liquid	206	161.6	Medium Bottom Leak	42.03	178.67	Flash Fire	LFL	30.15	25.60	30.76	25.15
								LFL Fraction	46.87	41.50	50.73	40.77
							Explosion	0.02068 Bar	138.41	129.80	151.73	129.44
								0.1 Bar	65.48	63.25	76.34	63.16
								0.2068 Bar	59.72	57.99	70.38	57.92
							Toxic Dispersion	IDLH= 100ppm	NH	NH	NH	NH
				Cat. Rupture	NA	NA	Flash Fire	LFL	304.54	266.83	316.76	262.46
								LFL Fraction	361.52	348	372.58	342.50
							Pool Fire	$4 KW/m^2$	82.05	83.66	82.62	83.21
								$12.5 KW/m^2$	51.03	54.65	51.40	54.36
								$37.5 KW/m^2$	28.19	35.46	29.09	35.63
							Toxic Dispersion	IDLH= 100ppm	222.22	175.13	229.84	170.76
							Explosion	0.02068 Bar	802.3	802.3	802.3	802.3
								0.1 Bar	207.74	207.74	207.74	207.74
								0.2068 Bar	160.74	160.74	160.74	160.74

Table 5.19: Summary of Consequences for HydroCracker Unit

Equipment Name	Material Flowing	Temp. in deg. C	Pressure in bar	Accident Scenario	Release Rate in kg/s	Release Duration in s	Event	Impact Criteria	Consequence Distance Meters			
									Day		Night	
									A/B 2 m/s	D 5 m/s	F 2 m/s	D 5 m/s
Product Fractionator 04-CC-001	Fraction ovhds	93.00	1.10	Small top leak	0.01	3600	Jet Fire	$4 KW/m^2$	NR	NR	NR	NR
								$12.5 KW/m^2$	NR	NR	NR	NR
								$37.5 KW/m^2$	NR	NR	NR	NR
							Flash Fire	LFL	.07	.11	.09	.11
								LFL Fraction	.17	.26	.22	.25
				Medium Top Leak	0.251	3600	Jet Fire	$4 KW/m^2$	NR	NR	NR	NR
								$12.5 KW/m^2$	NR	NR	NR	NR
								$37.5 KW/m^2$	NR	NR	NR	NR
							Flash Fire	LFL	0.31	0.49	0.42	0.48
								LFL Fraction	0.81	1.25	1.08	1.24
				Cat. Rupture	NA	NA	Flash Fire	LFL	0.31	0.49	0.42	0.48
								LFL Fraction	0.81	1.25	1.08	1.24
							Fire Ball	$4 KW/m^2$	192.25	192.25	199.14	199.14
								12.5 KW/m2	84.2	84.2	88.78	88.78
								$37.5 KW/m^2$	NR	NR	NR	NR
							Explosion	0.02068 Bar	521.09	521.09	521.09	521.09
								0.1 Bar	134.92	134.92	134.92	134.92
								0.2068 Bar	104.4	104.4	104.4	104.4

Table 5.20: Summary of Consequences for HydroCracker Unit

Equipment Name	Material Flowing	Temp. in deg. C	Pressure in bar	Accident Scenario	Release Rate in kg/s	Release Duration in s	Event	Impact Criteria	Consequence Distance Meters			
									Day		Night	
									A/B 2 m/s	D 5 m/s	F 2 m/s	D 5 m/s
Fractionator Bottoms pump 04-PA-007	Fraction Bottoms	349	1.80	Small Leak	0.018	3600	Jet Fire	$4 KW/m^2$	NR	NR	NR	NR
								$12.5 KW/m^2$	NR	NR	NR	NR
								$37.5 KW/m^2$	NR	NR	NR	NR
							Flash Fire	LFL	1.18	1.1	1.2	1.08
								LFL Fraction	2.04	1.83	2.14	1.8
				Medium Leak	0.444	3600	Jet Fire	$4 KW/m^2$	12.6	13.51	12.53	13.38
								$12.5 KW/m^2$	9.47	11.02	9.42	10.89
								$37.5 KW/m^2$	NR	NR	NR	NR
							Flash Fire	LFL	5.32	4.76	5.59	4.66
								LFL Fraction	8.73	7.31	9.2	7.16
Heavy Naptha Stripper 04-CC-002	Heavy Naptha	148	1.2	Small Top Leak	.011	3600	Jet Fire	$4 KW/m^2$	NR	NR	NR	NR
								$12.5 KW/m^2$	NR	NR	NR	NR
								$37.5 KW/m^2$	NR	NR	NR	NR
							Flash Fire	LFL	0.06	0.1	0.8	0.1
								LFL Fraction	0.17	0.25	0.20	0.25
				Medium Top Leak	0.265	203.87	Jet Fire	$4 KW/m^2$	NR	NR	NR	NR
							Flash Fire	LFL	0.06	0.10	0.08	0.10
								LFL Fraction	0.17	0.25	0.20	0.25

Table 5.21: Summary of Consequences for HydroCracker Unit

Equipment Name	Material Flowing	Temp. in deg. C	Pressure in bar	Accident Scenario	Release Rate in kg/s	Release Duration in s	Event	Impact Criteria	Consequence Distance Meters			
									Day		Night	
									A/B 2 m/s	D 5 m/s	F 2 m/s	D 5 m/s
Heavy Naptha Stripper 04-CC-002	Heavy Naptha	148	1.2	Cat. Rupture	NA	NA	Flash Fire	LFL	16.46	41.67	61.19	40.75
								LFL Fraction	28.02	72.52	132.02	71.27
							Fire Ball	$4KW/m^2$	54.15	54.15	55.63	55.63
								12.5 KW/m^2	20.99	20.99	22.08	22.08
								37.5 KW/m2	NR	NR	NR	NR
							Explosion	0.02068	155.56	155.56	155.56	155.56
								0.1 Bar	40.28	40.28	40.28	40.28
								0.2068 Bar	31.17	31.17	31.17	31.17
Heavy Naptha product pump 04-PA-010	Heavy Naptha	155	1.30	Small Leak	0.012	3600	Jet Fire	$4KW/m^2$	NR	NR	NR	NR
								12.5 KW/m^2	NR	NR	NR	NR
								37.5 KW/m^2	NR	NR	NR	NR
							Flash Fire	LFL	1.06	0.99	1.07	0.98
								LFL Fraction	1.83	1.65	1.91	1.63
				Medium Leak	0.289	210.5	Jet Fire	$4KW/m^2$	NR	NR	NR	NR
							Flash Fire	LFL	4.80	4.33	5.01	4.27
								LFL Fraction	7.78	6.67	8.61	6.58
Kersoene Stripper 04-CC-003	Kersosene	202	1.4	Small Top Leak	0.013	3600	Jet Fire	$4KW/m^2$	NR	NR	NR	NR
								12.5	NR	NR	NR	NR

Table 5.22: Summary of Consequences for HydroCracker Unit

% ARD				
FAME	**CG**	**MP**	**Joback**	**Yuan**
Methyl Caprylate (C8:0)	21.8333	3.6301	3.3054	4.0317
Methyl Decanoate (C10:0)	18.6941	3.5748	6.0679	0.2094
Methyl Laurate (C12:0)	14.0017	5.1235	7.0870	0.1484
Methyl Myristate (C14:0)	10.5852	5.9029	8.9211	0.2595
Methyl Palmitate (C16:0)	5.5404	8.3272	8.7450	2.0206
Methyl Stearate (C18:0)	5.6487	6.4475	13.6292	0.0984
Methyl Oleate (C18:1)	6.1559	6.2537	14.8457	0.3832
Methyl Linoleate (C18:2)	3.3304	8.9980	12.4421	2.2865
Methyl Linolenate (C18:3)	2.8777	9.6458	12.5996	0.8726

Table 5.23: Summary of Consequences for HydroCracker Unit

Equipment Name	Material Flowing	Temp. in deg. C	Pressure in bar	Accident Scenario	Release Rate in kg/s	Release Duration in s	Event	Impact Criteria	Consequence Distance Meters			
									Day		Night	
									A/B 2 m/s	D 5 m/s	F 2 m/s	D 5 m/s
Kersoene Stripper 04-CC-003	Kersosene	202	1.4	Small Top Leak	0.013	3600	Jet Fire	37.5	NR	NR	NR	NR
							Flash Fire	LFL	0.08	0.12	0.09	0.12
								LFL Fraction	0.20	0.29	0.22	0.28
				Medium Top Leak	0.324	443.42	Jet Fire	$4 KW/m^2$	NR	NR	NR	NR
								$12.5 KW/m^2$	NR	NR	NR	NR
								37.5	NR	NR	NR	NR
							Flash Fire	LFL	0.36	0.55	0.43	0.54
								LFL Fraction	0.92	1.38	1.10	1.37
				Cat. Rupture	NA	NA	Flash Fire	LFL	22.80	56.50	91.08	54.37
								LFL Fraction	39.36	100.54	200.95	97.90
							Fire Ball	$4 KW/m^2$	78.24	78.24	80.53	80.53
								12.5	32.08	32.08	33.69	33.69
								$37.5 KW/m^2$	NR	NR	NR	NR
							Explosion	0.02068 Bar	216.82	216.82	216.82	216.82
								0.1 Bar	56.14	56.14	56.14	56.14
								0.2068 Bar	43.44	43.44	43.44	43.44
Kerosene Product Pump 04-PA-009	Kerosene	234	1.4	Small Leak	0.014	3600	Jet Fire	$4 KW/m^2$	NR	NR	NR	NR
								$12.5 KW/m^2$	NR	NR	NR	NR
								$37.5 KW/m^2$	NR	NR	NR	NR
							Flash Fire	LFL	1.21	1.13	1.24	1.11
								LFL Fraction	2.06	1.85	2.17	1.82

Table 5.24: Summary of Consequences for HydroCracker Unit

Equipment Name	Material Flowing	Temp. in deg. C	Pressure in bar	Accident Scenario	Release Rate in kg/s	Release Duration in s	Event	Impact Criteria	Consequence Distance Meters			
									Day		Night	
									A/B 2 m/s	D 5 m/s	F 2 m/s	D 5 m/s
Kerosene Product Pump 04-PA-009	Kerosene	234	1.4	Medium Leak	.0348	480.87	Jet Fire	4KW/m^2	11.07	11.94	11.01	11.82
								12.5 KW/m^2	8.20	9.71	8.17	9.60
								37.5 KW/m^2	NR	NR	NR	NR
							Flash Fire	LFL	5.45	4.86	5.73	4.78
								LFL Fraction	8.98	7.35	10.21	7.24
Diesel Stripper 04-CC-004	Diesel	299	1.60	Small Top Leak	0.015	3600	Jet Fire	4KW/m^2	NR	NR	NR	NR
								12.5 KW/m^2	NR	NR	NR	NR
								37.5 KW/m^2	NR	NR	NR	NR
							Flash Fire	LFL	0.06	0.10	0.07	0.09
								LFL Fraction	0.16	0.24	0.19	0.24
				Medium Top Leak	0.381	157.85	Jet Fire	4KW/m^2	NR	NR	NR	NR
								12.5 KW/m^2	NR	NR	NR	NR
								37.5 KW/m^2	NR	NR	NR	NR
							Flash Fire	LFL	0.29	0.45	0.35	0.45
								LFL Fraction	0.78	1.16	0.92	1.14
				Cat. Rupture	NA	NA	Flash Fire	LFL	12.40	26.92	16.66	26.10
								LFL Fraction	19.21	43.65	26.90	40.94
							Fire Ball	4KW/m^2	57.63	57.63	59.22	59.22
								12.5 KW/m^2	23.10	23.10	24.22	24.22
								37.5 KW/m^2	NR	NR	NR	NR

Table 5.25: Summary of Consequences for HydroCracker Unit

Equipment Name	Material Flowing	Temp. in deg. C	Pressure in bar	Accident Scenario	Release Rate in kg/s	Release Duration in s	Event	Impact Criteria	Consequence Distance Meters			
									Day		Night	
									A/B 2 m/s	D 5 m/s	F 2 m/s	D 5 m/s
Diesel Stripper 04-CC-004	Diesel	299	1.60	Cat. Rupture	NA	NA	Explosion	0.02068	59.16	59.16	59.16	59.16
								0.1 Bar	15.32	15.32	15.32	15.32
								0.2068 Bar	11.85	11.85	11.85	
Diesel Product Pump 04-PA-008	Diesel	282	1.70	Small Leak	0.016	3600	Jet Fire	$4 KW/m^2$	NR	NR	NR	NR
								$12.5 KW/m^2$	NR	NR	NR	NR
								$37.5 KW/m^2$	NR	NR	NR	NR
							Flash Fire	LFL	1.06	1.00	1.07	0.98
								LFL Fraction	1.85	1.68	1.93	1.65
				Medium Leak	1.405	161.01	Jet Fire	$4 KW/m^2$	11.88	12.72	11.82	12.60
								$12.5 KW/m^2$	8.91	10.34	8.86	10.22
								$37.5 KW/m^2$	NR	NR	NR	NR
							Flash Fire	LFL	4.83	4.37	5.02	4.28
								LFL Fraction	7.92	6.80	8.66	6.66
Deethanizer 04-CC-005	Hydrogen Sulfide, Naptha	54	13.40	Small Top Leak	0.065	3600	Jet Fire	$4 KW/m^2$	NR	NR	NR	NR
								$12.5 KW/m^2$	NR	NR	NR	NR
								$37.5 KW/m^2$	NR	NR	NR	NR
							Flash Fire	LFL	0.08	0.14	0.12	0.14
								LFL Fraction	0.24	0.37	0.31	0.37

Table 5.26: Summary of Consequences for HydroCracker Unit

Equipment Name	**Material Flowing**	**Temp. in deg. C**	**Pressure in bar**	**Accident Scenario**	**Release Rate in kg/s**	**Release Duration in s**	**Event**	**Impact Criteria**	**Consequence Distance Meters**			
									Day		**Night**	
									A/B 2 m/s	**D 5 m/s**	**F 2 m/s**	**D 5 m/s**
Deethanizer 04-CC-005	Hydrogen Sulfide, Naptha	54	13.40	Small Top Leak	0.065	3600	Toxic Dispersion	IDLH= 100ppm	NH	NH	NH	NH
							Flash Fire	LFL	0.41	0.71	0.57	0.70
								LFL Fraction	1.16	1.85	1.58	1.84
							Toxic Dispersion	IDLH= 100ppm	NH	NH	NH	NH
				Cat. Rupture	NA	NA	Flash Fire	LFL	13.09	21.73	15.94	21.21
								LFL Fraction	19.52	39.98	26.90	38.74
							Fire Bal	$4 KW/m^2$	139.87	139.78	144.17	144.17
								$12.5 KW/m^2$	69.66	69.66	72.21	72.21
								$37.5 KW/m^2$	NR	NR	NR	NR
							Explosion	0.02068 Bar	283.94	283.94	283.94	283.94
								0.1 Bar	73.52	73.52	73.72	73.52
								0.2068 Bar	56.89	56.89	56.89	56.89
							Toxic Dispersion	IDLH= 100ppm	112.86	NH	443.3	NH
Deethanizer Bottom Pump 04-PA-016	Naptha	141	13.70	Small Leak	0.078	3600	Jet Fire	$4 KW/m^2$	NR	NR	NR	NR
								$12.5 KW/m^2$	NR	NR	NR	NR
								$37.5 KW/m^2$	NR	NR	NR	NR

Table 5.27: Summary of Consequences for HydroCracker Unit

Equipment Name	**Material Flowing**	**Temp. in deg. C**	**Pressure in bar**	**Accident Scenario**	**Release Rate in kg/s**	**Release Duration in s**	**Event**	**Impact Criteria**	**Consequence Distance Meters**			
									Day		**Night**	
									A/B 2 m/s	**D 5 m/s**	**F 2 m/s**	**D 5 m/s**
Deethanizer Bottom Pump 04-PA-016	Naptha	141	13.70	Small Leak	0.078	3600	Flash Fire	LFL	2.18	2.06	2.22	2.03
								LFL Fraction	3.82	3.43	4.01	3.39
				Medium Leak	1.941	303.38	Jet Fire	$4 KW/m^2$	24.33	24.69	24.24	24.54
								$12.5 KW/m^2$	19.26	20.41	19.19	20.26
								$37.5 KW/m^2$	14.72	16.62	14.91	16.56
							Flash Fire	LFL	10.37	9.28	10.83	9.08
								LFL Fraction	23.38	21.63	25.70	21.09
							Explosion	0.02068 Bar	40.76	39.8	42.18	39.68
								0.1 Bar	25.38	25.13	25.74	25.09
								0.2068 Bar	24.16	23.97	24.44	23.94
First Stage off gas compressor 04-KA-002	Hydrogen Sulfide, Naptha, H2	77	2.7	Small Leak	0.018	3600	Jet Fire	$4 KW/m^2$	NR	NR	NR	NR
								$12.5 KW/m^2$	NR	NR	NR	NR
								$37.5 KW/m^2$	NR	NR	NR	NR
							Flash Fire	LFL	1.16	1.10	1.17	1.09
								LFL Fraction	2.05	1.87	2.13	1.84
							Toxic Dispersion	IDLH= 100ppm	NH	NH	NH	NH
				Medium Leak	0.457	855.79	Jet Fire	$4 KW/m^2$	11.69	12.03	11.61	11.91
								$12.5 KW/m^2$	8.94	9.62	8.88	9.52

Table 5.28: Summary of Consequences for HydroCracker Unit

Equipment Name	**Material Flowing**	**Temp. in deg. C**	**Pressure in bar**	**Accident Scenario**	**Release Rate in kg/s**	**Release Duration in s**	**Event**	**Impact Criteria**	**Consequence Distance Meters**			
									Day		**Night**	
									A/B 2 m/s	**D 5 m/s**	**F 2 m/s**	**D 5 m/s**
First Stage off gas compressor 04-KA-002	Hydrogen Sulfide, Naptha, H2	77	2.7	Medium Leak	0.457	855.79	Jet Fire	37.5	NR	NR	NR	NR
							Flash Fire	LFL	5.38	4.92	5.57	4.85
								LFL Fraction	9.10	7.73	10.16	7.62
							Toxic Dispersion	IDLH= 100ppm	45.79	35.58	64.06	34.53
2nd Stage off gas compressor 04-KA-002	Hydrogen Sulfide, Naptha, H2	101	18.10	Small Leak	0.059	2227.72	Jet Fire	4KW/m^2	NR	3.50	3.50	3.53
								12.5 KW/m^2	NR	NR	NR	NR
								37.5 KW/m^2	NR	NR	NR	NR
							Flash Fire	LFL	1.31	1.11	1.45	1.09
								LFL Fraction	2.21	1.83	2.51	1.80
							Toxic	IDLH= 100ppm	NH	NH	NH	NH
				Medium Leak	1.48	89.11	Jet Fire	4KW/m^2	18.13	17.93	18.31	18.17
								12.5 KW/m^2	NR	10.73	NR	10.98
								37.5 KW/m^2	NR	NR	NR	NR
							Flash Fire	LFL	6.29	5.26	6.69	5.17
								LFL Fraction	10.45	8.65	11.19	8.52
							Toxic Dispersion	IDLH= 100ppm	NH	NH	NH	NH
KO Drum 04-VV-013	Hydrogen Sulfide, Naptha	40	16.8	Small Leak	0.546	3600	Jet Fire	4KW/m^2	16.52	17.01	16.77	17.21
								12.5 KW/m^2	9.67	10.95	9.83	11.07
								37.5 KW/m^2	NR	6.55	NR	6.65

Table 5.29: Summary of Consequences for HydroCracker Unit

Equipment Name	Material Flowing	Temp. in deg. C	Pressure in bar	Accident Scenario	Release Rate in kg/s	Release Duration in s	Event	Impact Criteria	Consequence Distance Meters			
									Day		Night	
									A/B 2 m/s	D 5 m/s	F 2 m/s	D 5 m/s
KO Drum 04-VV-013	Hydrogen Sulfide, Naptha	40	16.8	Small Leak	0.546	3600	Flash Fire	LFL	5.01	4.17	5.72	4.11
								LFL Fraction	7.97	6.89	9.46	6.81
							Toxic Dispersion	IDLH= 100ppm	NH	NH	NH	NH
				Medium Leak	13.63	679.07	Jet Fire	$4KW/m^2$	76.45	74.49	77.95	75.86
								12.5	46.76	47.04	47.52	47.85
								37.5	24.51	30.15	25.76	30.53
							Flash Fire	LFL	25.83	21.30	31.19	21.11
								LFL Fraction	40.66	38.93	51.57	38.45
							Explosion	0.02068 Bar	126.16	103.49	143.15	103.41
								0.1 Bar	62.31	49.03	74.12	49.01
								0.2068 Bar	57.26	44.72	68.66	44.71
							Toxic Dispersion	IDLH= 100ppm	NH	NH	NH	NH
				Catastrophic Rupture	NA	NA	Flash Fire	LFL	200.31	185.87	206.60	178.30
								LFL Fraction	259.56	250.96	250.41	242.36
							Pool Fire	$4KW/m^2$	189.75	192.47	200.46	200.19
								12.5	118.66	125.69	125.07	130.38
								37.5	70.18	83.87	74.95	87.12

Table 5.30: Summary of Consequences for HydroCracker Unit

Equipment Name	**Material Flowing**	**Temp. in deg. C**	**Pressure in bar**	**Accident Scenario**	**Release Rate in kg/s**	**Release Duration in s**	**Event**	**Impact Criteria**	**Consequence Distance Meters**			
									Day		**Night**	
									A/B 2 m/s	**D 5 m/s**	**F 2 m/s**	**D 5 m/s**
KO Drum 04-VV-013	Hydrogen Sulfide, Naptha	40	16.8	Cat. Rupture	NA	NA	Explosion	0.02068 Bar	610.74	610.74	610.74	610.74
								0.1 Bar	158.14	158.14	158.14	158.14
								0.2068 Bar	122.36	122.36	122.36	122.36
							Toxic Dispersion	IDLH= 100ppm	NH	NH	NH	NH

- **Consequences Analysis for fire**

The fire ball due to catastropic rupture of First Stage Main Reactor 04-RB-002 at 2.0 F weather condition can cause 100% fatality risks within 488m distance for 37.5KW/m^2 radiation and the equipment may be subject to major damages. Piloted ignition of wood, melting of plastics tubings and will cause extreme pain in 20 seconds within the distance of 268 m for 12.5KW/m^2 radiation. This level indicates around 6% fatality for 20 seconds exposure. Sufficient pain will occur to personnel is unable to reach cover in 20sec within 118m for 4KW/m^2radiation. The consequences for fire contour is there in Appendix B.

- **Consequences Analysis for explosion**

The maximum damage can be felt in case of a catastrophic rupture of Second Stage Reactor 04-RB-003 at 2.0 F weather condition. An overpressure of 0.2068 bars can be felt up to a distance of 784 meters enough to cause permanent damage to plant and structure within this distance, it will also cause 100% fatality for persons who are within this distance. An overpressure of 0.10 bar can be felt up to a distance of 202 meters, equipment within this range can suffer repairable damages, it can also cause 1% death, 1% eardrum damage, 1% serious wound from the fragments of flying glass for persons who are present in this distance range. An overpressure of 0.0206 bars can be felt up to a distance of 157 meters, glass breakage and damage can be experienced in this distance range.The consequences contour for fire is there in Appendix B.

- **Consequences Analysis for toxicity**

In case of catastrophic rupture of Dethanizer 04-CC-005, the maximum damage distance for toxic concentration of 100ppm (IDLH) for weather condition 2.0F will be around 440 meters. As per NIOSH guidelines 100ppm for exposure of 30 minutes within this distance may have immediate dangerous effect on health and life of people.The consequences contour for fire is there in Appendix B.

5.4 Risk Assessment

In order to determine acceptability, the risk results are assessed against a set of risk criteria.

5.4.1 Individual Risk Criteria

The term individual risk is used for the calculations of the risk of fatality for someone at a specific location, assuming that the person is always present at the location, i.e. is continuously exposed to the risk at that location. This is sometimes referred to as Location-Specific Individual Risk (LSIR), to distinguish from the person-specific individual risk that would depend on the movements of a given individual. It is a measure of the geographic distribution of risk, independent of the distribution of people at that location or in the surrounding area. The risk results are presented in the form of Risk Contour Plot, which shows the distribution of LSIR against the background of a map.

The Individual Risk Criteria was considered to assess the risk for this study. Individual risk above 10^{-3} per annum for any person shall be considered intolerable and fundamental risk reduction improvements are required. Risk criteria for Individual Risk for Workers are as follows as per UK HSE standard:

- Individual risk levels above 1 x 10-3 per year will be considered unacceptable and will be reduced, irrespective of cost.
- Individual risk levels below 1 x 10-6 per year will be broadly acceptable.
- Risk levels between 1 x 10-3 and 1 x 10-6 per year will be reduced to levels as low as reasonably practicable (ALARP). That is the risk within this region is tolerable only if further risk reduction is considered impracticable because the cost required to reduce the risk is grossly disproportionate to the improved gain.

5.4.2 Societal Risk Criteria

The societal risk is a measure of the risk that the events pose to the local population, taking into account the distribution of the population in the local area. The societal risk is expressed in terms of the likelihood of event outcomes that affect a given number of people in a single incident (e.g. the likelihood of event outcomes that affect up to 10 people, or the likelihood of event outcomes that affect up to 20 people).

For this study, Societal Risk criteria have been used which is represented as follows:

- The level of societal risk to workers is considered intolerable if there is the potential to cause 1 or more fatalities every 100 years.
- The level of societal risk to workers is considered broadly acceptable if there is potential to cause 1 or more fatalities in 100000 years.

- The level of societal risk to workers is considered as low as reasonably practicable (ALARP) if there is potential to cause 1 or more fatalities between 100 and 100000 years.

5.5 Risk result for Hydro Cracker Unit

5.5.1 Individual Risk

The following fig shows the LSIR contour for NRL Refinery, Assam. From this contour, following conclusions can be drawn:

- The Location Specific Individual Risk (LSIR) contour indicate that the maximum risk that the facility is exposed to is in the range of 1e-0005 (pink color) and 1e-0006 (orange color) ALARP Region.

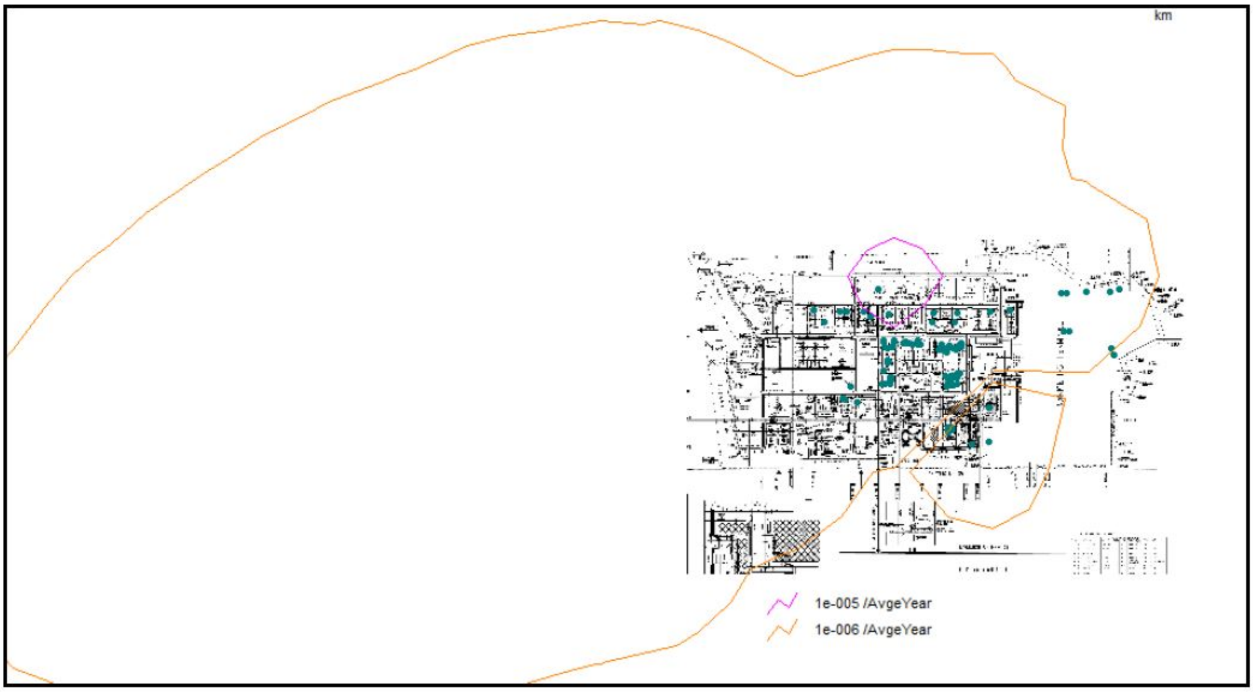

Figure 5.1: LSIR Contour for Hydro Cracker Unit

5.5.2 Societal Risk

Figure below further provides the associated F-N Curve for societal risk. The region beyond Green line represents the risk in unacceptable region whereas the region below the Yellow line represents the risk in highly acceptable region. The region between these two lines represents the risk in ALARP region. Blue colored line shows the comparative societal risk for existing facility. When compared below curve to the proposed risk criteria, the societal risk is in ALARP region.

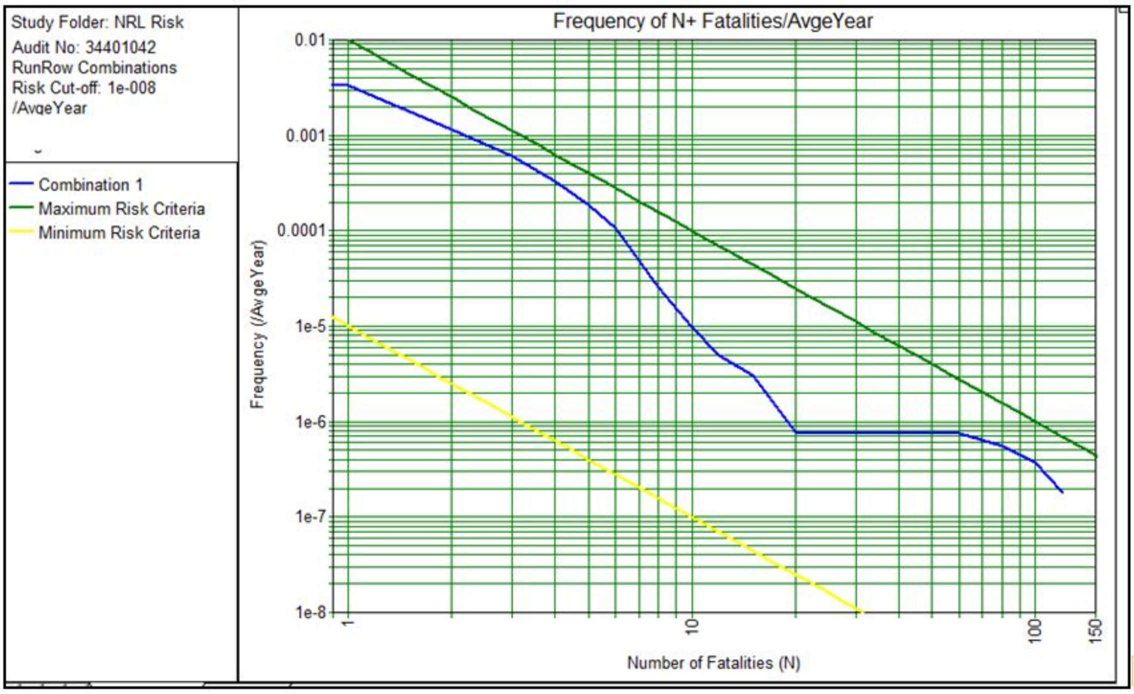

Figure 5.2: F-N Curve Represting Societal Risk for Hydro Cracker unit

Following conclusion can be drawn from the above F-N Curve:

Table 5.31: F/N curve conclusion

Number of Fatality	Frequency per year
1	3.24E-03
10	9.70E-06
100	3.62E-07

5.6 Conclusion and Recommendations

5.6.1 Main Conclusion

From the LSIR (Location Specific Individual Risk) contours and the F-N curve, the following observations can be taken further:

Table 5.32: F/N curve conclusion

1	**Location Specific Individual Risk(LSIR)**
	Maximum level of risk that the plant is exposed to is in the range of 1 X 10-5 which is ALARP for the onsite workers.
2	**Expected Number of Fatalities**
	It has been shown that the Potential Loss of Life (PLL) calculated or fatality 1 is 3.24E-03 per avg year and for fatality 100 is 3.62E-07
3	**Societal Risk (F-N Curve)**
	The F-N curves show that societal risk is in the ALARP region.

5.6.2 Recommendations

Based on the risk assessment study the major recommendations to bring down risk level to broadly acceptable as giver below:

- **Recommendation for Frequency Reduction:**

1. Since it is a refinery, recommended to conduct SIL identification study for instruments associated with facility and minimum SIL 3 level should be maintained.

2. Instruments and trip interlocks shall be checked and calibrated at regular intervals to prevent any wrong signaling and consequence failures.

3. Pipelines should be painted as per the displayed color coding chart and identification numbers, flow direction; content in the pipeline etc. should be shown on the pipeline. This will reduce the hazard of wrong operation and maintenance and ultimately the risk.

4. SOP/SMPs should be in place and should be used with proper training which will drastically reduce probability of failure of the process or system and minimize accidents.

5. Popularize the concept of preventive and predictive maintenance procedure and follow good MIQA procedures.

6. Periodic site inspection should be carried out to ensure that there is no leakage from the pipelines or any of the storage tanks. This is the concept of LDAR (Leak detection & repair) program in place. This will help for root cause analysis for leak & timely corrective and preventive action. This will reduce the PFD frequency and minimize catastrophic rupture.

7. For the smooth and safe operation of plant, a thorough safety audit once a year is recommended. Safety audit will help to identify potential hazards prevailing in the facilities and hence will reduce the frequency.

8. For detailed identification of ignition sources and area with flammable material accumulation, Hazardous Area Classification for the facility is recommended. The overall risk can be minimized by reducing the ignition probabilities and ignition sources. Also ensure that the cables, wires, electrical fittings are selected as per area classification.

9. Since the plant is handling several flammable hydrocarbons, implementation of PSM system can drastically reduce the chances of accidents.

10. Electrical continuity for the earthing of tanks, pipelines and other critical equipments should be ensured to minimize static charge collection and provide ignition source.

11. On site and off site emergency procedure shall be reviewed periodically with reference to mock drill results. What is mentioned in the manual is to be ensured to have it and practiced it at the Site.

- **Recommendation for Consequences Reduction:**

1. Adequacy of the firefighting system shall be assessed for consideration of minimizing the heat radiation effects due to fire as per OISD 116.
2. Emergency escape and evacuation plan (site specific) should be prepared and escape routes should be displayed with fluorescent color.
3. Proper access roads should be provided to storage areas from all sides and access should be kept free from any obstacles all the time.
4. SOP (Standard operating procedure) for Spillage Management and facility to transfer all the contaminated material to ETP / disposal site or other container to be ensured and followed.
5. Mock drill is to be conducted during day and night time once in three months.
6. It is to be ensured that assembly point sign boards identified emergency escape and evacuation route in the plant in case of various accident scenarios are available. These identified routes should be displayed at various locations and marked with fluorescent paint sign boards.
7. It is to be ensured that weather wind socks or wind direction indicators are installed in strategic locations such that it is visible from each and every corner of the plant.

5.7 Limitations of quantitative risk assessment

- Different approaches and methodologies give the different results.
- Scenario selection depends on the expertise of the risk assessor.
- Change in environment conditions like temperature, humidity and wind speed can alter the results.
- Dispersion values are not available for all chemicals.
- Each software model simulate different results for the same chemical release scenarios.
- All countries do not have specified acceptable risk limits.
- Data base used for the frequency can be different.

Chapter 6

Results and Discussion

The HAZOP study was conducted at the facility for a total of 12 days. 26 Nodes of 41 P&ID as discussed earlier were addressed and suitable recommendations where required were given. The team comprised of total of 7 different disciplines consisting of process engineer, instrument engineer, HAZOP chairman, safety engineer, technical scribe, project engineer and operation representative. The study provided recommendations which will not be considered for this project. Only major hazardous consequences scenario where qualitative assessment fails to provide a light are discussed in this report. As described earlier, the aim of the HAZOP method was not to provide recommendations but to create the scenarios for Quantitative Risk Assessment study.

6.1 Scenarios from HAZOP

There are many ways how a scenario can be determined for Quantitative Risk Assessment study. Some of the most common ways how scenarios are developed for Quantitative Risk Assessment are through inspecting plant operations, recent incidents in the process, any change that has occurred or is required during the life time of the process, and suggested interlocks for safer operations in the process. One can also use the major consequences determined in the HAZOP method to screen the scenarios for Quantitative Risk Assessment study. This report considers the later methods for determining the scenarios through HAZOP study. The advantage of these methods over other is, while analysis the analysts get more friendlier to plant operations and the operating problems faced by them. The major scenarios identified during the HAZOP study are listed in Table 6.1 and 6.2 below. The HAZOP worksheet and P&ID study carried out for this thesis is attached in Appendix A.

Table 6.1: Major Consequences of HAZOP for Accidental Scenario Identification

Major Consequences from HAZOP	**Equipment**	**Accident Scenario**
High pressure in the Lead reactor 04-RB-001 and it may damage.	First Stage Lead Reactor 04-RB-001	Leak-Small, Medium & Catastrophic Rupture
High pressure in the reactor 04-RB-002 and it may damage.	First Stage Main Reactor 04-RB-002	Leak-Small, Medium & Catastrophic Rupture
High pressure in the reactor 04-RB-003 and it may damage.	Second Stage Reactor 04-RB-003	Leak-Small, Medium & Catastrophic Rupture
Liquid carry over to the compressor 04-KA-001 and it will damage it.	Recycle Gas Compressor 04-KA-001	Leak-Small, Medium
High Temperature in reactor effluent which will cause Possibility of material damage due to Hydrogen embritlement.	Cold High Pressure Separator (CHPS) 04-VV-004	Leak-Small, Medium & Catastrophic Rupture
High Pressure in the Cold Low Pressure, due to high liquid flow from CHPS and vapor from HLPS.	Cold Low Pressure Separator (CLPS) 04-VV-006	Leak-Small, Medium & Catastrophic Rupture
High Pressure in Hot Low Pressure Separator (HLPS) 04-VV-005	Hot Low Pressure Separator (HLPS) 04-VV-005.	Leak-Small, Medium & Catastrophic Rupture
High Temperature in the separator 04-VV-003, material damage due to Hydrogen embritlement.	Hot High Pressure Separator (HHPS) 04-VV-003	Leak-Small, Medium & Catastrophic Rupture
High Pressure in Product Fractionator 04-CC-001	Product Fractionator 04-CC-001	Leak-Small, Medium & Catastrophic Rupture
Due to Low/ no flow at the pump 04-PA-007 suction it will run dry which will lead to pump seal damage.	Fractionator bottom pump 04-PA-007 suction line	Leak-Small, Medium

Table 6.2: Major Consequences of HAZOP for Accidental Scenario Identification

Major Consequences from HAZOP	**Equipment**	**Accident Scenario**
High Pressure in Heavy Naptha stripper 04-CC-002	Heavy Naptha Stripper 04-CC-002	Leak-Small, Medium & Catastrophic Rupture
Due to Low/ no flow at the pump 04-PA-010 suction it will run dry which will lead to pump seal damage.	Heavy Naphtha Product Pump 04-PA-010 suction line	Leak-Small, Medium
High Pressure in Kerosene Stripper 04-CC-003	Kerosene Stripper 04-CC-003	Leak-Small, Medium & Catastrophic Rupture
Due to Low/ no flow at the kerosene pump 04-PA-009 suction it will run dry which will lead to pump seal damage.	Kerosene Product Pump 04-PA-009 suction line	Leak-Small, Medium
High Pressure in Kerosene Stripper 04-CC-004	Diesel Stripper 04-CC-004	Leak-Small, Medium & Catastrophic Rupture
Due to Low/ no flow at the pump 04-PA-010 suction it will run dry which will lead to pump seal damage.	Diesel Product Pump 04-PA-008 suction line	Leak-Small, Medium
High Pressure in Deethanizer 04-CC-005	Deethanizer 04-CC-005	Leak-Small, Medium & Catastrophic Rupture
Due to Low/ no flow at the Deethanizer pump 04-PA-016 suction it will run dry which will lead to pump seal damage.	Deethanizer Bottom Pumps 04-PA-016 suction line	Leak-Small, Medium
Liquid carry over to first stage compressor 04-KA-002 and it will damage it.	First Stage off gas compressor 04-KA-002	Leak-Small, Medium
Liquid carry over to the 2nd stage compressor 04-KA-002 and it will damage it.	2nd Stage Off gas Compressor 04-KA-002	Leak-Small, Medium
High Pressure in KO Drum 04-VV-013	KO Drum 04-VV-013	Leak-Small, Medium & Catastrophic Rupture

6.2 Risk Software

Phast and Phast risk software are utilized for risk calculation and its quantification. The accidental scenarios determined from the HAZOP study will act as a source model for the Phast and Phast Risk software for the consequences and risk determination of Hydro Cracker Facility for QRA study. The various models for the discharge, dispersion, toxic, explosive and flammable has been understood for Phast software for consequence analysis. Phast consequence provides us comprehensive hazard analysis facilities in terms of consequences contour fire, explosion and toxicity to examine potential incident from the initial release to its far-field effects. This consequences from the Phast will be imported to the Phast risk for the risk determination for the Hydro cracker unit in the form of F/N curve and Location Specific Individual Risk(LSIR). The Phast risk allows us to take account of local population distribution, sources of ignition, land usage and local prevailing weather conditions for estimation of the risk in the facility. This will allow to quickly identifying major risk contributors so that time and efforts can be directed to mitigate these highest risk activities. The established individual and societal risk indicators will be predicted across the Hydro cracker unit and surrounding area.

6.3 Software results in terms of risk

Consequences Analysis for fire determined that fire ball due to catastropic rupture of First Stage Main Reactor has major hazard. Consequences Analysis for explosion determined that maximum damage can be felt in case of a catastrophic rupture of Second Stage Reactor 04-RB-003. Consequences Analysis for toxicity determined that catastrophic rupture of Dethanizer 04-CC-005 have maximum toxic hazard.

For the given population density, meteorological condition and process parameters, the individual risk for Hydro Cracker Unit is between 1e-0005 and 1e-0006 per year which is As Low As Reasonably Practicable (ALARP) region per average year. Societal risk for Hydro Cracker unit from F/N curve also falls in in ALARP region. Hence individual risk and societal risk falls under ALARP region as per standard guidelines of HSE UK, hence additional risk control measures as discussed in chapter 5.6.2 to be considered to bring down the risk level in to broadly acceptable region.

Chapter 7

Summary

HAZOP technique is a well recognized approach for hazard identification of definite system. But as with every technique, HAZOP has some pros and cons. An effective HAZOP is usually composed of well interacted brain storming session of the HAZOP team and therefore different teams performing study of the same plant may conclude to different results. There are other tools and techniques available for the identification of hazards such as Failure Mode and Effect Analysis (FMEA), Hazard Identification (HAZID), What-if analysis etc., When compared to these techniques, HAZOP provides more comprehensive information and errors in system design. Additionally, HAZOP gives a concrete basis for QRA study making it preferred choice for scenarios identification.

The topics covered in the study are:

- Understanding the problem statement.
- Carrying out the literature review of HAZOP.
- Studying the case study thoroughly.
- Collecting the necessary documents required for the study Applying the HAZOP.
- Identify the scenarios for QRA study

The other objective of the report was to identify over all risk of different scenarios deduced from the hazard and operability study. Phast and Phast Risk are utilized for identifying the consequences contour, Individual Risk ans Societal Risk in form of F/N curve. This method also has some pros and cons as discussed in chapter 5.7. Other methods has complicated process, requires considerable amount of time to complete, more manual error, we cannot quantify exact risk w.r.t distance/ concentration/ time on plot plan/ map, potential loss of life cannot be identified and at last results are not conservative.

The topics covered in the study are:

- Understanding the risk softwares and models on which it works.
- Collection of necessary data required for software input.
- Understanding the risk for the case study w.r.t individual and societal risk.
- Comparing risk with standard criteria.
- Recommendation to bring risk to broadly acceptable range.

Conducting QRA study for risk analysis and assessment after HAZOP study ultimately allows the industries to identify the major hazard. The study in this case also addresses the cases where the safeguards provided were not adequate or safeguards provided were not strong enough to alter the event and protect the industry. Thus the basic ideology of QRA study for risk analysis and assessment was applied on refinery for hydro cracker unit.

Future scope

Risk software shall be run again after the compliance of the recommendations given after the study. The credit of the recommendation shall be taken to reduce frequency and consequences. The new consequences and frequency data will be utilized to generate the risk for the selected facility. This will ultimately allow us to know whether the risk falls under broadly acceptable region.

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Appendix A

Node marked P&ID of HAZOP for Hydro Cracker Unit

Appendix B

HAZOP Worksheets and Consequences Contour for Hydro Cracker Unit

Inventory of accompanying CD

The CD contains following materials:

1. Microsoft Excel files for the HAZOP study.

2. Microsoft word file of Consequences Contour for the QRA study.