RISK ASSESSMENT ON A CROSS COUNTRY LIQUID PETROLEUM PIPELINE

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Master of Technology
(Pipeline Engineering)

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This is to certify that the work contained in this thesis titled **"Risk Assessment On a Cross Country Liquid Petroleum Pipeline"** has been carried out by **Charanya Kumar Duvvuru Mohan** of University of Petroleum & Energy Studies Dehradun, under our official supervision as part of his terminal project; for completion of degree M.Tech (Pipeline Engg.). Hereby we acknowledge the validity of the data used in this project and declare that this thesis has not been submitted else where for a degree. The study was carried out on a real time basis, as it was part of a contract assignment to PDIL, as we provide professional risk consultancy.

M/s Projects & Development India Ltd and Indian oil Corporation Ltd, hold the rights for the data used in this study, thereby we strictly prohibit illegal and unauthorized use or repetition of the data in any form. We also certify that the conduct of the student during the time spent in working with us was excellent.

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Dakshinamurthi Sam-aarambham Shankaracharya Madhyamam |

Asmadh-acharya Paryantham Vandhe guru paramparam ||

Hare krishna

ABSTRACT

Chemical process industries handle store and process large quantities of hazardous chemicals and intermediates. Risk assessment techniques have been recognized as an important tool for integrating and internalizing safety, reducing hazards to the environment, minimizing loss of life and damages to property. These assessments are carried out on proposed projects to estimate their hazards.

The process of risk assessment of a proposed pipeline project in the Indian scenario is carried out by a rigorous risk plan suggested by the Oil Industries Safety Directorate, which emphasizes process risk, unlike the west where the process is specialized to pipelines using the Muhlbauer model. The Muhlbauer model allows quantification of risk, even to the features specific to pipelines, which are not under the purview of process hazards.

This project report covers the viability of applying the Indian model and the Muhlbauer model to pipelines and compares their results. Further an attempt has been made to combine the features of both the models to suit the exact Indian pipeline scenario.

Selection of the most appropriate hazard / risk identification and assessment has been accomplished by the estimating required level of safety and literature review. A combination of the following techniques of both the models mentioned previously have been used which include, Hazard identification (HI), Consequence analysis(CA), Fire/explosion indices (DOW Index), Fire hazard analysis(FHA), Quantitative risk assessment (QRA),Failure mode and effect analysis(FMEA)and Index Sum of failure. The project suggests the right methodology to assess the risk associated with a pipeline. The outcome of the study brings out ways to minimize the risk and also ease mitigation

activities in case of risk and failure. At the same time an attempt has also been made to model a scoring procedure for the Muhlbauer model, which today in the hands of consultants, has become inaccessible to common personnel.

Through this project, a conclusion can be made that neither the Indian model nor the Muhlbauer model are fully self sufficient and the process safety model lacks focus to pipelines. Other major conclusions of this study are that, just as transmission pipelines pose a risk to their surroundings, so does human activity in the vicinity of pipelines pose a risk to pipelines. These risks increase with growth in population, urban areas, and pipeline capacity and network. Pipeline safety and environmental regulation have generally focused on (*a*) the design, operation, and maintenance of pipelines and (*b*) incident response and have not directed significant attention to the manner in which land use decisions can affect public safety. A major feature like third party damage index is being ignored in the Indian model, which challenges the validity of the model to the pipeline scenario. The probability of explosion arising from a leak on an ATF pipeline is statistically very remote. If a pipeline spill and subsequent ignition occurs, a flash fire and/or pool fire is possible. However, 96 percent of pipeline jet fuel spills do not ignite. The areas potentially impacted by heat effects along the pipeline show ranges in distances from the pipeline from a few hundred feet up to approximately 2,000 ft from the pipeline, depending on the size of a spill and site-specific drainage conditions. ATF fires affect distances about 20 percent farther than crude oil fires.

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CHARANYA KUMAR DUVVURU MOHAN

"WIKARANSCHA GUNASCHAIWA PRAKRUTI SAMBHAVAN"
Deviations bring to fore, the attributes of nature. Risk exists only because deviations occur from process safety, which brings to fore the HAZARD attributes inherent in the system.
HARE KRISHNA

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SYMBOLS AND ACRONYMS

< less than

> greater than

/ per

°C degrees Celsius

°F degrees Fahrenheit

°K degrees Kelvin

g gram

k kilo- (multiplied 1000 times; e.g. 5 kW = 5000 watts)

mph mile per hour (1 mph = 1.15 km per hour)

m meter (1 m = 39.37 inches)

sq **m/m2** meter squared (an area measuring one meter on each side)

m (as a prefix) milli- (1/1000; e.g., 1 mm = 1/1000 of a meter)

s second

MMTPA Million metric tones per annum.

W Watt

(CFD) Computational Fluid Dynamics a modern analysis technique using computer technology to numerically solve the complete nonlinear partial differential equations governing complex fluid flows

Credible event a group (or groups) could have the general means and technical skill to accomplish successfully an intentional breach.

(LFL) Lower Flammability Limit lowest concentration of a fuel by volume mixed with air that is flammable

ATF A superior kerosene which is used as aviation gasoline or jet fuel.

Nominal Case expected outcomes of a potential breach of conditions and associated thermal hazards based on an assessment of identified credible threats and the use of best available data to select model input parameters. Minimum negative effects are assumed.

(RPT) Rapid Phase Transitions the rapid evaporation of a liquid resulting from contact with another liquid that is at a temperature significantly above the boiling temperature of the evaporating liquid

(UFL) Upper Flammability Limit highest concentration of a fuel by volume mixed with air that is flammable

Validation comparison of analytical results from a model with experimental data to ensure that the physical bases and assumptions of the model are appropriate and produce accurate results

POF Probability of failure

Chapter 1
Introduction

Risk assessment, which is the process involving identification, estimation, evaluation and subsequent effective management is a matter to be considered seriously by all those having responsibility for producing or handling of chemicals or hazardous material. Nonetheless, most extensive precautions are taken, accidents are likely to occur, hence the need of contingency planning. Risks can only be minimized, controlled and managed with defined and acceptable area by effective enforcement and adequate awareness. But the total risk can never be reduced to zero.

"No risk is not an option."

The ultimate objective is to minimize both controllable and unnecessary risks to make responsible decisions aiming to implement feasible and beneficial courses of action.

1.1 Background and Purpose

The Settlement Agreement calls for an overall risk assessment of a Pipeline System (System) owned by any of the oil companies in India. A risk assessment for the pipeline's condition, surroundings, and operation is performed. This risk assessment is termed the "pre-mitigation" assessment and is conducted in two parts. The first part is a relative risk assessment using a scoring technique that compares the probability of failure for different segments of the overall pipeline and then uses these scores in the context of an impacts assessment. This allows the setting of priorities for mitigation of spills. The second part is a probabilistic risk assessment that allows the comparison of the risk at specific locations with other societal risks. This provides a comparative context for making risk based decisions on the pipeline's operation. An additional relative risk assessment is performed on the pipeline's condition, surroundings, and planned operation after all Mitigation Plan

(MP) actions are completed . This is termed the "post -mitigation" assessment . This project discusses only the pre mitigation risk assessments.

The statuary Settlement (Govt. of India) requires:

- "An overall risk assessment of the pipeline project consistent with recognized professional risk assessment standards;
- Discounting the magnitude of potential adverse consequences by probability of their occurrence and considering mitigation measures (both preventive and responsive) that has been implemented or has been agreed to implement; and
- Consideration of:

1. Characteristics of products to be transported in the pipeline, including physical and chemical properties, and toxicity;
2. Potential hazards (e.g., fire, explosion, and toxicity);
3. Most vulnerable points (e.g., stream crossings, pump stations, valves, construction areas);
4. Magnitude of hazards based on volume of product in the uncontrolled pipeline segment, pressure in the segment, time typically required to shut down pipeline and range of ambient temperatures;
5. Speed and extent of plume spread, considering further:

   (i) products the pipeline will carry;

   (ii) spill to Rivers or tributary at low flow, average flow, and flood conditions;

   (iii) spill onto the ground with wet or dry antecedent soil conditions; high and low water table conditions; and

(iv) differing wind, temperature, and other climactic variations;

6. Emergency response plans and procedures, including procedures for communicating releases or other hazardous conditions and for deploying personnel and equipment;
7. Availability of qualified emergency preparedness agencies and services provided, including trained personnel, containment equipment, personal protection equipment, and communications capabilities; and
8. Health, safety, and environmental consequences of the pipeline location in densely populated areas."

Chemical process industries handles, store and process large quantities of hazardous chemicals and intermediates. These activities involve many different types of material, some of which can be potentially harmful if released into the environment , because of their toxic, flammable or explosive properties. The rapid growth in the use of hazardous chemicals in industry and trade has increased the risk to employees as well as the neighboring community.

Under these circumstances, it is essential to apply modern approaches to safety based on good design, management and operational control .The major hazard units should try to achieve and maintain high standards of plant integrity with due regards to the probabilities of undesirable events. While assessing design and development proposals for plants which handle hazardous materials, it is essential to identify potential hazards. Risk assessment techniques have been recognized as an important tool for integrating and internalizing safety in plant operation and production sequencing (Hoffman, 1973). In India risk assessment is mandatory for all new projects in chemical process industries dealing with hazardous chemicals and severe operating conditions.

Risk assessment includes identification of hazard scenarios and consequence analysis. Scenario identification describes how an accident occurs, while consequence analysis describes the anticipated damage to environment, life and equipment. This project presents the results of a risk assessment study carried out for a pipeline system proposed for the transportation of petroleum products.

India is heavily dependent on transmission pipelines to distribute energy because they are the safest mode available for transporting energy fuels. Virtually all natural gas, which accounts for about 28 percent of energy consumed annually, and two-thirds of petroleum products are transported by transmission pipelines, which make up 20 percent of the 15000 km total miles of pipelines in the India. Energy demand has increased by about 35 percent in the last decade, and recent estimates indicate that the demand for energy fuels may increase by another 36 percent between 2002 and 2010. The nation's projected demand for energy, particularly in new and fast-growing metropolitan areas, may require many additional miles of transmission pipelines. Increasing urbanization, which is accompanying the increasing demand, is resulting in more people living and working closer to pipelines. In many cases, development near pipelines is occurring in formerly rural, unincorporated areas long after pipelines have been constructed but before local agencies develop land use regulations that take into account the risks of allowing such development to occur. Given these projections and the fact that pipeline incidents occur almost daily in the India, regulatory agencies at the national level view pipeline safety as an issue that needs to be addressed.

In recent years major pipeline incidents have occurred, and public opposition to the construction of new pipeline rights-of-way has increased. These events have focused more attention on the need to assess carefully and rationally the actual risks associated with living and working in proximity to transmission pipelines and to consider land use controls near pipelines that will allow people and pipelines to coexist in a manner that does not pose undue risk to each other. In December 2002, Congress requested the Transportation Research Board (TRB) to assist in meeting this legislative mandate. Specifically, TRB was asked to convene a committee to consider the feasibility of developing risk-informed guidance that could be used in making land use-related decisions as one means of minimizing or mitigating hazards and risks to the public, pipeline workers, and the environment near existing and future hazardous liquids and natural gas transmission pipelines. In addition, the committee was asked to consider environmental resource conservation issues (e.g., preservation of trees and habitat) in pipeline rights-of-way.

1.2 Data

Transportation of energy fuels via transmission pipelines is safer than transportation via other modes, but a significant failure can result in loss of life, personal injury, property damage, and environmental damage. In the last 3 years, hazardous liquids pipeline incidents have resulted in an average of 2 deaths, 11 injuries, and $97 million in property damage each year; natural gas transmission pipeline incidents have resulted in an annual average of 6 deaths, 10 injuries, and $20 million in property damage. From 2000 through 2002, the annual average number of gross barrels of hazardous liquids lost was 100,000, a decrease from the annual average of 270,000 gross barrels lost in the 1986 to 1989 time period. There are many causes and contributors to pipeline failures, including construction errors, material defects, internal and external corrosion, operational errors, malfunctions of control systems or relief equipment, and outside force damage (e.g., by third parties during excavation). Excavation and construction-related damage to pipelines remain the leading causes of pipeline failure. Such failures in 2003 were estimated by OISD to contribute 22 percent of hazardous liquids and 24 percent of natural gas transmission pipeline incidents. With the growth in population, urbanization, and land development activity near transmission pipelines and the addition of new facilities, the likelihood of pipeline damage due to human activity and the exposure of people and property to pipeline failures may increase.

1.3 Risk Informed Guidance

While there is a general recognition that pipelines pose a hazard to people, property, and the environment, the extent of the danger is not well understood. Risk is inherent in the pipeline system—it can be reduced and managed, but it cannot be eliminated. Risk assessment practice attempts to answer the following questions:

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

Regulatory approaches can be risk-based, risk-informed, risk-informed performance-based, or other variations of these. In the risk-based approach, decisions or regulations are heavily based on risk assessment calculations, without other considerations. Because such an approach places a heavy burden on risk computation, which may suffer from lack of data or models or imperfect consideration of scenarios, its application is limited. In the risk-informed approaches, risk insights are used in conjunction with other information, both quantitative and qualitative, in making safety decisions. Because risk-informed approaches allow for the logical structuring of decisions by including relevant factors, they are of more practical value. Effective use of a risk-informed approach requires an understanding of the relevant factors and the relationships among these factors. In a risk assessment, which is a systematic and comprehensive approach, the likelihood of initiating events, as well as the likelihood of the various outcomes that may result from each initiator, is a concern. In assessing likelihood, a fundamental issue is the metric to be used. Likelihood can be expressed in terms of probability, and the combinations needed to yield the various outcomes can be computed by the use of logic and probability theory. However, the data that go into such calculations may entail significant uncertainties. Unless these uncertainties are explicitly acknowledged, the viability of the whole approach in decision making is compromised.

Local governments are increasingly faced with issues of land use. It appears beneficial for them to have available an easy-to-apply means for making decisions in a manner that allows flexibility in choosing the level of risk deemed appropriate. This is possible if the decision process is structured in a risk framework as outlined above. In addition, most local governments have neither the resources nor the in-house expertise to develop such a structure. Rather, a national-level effort is needed to develop a risk-informed approach and provide an appropriate level of abstraction that is easy to understand and use at all levels of government. Following implementation of selected options, system performance can be monitored to determine whether risk control measures are effective. This iterative process can, over time, continue to reduce overall risk. For the pipeline system, there are many stakeholders—policy makers, planners and system design experts, pipeline workers, local officials, property owners, residents, pipeline companies, and trade associations. They all should be knowledgeable about the risks so that informed guidance can be provided. Involvement and a shared commitment among these interested parties, effective communication, training, and procedures can make managing the risks associated with pipeline operations more effective. A well-thought-out risk management framework that measures the risks and identifies a set of risk mitigation alternatives would facilitate discussions among the stakeholders.

1.4 Current Approach To Risk Assessment In The Pipeline Industry

Risk assessment is the process of identifying, describing, and analyzing risk with the following elements:

- Recognition or *identification* of a hazard or potential adverse event, perhaps with definition of accident scenarios in which the hazards are realized or experienced;
- Analysis of the *mechanisms* by which an event can occur and the mechanisms by which the event can create loss;

• Analysis of the *consequences* of an adverse event as a function of various factors of design or circumstance; and

• Estimation of likelihood of sequences; of events that lead to consequences.

1.5 Summary of Two Techniques Followed in The Project

1.51 Muhlbauer Model of Risk Assessment

According to Muhlbauer (1999), because the risk of pipeline failure is sensitive to immeasurable or unknowable initial conditions, risk efforts are often not attempts to predict how many failures will occur or where the next failure will occur. Instead, efforts are designed to systematically and objectively capture everything that is known and use the information to make better decisions.

Risk assessments can guide pipeline operators to make decisions and take precautions that allow the risks to be minimized or avoided entirely. *Risk management* is a systematic focusing of limited resources on those activities and conditions with the greatest potential for reducing risk. In risk management, decision makers take the results from risk assessments and use them to prioritize risk reduction actions. Risk controls can involve measures both to prevent adverse events and to mitigate their magnitude. One reduces the likelihood; the other reduces the severity of impact. Another step in risk management is the monitoring of performance to determine whether risk control measures are effective.

The process can be repeated to further address and reduce overall risk. The first step in defining risk is to identify a potential hazard or dangerous situation and describe the mechanisms by which the hazard can cause harm to people, property, and the environment. Risk is then analyzed for *each* hazard or hazard scenario. In terms that can be analyzed, risk is defined as the product of (*a*) severity of impact and (*b*) the likelihood of impact from an adverse event. The severity of impact, often called consequences, can be expressed in human terms such as fatalities or injuries or some other metric such as Rupees lost. The likelihood of occurrence of an adverse event can be estimated with a variety of methods, ranging from prior experience with the frequency of occurrence, perhaps using statistical data of similar events, to computations based on mathematical models. Likelihood can also be determined by examining the probability of the adverse event occurring in a Bayesian sense, a prior perception of probability.

Data on pipeline incidents are collected and analyzed for each reportable safety incident. These data provide the number of incidents that result in death, injury, or significant property damage. They also provide the general causes of these incidents, including damage by outside force, corrosion, construction defects, operator error, natural forces such as ground movement, and many other categories. At some level of aggregation, the data can be used to determine, or quantify, the risk from various types and sizes of pipelines. On the basis of this experience, one can begin to identify factors that determine risk.

The principle of exposure can be applied to pipelines as well. For an individual who seldom crosses or comes near a pipeline right-of-way—a person who has little exposure—the risk is minimal, while people who live, work, or congregate near pipelines have greater exposure. Exposure is a function of time near a pipeline and effective distance. Exposure to the potential dangers of a pipeline leak or rupture is the result of proximity to the pipeline, natural or man-made barriers, and the mobility of people near the pipeline. People pursuing activities on or near the pipeline that can cause damage to the pipeline have the greatest exposure.

Muhlbauer believes that "data on pipeline failures are still insufficient to perform a thorough risk assessment using purely statistical concepts" and that an assessment using probabilistic theory is not required because the probabilities used in the assessment are of questionable benefit.

A hazard, according to Muhlbauer, is a characteristic that provides the potential for loss; it cannot be changed. Risk is the probability of an event that causes a loss and the magnitude of that loss, and therefore actions can be taken to affect the risk. Thus when risk changes, the hazard may remain unchanged. Risk can change continuously; conditions along a pipeline are usually changing, and as they change, the risk also changes.

Risk is defined by answering three questions:

- What can go wrong (every possible failure must be identified)?
- How likely is it to go wrong?
- What are the consequences?

In this technique, numerical values are assigned to conditions on the pipeline system that contribute to risk. The score, which reflects the importance of an item relative to other items, is determined from a combination of statistical failure data and operator experience.

As do all techniques, this model has a number of assumptions:

- All hazards are independent and additive.
- The worst-case condition is assigned for the pipeline section.
- All point values are relative, not absolute.
- The relative importance of each item is based on expert judgment; it is subjective.
- Only risks to the public are considered, not risks to pipeline operators or contractors.

In Muhlbauer's basic risk assessment model, data gathered from records and operator interviews are used to establish an index for each category of pipeline failure initiator (i.e., what can go wrong and the associated likelihood): (*a*) third-party damage, (*b*) corrosion, (*c*) design, and (*d*) incorrect operations. These four indexes score the probability and importance of all factors that increase or decrease the risk of a pipeline failure. The indexes are summed. The last portion of the assessment addresses the potential hazards, their probabilities of occurring, and their consequences. The consequence factor begins at the point of pipeline failure, called the leak impact factor. The leak impact factor is the sum of the product hazards divided by the dispersion factor. This basic model can be expanded to include other modules such as the cost of service interruption, distribution systems, offshore pipelines, environment, failure adjustment, leak history adjustment, sabotage, and stress.

1.52 The Indian Risk Assessment model (OISD)

Though the International scenario follows a risk assessment plan, the one suggested by the Oil Industries Safety Directorate varies as it is generally attributed to care of process plants. Though the international models follows a different highway the Indian model is also one made after serious thought research. This has been developed after the Bhopal disaster in the year 1984.

This is evident from the very fact that even this model gives us a few results untold in the previous model. This model helps relatively in the actual quantification of risk factors. Unlike the previous model which is an experience based approach this model is a mathematical and a more probabilistic approach.

The western model really suits only pipelines under operation, whereas this model entitles to assess risk better even on proposed facilities. But this model emphasizes more on process safety and neglects the aspect of environment and land safety, features which characterize pipeline safety uniquely. Thus bearing in mind the legal implications in the Indian scenario the following risk methodologies are to be followed:

- **HAZOP**
- **HAZAN**
- **DOW INDICES**
- **FMEA ANALYSIS**
- **RBI MATRIX(already suggested)**
- **Scenario development and source modeling.**
- **Analysis of ASCALP(atmospheric stability class) and meteorological data.**

1.6 Scenario Based Risk Assessment

This category of risk assessment includes a number of methods: HAZOP studies, scenario-based fault tree/event tree analysis, and so forth. These techniques are useful for examining specific situations, and often they are used with other techniques.

1.61 HAZOP Technique

In the HAZOP study approach, all possible failure modes are examined, but it is very time-consuming and costly. HAZOP analysis is used in the preliminary safety assessment of new systems or modifications of existing systems. A HAZOP analysis involves a detailed examination of pipeline system components to determine the outcome if a specific component does not function as it is designed to (within its normal parameters). Each parameter (e.g., pressure or flow rate) is examined to identify potential changes in the system that are based on changes in the component parameter.

1.62 Fault Tree Analysis

In scenario-based fault tree analysis, the sequence of events is traced backwards from a failure. This technique uses most probable or most severe pipeline failure scenarios, and then resulting damage is estimated and mitigation responses and prevention strategies are developed.

Fault tree analysis is a method of risk identification and scenario building in which the outcome of an event is traced backward to all possible causes (Mc2 Management Consulting 2004). It is a probabilistic top-down analysis that is used to assess the likelihood of occurrence of an undesired system-level event (e.g., a release of product, an explosion), and it can be used to quantify the risk associated with resulting safety hazards. Factors or combinations of factors that could cause the event are put in a structured logic diagram (which takes interdependencies in components into account). The network branches from the outcome event to individual factors (e.g., failure of pump, failure of switch, no response from operator) in a treelike structure.

Fault tree analysis can include such factors as natural disasters, human activity, and other externally induced causes. The method can also be used to establish cost-effective troubleshooting procedures based on the factors that are most likely to cause a failure.

1.7 Probabilistic Risk Assessment Techniques

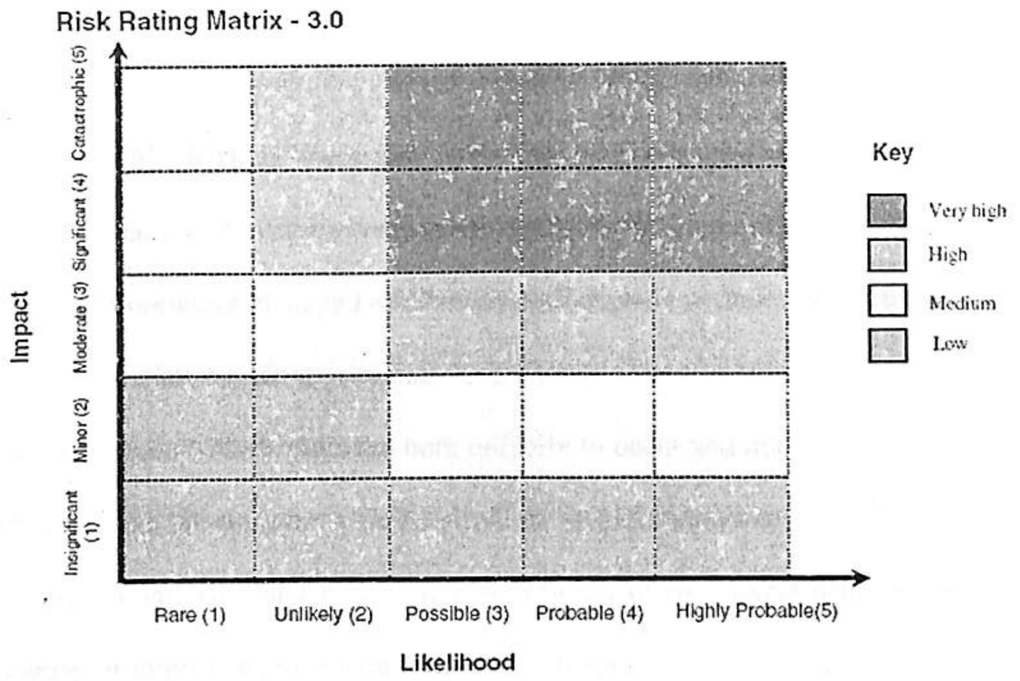
While fault tree analyses are better suited to examine systems in which the failures of components or processes can be described in terms of pass/fail outcomes (a binary description), they are not ideal for systems in which the processes are not discrete and the outcomes cannot be described simply as pass or fail. (Typically, these are natural events.) Other probabilistic risk assessment techniques have been developed that can consider a range of outcomes of individual processes in a scenario.

1.8 Index Models

Index models use customized algorithms to conduct pipeline risk assessment.

There are a variety of index models, RBI matrix , DOW indices , SMOD indices and simulation based index models. The main component of risk assessment lies in the construction of a risk rating matrix. The qualitative and quantitative measurements of risk are derived and illustrated by using this tool. Designed in a graphical format, the matrix rates impact on the vertical axis, ranging from insignificant to catastrophic.

1.9 Risk Matrix : figure 1.1



1.91 Definitions of Risk Ratings –

Very High (VH) Risk – These risks are classed as primary or critical risks requiring immediate attention. They may have a high or probable likelihood of occurrence and their potential consequences are such that they must be treated as a high priority. This may mean that strategies should be developed to reduce or eliminate the risks and that mitigation in the form of (multi-agency) planning, exercising and training for these hazards should be put in place and monitored on a regular basis. Consideration should be given to *specific* planning to the risk rather than generic.

High (H) Risk – These risks are classed as significant. They may have high or low likelihood of occurrence, however their potential consequences are sufficiently serious to warrant appropriate consideration, after those risks classed as 'very high' are addressed. Consideration should be given to the development of strategies to reduce or eliminate the risks, and that mitigation in the form of (multi-agency) generic planning, exercising and training should be put in place and monitored on a

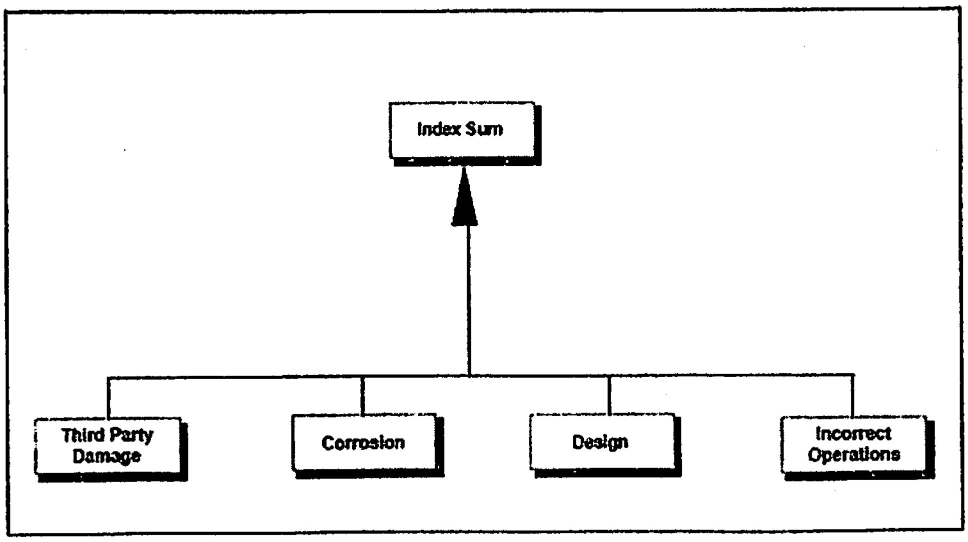
regular basis.

Medium (M) Risk – These risks are less significant, however may cause upset and inconvenience in the short-term. These risks should be monitored to ensure that they are being appropriately managed and consideration given to their management under generic emergency planning arrangements.

Low (L) Risk – These risks are both unlikely to occur and not significant in their impact. They should be managed using normal or generic planning arrangements and require minimal monitoring and control unless subsequent risk assessments show a substantial change, prompting a move to another risk category.

1.10 International Guidance Model

The whole model both in the Indian and international scenarios would follow the model that is graphical represented as follows:



Relative Probability of Failure Assessment

A number of risk assessment methods are being used by the pipeline industry to prioritize risk mitigation actions. Regulatory agencies in the India and abroad have developed risk-based regulations and criteria for safe operation of pipelines. While the risk assessment methodologies in use allow scarce resources to be focused on mitigation of the highest-risk items by emphasizing a single risk number, they do not adequately characterize all the dimensions of risk. A broader characterization of risk, as outlined, will enable state and local policy makers, with input from stakeholders, to make land use decisions in a systematic manner.

Thus the amount of damage to life and property, the risk involved in proposed facilities and of course the lack of proper "pipeline compatibility" in the Indian risk model as compared to the Muhlbauer model, has been the major reason to take up this project. An attempt has through out been made to combine the good features of the Indian model with the Muhlbauer model as the base to bring out a new model to suit the Indian scenario.

In general the risk assessment followed for this project would stress more on the importance of the Indian process scenario and the added features of the western model in the simulation and associated software development. The main crux of this project would be in the math modeling and simulation that would be involved in the project. As a data feed that would be required for the results are the data from INDIAN OIL CORPORATION , from its proposed pipeline the CPCL-CHENNAI AFS ATF PIPELINE , would be used. Since the data available is that of a pipeline under construction the integrity of the operations risk would be ensured from P&I diagrams and not through live data. This may not be of great importance as the HAZOP concentrates on P&Ids only. Since the results of site operation are important only if anomalies were detected and need to be rectified, this aspect loses importance as the project is a simulation by an amateur, as IOC would not implement the results and advices. Also data being that of proposed facilities, the question of operation does not arise. Also the development of software for risk assessment and graphical representation would be attempted as part of this project to simulate the results.

Chapter 2

Literature Review

2.1 Risk Concepts

Risk assessment is the core of risk management, the process of evaluating risks and allocating resources in a manner that controls risks and costs. Risk is defined in terms of an event probability and consequence as follows:

Risk = (event probability) X (severity of event consequence)

In the context of this study, risk can be expressed in absolute terms such as the probability of a leak or spill of a certain size. The "absolute scale" offers the benefit of comparability with other types of risks. Also common is the use of relative risk measures, whereby the risk of different parts of a system can be compared. The "relative scale" offers the advantage of ease-of-use when data are uncertain and when effects of individual system factors on risk are assessed. It is important to note that the two scales are not mutually exclusive. A relative risk ranking can be converted into an absolute scale by correlating absolute probabilities with relative risk values.

Some overall assumptions used in assessing the risks of pipeline transportation include the following:

- Increased probability of failure (POF) increases risk;
- Objects closer to the pipeline are at greater risk
- Hazards associated with a product can be acute (immediate), chronic (longer term),or both;
- A greater release quantity increases risk; and

- A greater spread area of released product increases risk.

In many cases, the high-risk portions of a system are relatively easy to identify, such as areas with a history of leaks, materials prone to failure, and areas with population density. A more detailed risk assessment becomes useful in areas where the risk picture is not so obvious. Interactions among many risk variables will often identify areas that would not otherwise be considered a high risk. Risk assessment cannot predict when or if an accident might occur at any particular location. Rather, the assessment shows where in the System the risk might be higher or lower, based on the knowledge of potential failures and risk reducing (mitigation) activities. In a good model, all information is preserved and the risks can be examined in both an overview manner and a detailed manner. An effective pipeline risk management program then uses the risk assessment to allow a company to become more "proactive" and less "reactive" in the management of their pipeline. This includes the management of regulatory compliance.

2.2 Risk Assessment Methodologies

Potential causes and consequences of leaks or spills, that are necessary as the starting point for the risk assessment, are determined through a hazard analysis of the System.

2.2.1 General Methods

Hazards can be identified and analyzed by a variety of techniques, varying in approach and degree, of formality. A relationship between procedures used to identify hazards and procedures, used to analyze the causes and consequences of such hazards is incorporated into a formal risk assessment. For the pipeline, a review of recent work performed on formal hazard analyses, for pump stations, potential causes of pipeline accidents based on the history of the pipeline and industry experience with similar pipelines, and previous risk assessments.

Common hazard evaluation tools such as event trees, fault trees, "what-if" analysis, and Hazard and Operability Studies (HAZOPS) are used to identify all factors that contribute to or reduce risk . HAZOPS is a common risk assessment technique commonly seen in the chemical and hydrocarbon processing industry. It relies on a structured and comprehensive question-answer approach and expert participants to identify and remedy potential safety and operability issues. The HAZOPS method is an accepted technique for Process Hazard Analysis, as described in technical literature recognized by OISD and Occupational Safety & Health Administration in their respective Accidental Release Prevention Risk Management Program and Process Safety Management rules. These hazard evaluation tools can then be combined into formal risk assessment methodologies including probabilistic risk assessments and scoring type techniques.

All methodologies have access to the same databases (at least when publicly available) and all must address what to do when data are insufficient to generate meaningful statistical input for a model. Data are not available for most of the relevant risk variables of pipelines. Including risk variables that have insufficient data require an element of "qualitative" evaluation. The only alternative is to ignore the variable, resulting in a model that does not consider variables that intuitively seem important to the risk picture.

Therefore, all models that attempt to represent all risk aspects must incorporate qualitative evaluations.

2.2.2 EA Risk Assessment Approach

One common overall framework for risk assessment is an "indexing" or "scoring" methodology for relative risk assessment. In the EA Risk Model, a well-known indexing risk assessment model is used as a base for developing a risk profile for the System and is referred to as the EA Risk Model. In this model, risk is examined in two components: the POF and the consequences of failure. The EA Risk Model is intended to be comprehensive—considering all critical aspects of risk. The use of more qualitative evaluations in the absence of statistical data is not thought to be a critical limitation, however, since a risk assessment can still provide at least a relative basis for judging the risks. General agreement among risk professionals can be used as a surrogate in the absence of "hard" data. The underlying risk assessment principle of the EA Risk Model is that conditions constantly change along the length of the pipeline. A mechanism is required to measure the changes and assess their impact on failure probability and consequence. In the absence of statistical data, this can be effectively done on a relative basis.

In the POF portion of the EA Risk Model, scores are assigned to each risk factor or variable and importance factor "weightings" are assigned to logical groupings of these variables. The individual scores for each System segment are combined for an overall score of the pipeline. The POF portion of the EA Risk Model was chosen for its usefulness in the process and is based on the most widely adopted pipeline risk model currently available. It is well suited to the EA application in terms of comprehensiveness and its ability to indicate improvement opportunities (mitigations). The methodology is documented and recognized in industry as is evidenced by its use as a textbook, numerous articles in industry publications, and presentations at technical conferences since 1992. These factors were all considered in the choice to base aspects of the EA on this approach. The model basis is fully described in Pipeline Risk Management Manual, 2nd Edition (Muhlbauer, 1996).

The second part of the EA Risk Model is the consequence or impacts portion of the risk assessment. It is an assessment of relative impacts, is based on a tiering system, and is fully described. Since a Superfund-type human health risk assessment is not within the scope of the EA nor considered appropriate in this application, chronic health effects from a pipeline spill, including receptor pathways, population classifications, and dose response predictions, are not specifically estimated. The consequence portion of the assessment methodology described by Muhlbauer (1996) is expressed as the "leak impact factor" and considers spill size, sensitive receptors (such as nearby population density and environmentally. This is consistent with the basic risk assessment methodology on which the EA model is based.

Muhlbauer states that it is often useful to separate the Index Sum component from the total risk score in order to focus on failure probabilities, which to a much larger extent, are under the control of the operator. Original documentation describing and supporting the relative risk methodology repeatedly emphasizes the need to examine risk components separately as well as in aggregate. The methodology is specifically designed to retain the intermediate calculations such as Index Sum for the express purpose of using them as independent measures of specific risk aspects (Muhlbauer, 1996).

Therefore, separating the Index Sum as an indicator of POF, as is done for the EA Risk Model, is consistent with the intended use of the original model. The subsequent use of the Index Sum with the tier system for impacts assessment completes the EA Risk Model.

In addition to the relative risk assessment, probabilistic risk assessment has been performed for selected locations along the pipeline. This examines risk in terms of the probability that a specific event type could occur at a specific location. The relationship between the relative POF assessment and the probabilistic assessment is discussed in the report.

2.3 Risk Factors

Models similar to the EA relative risk methodology have also been called "decision support" models. Such models are designed to provide guidance or "decision support," as well as identification of areas with relatively higher risks. They do this by preserving the evaluation of conditions and activities that are causing the higher risks, thereby indicating specific factors that can be addressed in order to reduce risks. The model, in effect, highlights deficiencies and points to potential remedies.

A decision-support model for risk management involves tradeoffs between the number of factors considered and ease-of-use of the model. The variables that impact risk are widely recognized in the industry, but the number of variables to consider in a model and the depth of that consideration are chosen by the model developers. A list of risk factors that add to or subtract from the amount of risk can be identified for the System. These factors are selected based on their ability to provide a useful evaluation of risk without adding unnecessary complexities. These factors and the rationale for their inclusion are detailed in the Pipeline Risk Management Manual, 2nd Edition (Muhlbauer, 1996) and discussed in later sections within this report.

The EA analysis does not solely rely on EPC or industry historical failure data, since such reliance could easily over- or underestimate the risks significantly. Extrapolations from population-wide data—failure rate information from all pipelines—to a specific pipeline are problematic. Since any conclusions drawn from such data must be considered weak, their usefulness in decision-making is accordingly weak. Industry-wide failure experience is captured informally in the risk assessment since knowledge gained from such failures contribute to the experience and judgment of variables.

The EA analyses focus on specific pipeline and environmental factors that contribute to the failure likelihood. These include consideration of all documented accidents on this pipeline while under EPC's ownership. The relative risk model penalizes pipeline segments with previous leaks or if they are near previous leaks. Therefore, previous accidents on this pipeline heavily influence the risk assessment and play a direct role in subsequent decisions regarding mitigation.

2.4 Assessable Facilities

2.4.1 Pump Stations and Tank Facilities

While pump station leak history is evaluated in this EA, a relative risk assessment similar to one completed for the pipeline is not done for pump stations. Since pump station risk factors on this System are not as variable as conditions along the pipeline, mitigation measures for pump stations are less site-specific in nature. More general mitigations can be applied to all pump stations. Pump stations also have different risk considerations than the pipeline. The leak rate for crude oil pump stations on the EPC portion of the pipeline (147 leaks in 29 years) does not accurately reflect potential leak rates for the new pump stations for refined product service on this pipeline since the new pump stations are designed and operated with significant differences from a typical crude oil operation. As an example, many previous EPC leaks are attributed to tanks (approximately 75 percent of all post 1980 spill volume).

Other than surge tanks, only two of the new pump stations have tanks, and those pump stations are substantially different in design and operation than those from the EPC crude oil service. Differences in risk variables between pump stations and pipeline right-of-way (ROW) include leak response issues: pump stations in general tend to have more direct observation (opportunity to detect and respond to abnormal conditions), and they often have secondary containment to avoid offsite contamination. However, the presence of high-pressure, aboveground components could support scenarios where product is sprayed outside of the pump station boundaries. Pump stations are also fenced and locked, therefore creating a more controlled environment compared to most pipeline ROW. Continuous video surveillance, frequent visits by employees, and alarm systems also provide more security. However, a pump station or tank farm might present a more attractive target to vandals or saboteurs. Pump stations have more rotating equipment and appurtenances that historically have been more leak-prone than the simpler pipe and valve equipment seen on the ROW. New pump stations are to have environmental evaluations, HAZOPS, and risk assessments performed.

2.4.2 Alternate Routes

The alternative route analysis focused primarily on environmental and population characteristics of the alternatives and associated possible impacts. It made use of broad-based information that was readily available. A risk assessment comparable in magnitude to the existing pipeline's risk assessment is not performed. Such an assessment would be based on many assumptions since there is no pipeline along these routes (design data would have to be assumed). Also, there is insufficient route-specific data upon which to make probability of failure estimates.

While a new pipeline can be designed to have a low POF, the design basis for a hypothetical pipeline along the new route is not known. If there is an assumption made that such a pipeline would be designed and built in accordance with current OSID minimum requirements and assuming no exceptional route conditions, it is reasonable to assume a failure frequency comparable to other new pipelines in similar environments.

2.5 RELATIVE RISK ASSESSMENT

The relative risk assessment is used to help identify or confirm high-risk areas. It is also used as a means to account for changes in absolute probabilities likely to be achieved with changes in design and operational practices.

2.5.1 Segmenting

An efficient way of evaluating risk along a pipeline is to divide it into segments of similar risk characteristics. The relative risk assessment process gathered data on conditions and activities, termed risk variables, all along the pipeline length. The number of variables considered, in the process determine the number of segments. Segmenting criteria included variables such as pipe specifications (diameter, wall thickness, etc.), coating type, age, and population density. The variables overlap. Every time any variable changed, a new segment was created. Each segment, therefore, has a unique set of variables. The smallest segments are only a few feet in length where one or more variables are changing rapidly; the longest segments are several hundred feet long where variables are fairly constant.

2.5.2 Index sum

The range of values for the POF measure, the Index Sum, is 0 to 400, where 0 represents the lowest safety level (highest risk)—imminent failure. At the opposite end of the scale, 400 is a theoretical value representing the most failure-proof system (i.e., the highest safety, lowest risk system possible). Therefore, the Index Sum can be viewed as a "safety scale," whereby increasing points mean increasing safety—lower failure probability. Unfavorable conditions around the pipeline, inadequate operator activities, and increasing uncertainty (about existing conditions) tend to reduce Index Sum scores—indicating a higher failure probability.

2.5.3 Data Gathering

Risk assessment data for the System are assembled from a variety of sources. The most desirable source of information is professional documentation that accurately describes conditions and/or activities related to risk. This information is used when available. It is not uncommon to find actual activities and/or conditions that deviate significantly from documentation. When such inconsistencies are encountered, reliance on the documentation is reduced.

In the absence of documentation, alternate sources of information were used, including field investigations and interviews with experienced company personnel. These types of data tend to be more subjective and are used cautiously. However, excluding such data would greatly limit the usefulness of the overall assessment. Many pieces of input data are used to produce a risk score for each pipeline section.

These data came from maintenance records, construction documents, design documents, employee interviews, expert testimonies, and inspections of facilities, including:

1)Design documents and calculations;

2)Reports and studies from outside agencies;

3)Brief field inspections of ROW and aboveground facilities;

4)Maintenance documentation (records, procedures, employee interviews, etc.); and

5)Other documentation (construction drawings, maps, reports, calculations, etc.).

2.5.4 Field Investigations

An integrity analysis and physical examination of the subject pipeline is made as described. Interviews are conducted with EPC employees regarding past operating and maintenance practices and with employees regarding future operations and maintenance procedures . The purpose of the fieldwork is primarily to support other data gathered and to provide an overall perspective on the facility. Field observations offer a frame of reference to "calibrate" against operator-subjective assertions of risk variables being described as, for example, "good," or "poor." For this reason, field investigations serve to establish a common ground for communication between the risk assessor and the operators of the System. Secondary benefits from the inspection include information that is useful in judging other items by inference. For example, the attention to items such as housekeeping and marking equipment provides evidence for some of the more subjective evaluation items, such as commitment to safety and professionalism of the operation.

2.5.5 Data Compilation

An electronic database for the System, for use with the relative risk assessment tool, is assembled in Microsoft Excel® and Access®.

2.6 EA Risk Model Probability of Failure Algorithm

The objective of the EA Risk Model's POF assessment is to capture all available data about the pipeline and condense it into useable summary numbers. The underlying algorithm is designed to capture existing information and produce relative POF values.

2.6.1 Uncertainty

A conservative overall assumption is made in the absence of data or information; increased uncertainty means increased risk. However, a degree of reasonableness must be exercised. "Known" deficiencies are certainly more evidence of risk than are "possible" deficiencies. For example, there are scenarios where a close interval survey must omit 50 ft of readings because of an asphalt road, and readings adjacent to the road are more than adequate. Such a situation should not drive the risk score to a point where an expensive investigation under the roadway is indicated over more productive expenditures. Alternatively, years of no integrity verification should reflect high risk since it is possible that a number of integrity-threatening mechanisms could have developed. Again, some assumptions and "reasonableness" are employed in setting scores in the absence of data, but in general, worst-case conditions are conservatively used for default values.

2.6.2 Leak/Repair History

An additional assumption concerns the use of previous flaw indications. For modeling purposes, previous flaw indications such as leaks, repairs, and internal line inspection (ILI) indications are considered evidence of increased susceptibility to failure. A "zone-of-influence" is assumed and all pipe within that zone is similarly shown to have increased risk. The presence of a leak or other flaw therefore "penalizes" several hundred feet of pipe in the model, depending on the type of leak or flaw. This is driven by the assumption that failure mechanisms can extend some distance from the actual event. This is conservative, since most flaws are from a very localized initiator that has been permanently repaired. However, such previous indications also show that conditions were conducive to deterioration and/or failure, at least at one time. Even after a repair, the model conservatively assumes that the underlying failure mechanism still exists. This risk "penalty" can be removed if a formal root cause analysis is done and the conditions are permanently changed so that the flaw initiator is not a threat. For these purposes, a root cause analysis is a thorough investigation that conclusively identifies the chain of events leading to the failure and indicates the primary mechanism which should be addressed to prevent any future such failures. By this approach, the EA Risk Model will normally overestimate the risk initially. This provides incentive for the operator to fully investigate and affect permanent repairs or system changes. After the operator performs a formal, documented root cause analysis, then the model can incorporate the new information and cease the overestimation of risk.

Table2.1 :Risk relevance

Action	Results	Risk Relevance
Timely and comprehensive inspection performed	No flaws detected	Least risk
Timely and comprehensive inspection performed	Some flaws or indications of flaw potential detected. Root cause analysis and proper follow-up.	More risk
No timely and comprehensive inspection performed	High uncertainty	
Timely and comprehensive inspection performed	Some flaws or indications of flaw potential detected—uncertain reactions	Most risk

A leak (or other detected flaw) was evidence that a certain integrity-threatening mechanism was present at one time. However, if this underlying mechanism is identified and effectively mitigated, then the threat no longer exists. It would be imprudent to ignore the evidence that a historical leak provides or to assume that the underlying cause could never be removed. This does not cause an underestimation of risk.

2.7 Model Structure

Many variables (approximately 75) are used in quantifying the relative POF for each pipeline segment. EA Risk Model variables were selected and weighted based on their role in the actual risk and on availability of information. Wherever possible, measurable data are used to assign risk points to these variables. When such data are unavailable, more qualitative assessments were made. Common industry practices, engineering judgment, and pipeline operations experience were used to support this effort in cases where measurable data are absent.

Probability-of-failure scores are grouped into the four failure probability indices: thirdparty damage, corrosion, design, and incorrect operations. Together these index scores comprise the relative POF for the segment of pipeline or pump station evaluated.

2.8 Sabotage

The risk of sabotage is not specifically addressed in the formal risk assessment. The likelihood of a pipeline system becoming a target of sabotage is a function of many variables, including the relationship of the pipeline owner with the community and with its own employees or former employees. Vulnerability to attack is another aspect. In general, the pipeline is not thought to be more vulnerable than other pipeline systems. Standard or above average security measures are to be in place, including fences, locks, increased patrols, and surveillance cameras. The motivation behind a potential sabotage episode would, to a great extent, determine whether or not this pipeline is targeted. Reaction to a specific threat would therefore be very situation-specific. The risk of sabotage is difficult to fully assess since such risks are so situation-specific and subject to rapid change over time. The assessment would be subject to a great deal of uncertainty, and recommendations would be problematic. This type of assessment is not thought to add significant value to the EA.

2.9 Chain Reactions

The risk of a pipeline can be influenced by the presence of another pipeline nearby. If a leak from one pipeline can cause a leak in the other, the POF of the other pipeline is increased. This can be termed a "chain reaction" event. Additionally, the consequences of the original leak can become more severe if the product of a second pipeline becomes involved in the scenario. The means that the risk for each pipeline has been increased, at least to some degree. The database on reportable accidents is examined in an attempt to identify such chain-reaction events.

2.10 Earth Movements

"Earth movements" is a variable for assessing the potential for seismic activity, land slides, and scour.

2.10.1 Seismic Activity

The initial risk assessment uses GSI data to roughly characterize seismic potential. Shaking and ground failure hazards can be estimated from the peak ground acceleration (PGA) value. Information on the PGA for the System route is compiled from the MSI hazard maps, at a two percent probability of exceedance over 50 years. These maps do not include induced seismic activity, such as from deep well injection or similar events. The PGA is a measure of the acceleration experienced by a particle on the ground in the event of an earthquake. This value is calculated for potential earthquake locations and magnitudes along the pipeline route. PGA is expressed as a percentage of gravitational acceleration. A serious earthquake can have a PGA over 11 percent of gravity. The correlation between PGA and damage to underground utilities, such as the pipeline, can be estimated. The PGA range over the length of the pipeline is 2 to 18 percent. A PGA of 1.5 percent of gravity is readily felt. Dishes and windows may break, and unstable objects may topple. A PGA of 15 percent causes considerable damage to ordinary buildings, including partial structural collapse especially for tall structures, such as columns and chimneys.

2.11 Index Sum

The combination of the above indices creates the Index Sum, which is the overall measure of relative POF.

2.11.1 Consequence Variables

As discussed earlier, the EA Risk Model deviates from the consequence portion of the relative risk assessment methodology described by Muhlbauer. This was done in order to more appropriately characterize the wide range of possible impacts from a spill on this pipeline. The probability of a pipeline leak (the Index Sum) is adjusted by the LIF to arrive at the risk value. The LIF includes consideration of:

- Product hazard (PH);
- Receptors (R);
- Spill volume (S); and
- Spread range or dispersion (D).

2.12 Risk Assessment Techniques in the Pipeline Industry

During the past two decades, emphasis on pipeline safety has shifted from response to prevention of accidents. Preventive actions have included greater levels of inspection, involvement of the public through communications, and prospective analysis of the dangers presented by pipelines. Pipeline companies also began to use various risk assessment techniques, including hazard and operability (HAZOP) analysis, fault tree analysis, scenario-based analysis, and indexing methods. Most analyses focus on specific factors affecting the probability of pipeline failure (e.g., internal corrosion, external corrosion, pipeline loading) or on the consequences of rupture (such as heat intensity, thermal impact radius, depth of cover). Some of these analyses focus on specific pipeline system components, while a few attempt to take component interdependencies into account.Some of the more commonly used techniques are described below.

The pipeline risk assessment and management approaches that have been published to date, regardless of the methodology used to obtain the probabilities and consequences of processes and events leading to risk, emphasize the calculation of a risk number (i.e., a mathematical product of probability and consequence). Although this calculation allows a quantitative comparison of the effect of different factors on pipeline safety, it is not adequate to define risk to the public.

2.13 Current Approaches To Risk Assessment

Risk assessment is the process of identifying, describing, and analyzing risk with the following elements:

- . Recognition or *identification* of a hazard or potential adverse event, perhaps with definition of accident scenarios in which the hazards are realized or experienced;
- Analysis of the *mechanisms* by which an event can occur and the mechanisms by which the event can create loss;
- . Analysis of the *consequences* of an adverse event as a function of various factors of design or circumstance; and
- . Estimation of the *likelihood* of the sequences of events that lead to the consequences.

According to Muhlbauer, because the risk of pipeline failure is sensitive to un measurable or unknowable initial conditions, risk efforts are often not attempts to predict how many failures will occur or where the next failure will occur. Instead, efforts are designed to systematically and objectively capture everything that is known and use the information to make better decisions.

Risk assessments can guide pipeline operators to make decisions and take precautions that allow the risks to be minimized or avoided entirely. *Risk management* is a systematic focusing of limited resources on those activities and conditions with the greatest potential for reducing risk. In risk management, decision makers take the results from risk assessments and use them to prioritize risk reduction actions. Risk controls can involve measures both to prevent adverse events and to mitigate their magnitude. One reduces the likelihood; the other reduces the severity of impact. Another step in risk management is the monitoring of performance to determine whether risk control measures are effective. The process can be repeated to further address and reduce overall risk. The first step in defining risk is to identify a potential hazard or dangerous situation and describe the mechanisms by which the hazard can cause harm to people, property, and the environment. Risk is then analyzed for *each* hazard or hazard scenario. In terms that can be analyzed, risk is defined as the product of (*a*) severity of impact and (*b*) the likelihood of impact from an adverse event. The severity of impact, often called consequences, can be expressed in human terms such as fatalities or injuries or some other metric such as dollars lost. The likelihood of occurrence of an adverse event can be estimated with a variety of methods, ranging from prior experience with the frequency of occurrence, perhaps using statistical data of similar events, to computations based on mathematical models. Likelihood can also be determined by examining the probability of the adverse event occurring in a Bayesian sense, a prior perception of probability.

Data on pipeline incidents are collected and analyzed by OISD for each reportable safety incident. These data provide the number of incidents that result in death, injury, or significant property damage. They also provide the general causes of these incidents, including damage by outside force, corrosion, construction defects, operator error, natural forces such as ground movement, and many other categories. At some level of aggregation, the data can be used to determine, or quantify, the risk from various types and sizes of pipelines. On the basis of this experience, one can begin to identify factors that determine risk. The principle of exposure can be applied to pipelines as well.

For an individual who seldom crosses or comes near a pipeline right-of-way—a person who has little exposure—the risk is minimal, while people who live, work, or congregate near pipelines have greater exposure. Exposure is a function of time near a pipeline and effective distance. Exposure to the potential dangers of a pipeline leak or rupture is the result of proximity to the pipeline, natural or man-made barriers, and the mobility of people near the pipeline. People pursuing activities on or near the pipeline that can cause damage to the pipeline have the greatest exposure.

2.14 Scenario Based Risk Assessment

This category of risk assessment includes a number of methods: HAZOP studies, scenario-based fault tree/event tree analysis, and so forth. These techniques are useful for examining specific situations, and often they are used with other techniques.

2.14.1 Muhlbauer's Risk Assessment Methodology

Muhlbauer (1996, *x*) believes that "data on pipeline failures are still insufficient to perform a thorough risk assessment using purely statistical concepts" and that an assessment using probabilistic theory is not required because the probabilities used in the assessment are of questionable benefit.

Summary

A number of risk assessment methods are being used by the pipeline industry to prioritize risk mitigation actions. Regulatory agencies in the India and abroad have developed risk-based regulations and criteria for safe operation of pipelines. While the risk assessment methodologies in use allow scarce resources to be focused on mitigation of the highest-risk items by emphasizing a single risk number, they do not adequately characterize all the dimensions of risk.

Thus this project attempts to diverge from the classical model and take up the Muhlbauer model as the basis. Also it uses the process safety model to suit need specific features of pipelines so that care is taken to see that the maximum number of risk factors are covered, so that the score obtained is a reasonably valid one. This helps in preventing hazards, easing relief work, stop hazardous projects from being implemented and finally prevents shelving of valuable projects due to wrongly assessed risk scores.

Chapter 3

Risk –Theory and Methodology: Theoretical Development

This chapter describes in detail the models and their equations used to validate risk on the CPCL- Chennai AFS ATF pipeline. As mentioned previously the project uses two models one, the Muhlbauer model and the Indian process safety model. The algorithms used in first model and the scoring technique is given in detail first and then the process safety equations follow later.

3.1 Muhlbauer Scoring Technique

The scoring technique used in the model is fully described by the RISK INDEX SUM, which is the final result of this model. This model is more qualitative in nature but focuses into factors, which are not part of the process safety model and is more realistic in nature. But it partially refuses to look into the process safety part of pipeline risk.

The index sum risk is the sum of four factors, they are :

- Third party damage index
- Design index
- Incorrect operations index
- Corrosion index

The tables below are self-explanatory. These give us the idea of the scoring technique and the split up to calculate index sum of failure. The index sum of failure is calculated for 400 points.

3.1.1 Third party damage index

Table 3.1

Scoring Variables for Third-Party Index

Parameter	Percent Contribution
Depth of cover	20
Activity level	20
Patrol	15
One-call	15
Public education	15
Aboveground exposures	10
ROW condition	5
Third-Party Index	**100**

The steps for the third party damage is developed as follows:

a)Depth of cover : (20%)

Amount of cover in inches /3 =point value up to a maximum of 20

Equivalents:

2 inches of concrete coating = 8 inches additional earth cover

pipe casing = 24" earth cover

concrete slab= 24" earth cover

if Y is the depth of cover

$Y_{avg} = \Sigma Y$ is the average depth throughout the line score for depth of cover = $Y_{avg}/3$

Incase of crossings involving water bodies:

Depth below water

0-5ft - 0pts

5ft- near anchor – 3pts

beyond – 7pts

Thus if depth increases the index score increases but the vice versa is true for depth of cover. The equivalents above are calculated using the maximum stress levels on the pipe by the earth mass on the pipe.

b) Activity Level (20%)

For an analysis of third party damage an idea of the opportunity to cause damage is very important. Bearing this in mind the activity level is scored using the following scoring methodology.

High activity level: 0 pts

- Class 3 population density
- High population density area measured by another scale
- Frequent construction activities
- High volume of digging/disturbance
- Railway or road traffic that poses a threat

- Many other buried utilities nearby
- Frequent damage from wildlife

Medium activity level: 8 pts

- Class 2 population density
- Medium population density by some other scale
- No routine construction activities
- Few digging/disturbance records
- Few buried utilities nearby
- Occasional wildlife damage

Low activity level : 15 pts

- Class 1 population density
- Rural, low population density by other scale
- Virtual no activity reports(<10)
- No routine (<5) harmful activities in the area (no penetrating activities inclusive of non penetrable agricultural activities)

If none of the above conditions are found then we can assign 20 points. This shows that increased activity level decreases index sum.

c) Above ground facilities: (10%)

In general above ground facilities may be any of the facilities which lead to destruction ranging from roads, vehicles shops to vandalism. These factors carry more weight on the above ground sections or crossings of the pipeline.

No above ground facilities 10 pts

Above ground facilities 0 pts

- Plus any of the following are to be applied (10 pts max)
- Facilities more than 200ft from vehicles 5 pts
- Area surrounded by chain link fence 2 pts
- Protective railings ,medians, bars 3 pts
- Trees(12" dia) , wall, or substantial 4 pts

  Structure between facilities
- Ditch (minimum 4ft depth/width) 3 pts

  Between vehicles and facilities
- Signs(warnings) 1 pts

d) Line locating: (15%)

Line locating means locating the exact position of the pipeline that is buried. This helps third parties who dig the facility to reduce the disturbance caused. Any way there is procedure to inform the line owner about the activity to be under taken. But the effectiveness of the system is to be assessed. It should be also borne in mind that the line must not be so easy to locate that it becomes a victim of vandalism or terrorism.

- Effectiveness 6 pts
- Proven record of efficiency and reliability 2 pts
- Widely known in the community and advertised 2 pts

- Meets minimum OISD standards 2 pts
- Appropriate reaction to calls / records 5 pts
- Maps and records of the line available 4 pts

e) Public education: (15%)

Public education programs are thought to play a significant role in reducing third party damage to pipelines. Most third party damage is unintentional and due to ignorance. This ignorance is not only of the buried pipeline's location but also ignorance of the indications available above ground. Thus these factors are to be validated.

- Mail outs 2 pts
- Meetings with local contractors/excavators per year 2 pts
- Meetings with public officials once a year 2 pts
- Regular education programs for community groups 2 pts
- Door to door contact with adjacent residents 4 pts

According to this schedule the best public education scenario will earn 15 pts.

f) Right of way (ROW) condition : (5%)

This item is a measure of the recognisablity and inspectablity of the pipeline corridor. A clearly marked, easily recognizable ROW reduces the susceptibility of third party damage and intrusions. It also eases leak detection that is sensing the vapor or liquid leak.

- Excellent condition 5 pts

Clear and unencumbered ROW ; route clearly indicated; signs and markers visible from any point on ROW or the above, even if one sign is missing, signs and markers at all road, railway crossings, ditches, river crossings, all changes of direction clearly marked; patrol.

- Good condition 3 pts

Clear route, no over growth obstructing view of indicators, well marked including Crossings. In general all are in place.

- Average condition 2 pts

ROW not uniformly graded/ cleared ; more markers are needed for clear identification at crossings etc

- Below average 1 pts

ROW is overgrown with vegetation in some places; ground not visible , poorly marked.

- Poor condition 0 pts

Indistinguishable as pipeline ROW, no markers present.

g) Patrol frequency: (15%)

Patrolling the pipeline is a proven effective method of reducing third party intrusions. The frequency and effectiveness should be considered in assessing the patrol value. The developed schedule for the patrol frequency rating is as follows

- Daily 15 pts
- Four days a week 12 pts

- Three days a week 10 pts
- Two days a week 8 pts
- Once a week 6 pts
- Less than four

But more than once a month 4 pts

- Less than once a month 2 pts
- Never 0 pts

3.1.2 Design index

a) Safety factor: (35%)

In this part of the assessment the overall stress levels are considered on the line. This includes an assessment of loads, stresses, and component strengths including the cycles of loading. Known and foreseeable weakness in the pipe, are also considered. The evaluation process involves the following parameters:-

- Internal pressure
- External loadings
- Special loadings
- Pipe wall thickness
- Pipe material strength
- Possible weakness in the pipe
- Other components

Table 3.2

Scoring Variables for the Design Index

Parameter	Percent Contribution
Pipe strength	20
System safety factor	10
Fatigue potential	15
Surge potential	15
Integrity tests	20
Earth movements	20
Design Index	**100**

1) $\sigma = P*d/2t$ to calculate internal loading - (E 3.1) [Muhlbauer 1996]

where

σ is the maximum stress psi

P is the internal pressure psig

D is the outside diameter inches

T is the wall thickness inches

2) $t = D * (6P/E)^{1/2}$ -(E3.2) [Rules of thumb 1992]

where E is the pipe modulus of elasticity.

3) $\sigma_{temp} = \alpha(\nabla T)*E$ -(E3.3) [Rules of thumb 1992]

where σ_{temp} is the temperature induced longitudinal stress

(Design to MAOP ratio –1)*35 = score - (E3.4) [Pipeline Risk Management Manual]

With these formula as base the following values have been calculated:

Table 3.3: score using design MAOP ratio

Design to MAOP ratio	points
2.0	35
1.75-1.99	28
1.50-1.74	21
1.25-1.49	14
1.10-1.24	7
1.00-1.09	0
<1.00	-10

The previous table can be can be applied to both pipe and all pipeline components. But in some cases it is not possible to calculate the design stress level. In such cases the following table can be used. This table is obtained by calculating the score from following equation.

(t-1)*35 = score - (E3.5) [Pipeline Risk Management Manual]

where t is the ratio required thickness to available wall thickness.

Table 3.4 : score using thickness ratio

t	Points
<1.0	-10 warning
1.0-1.1	3.5
1.11-1.20	7
1.21-1.40	14
1.41-1.60	21
1.61-1.80	28
>1.81	35

b) Fatigue : (15%)

Fatigue failure has been identified to be the largest single cause of metallic material failure. Fatigue is weakening of material due to repeated cycles of loading and stress. The amount of weakening depends on cycles and magnitude of stress. Thus analyzing this, in general a table given under can be followed to score fatigue based on the cycles of life.

Table 3.5: Fatigue score based on magnitude ad pressure cycles combination

%MAOP	$<10^3$	10^3-10^4	10^4-10^5	10^5-10^6	$>10^6$
100	7	5	3	1	0
90	9	6	4	2	1
75	10	7	5	3	2
50	11	8	6	4	3
25	12	9	7	5	4
10	13	10	8	6	5
5	14	11	9	7	6

c) Surge Potential: (15%)

The potential for pressure surges or water hammer effects is assessed here. The common mechanism of analysis is sudden conversion of kinetic to potential energy. A sudden valve closure or pump stoppage is a common initiator of such surges. The analysis has been carried out using the energy conservation model and a score table has been brought out. The point schedule has been brought out, by considering that surge pressure depends on fluid modulus. The point schedule can be set up with three general categories and room for interpolation between the categories.

High probability - 0 pts

Low probability - 5 pts

Impossible - 10 pts

The score is decided bases on the prevention system in place at the control room and the associated facilities, and of course on the main line.

d) Integrity verification: (25%)

Pipeline integrity is ensured by removal of existing anomalies and avoidance of future threat to pipelines. These are addressed by the following verification test. But practically, the pressure test or **hydrostatic test** can completely be used for scoring the risk.

- Age verification
- Robustness of test
- Pressure test

The table that follows shows the value of score associated with pressure test results. Here a ratio of test pressure to MAOP is calculated and is denoted by H.

Table 3.6: score using test pressure to MAOP ratio

H ratio of test pressure/MAOP	Points
H< 1.10	0
1.11<H<1.25	5
1.26<H<1.40	10
H>1.41	15

The above table was calculated using the equation,

(H-1)*30 = Score

The age of verification can be assessed by a standard as follows

Test 4 years ago 6 pts

Test 11 years ago 0 pts

For age values in between 4 and 11 a round score of 3 pts can be assigned.

e) Earth movements: If the area of the pipeline falls under special seismic zones then a score for the earth movement can be considered. For this the records of the earth movements in the past fifty years are taken in that area. 10% of that value becomes the positive risk score.

3.1.3 Incorrect operations index

It has been reported that 80% of all due to human fallibility. Process of moving products is hazardous one and its operations if done incorrectly result in damage.

Table 3.7

Scoring Variables for Incorrect Operations

Parameter	Percent Contribution
Construction/design	10
Training	20
Procedures	15
Maps and records	5
Overpressure potential	10
Safety systems	10
Maintenance	10
Communications	10
Mechanical error preventors	5
Risk assessment	5
Incorrect Operations Index	**100**

a) Design : (30%)

- Hazard identification: 4 pts

Here on a qualitative scale a maximum of 4 points is given based on the criterion of the effort to identify all the hazards accurately.

- MAOP potential: 12 pts

The possibility of exceeding the pressure potential of the system is an element of risk capture. Here based on the possibility the following scale is adopted.

Table 3.8 scoring pattern for MAOP potential

A.	Routine	0 pts
B.	Unlikely	5 pts
C.	Extremely unlikely	10 pts
D.	Impossible	1 2 pts

- Safety systems 10 pts

Safety devices as a component of the risk picture are included throughout the system in pipelines. This is done assuming that safety devices exist as a back up situation. Thus all safety systems in place are carefully considered. This is done using the following scoring pattern.

Table 3.9 score for safety system

A.	No safety devices present.	0 pts
B.	On site one level only	3 pts
C.	On site two or more levels	6 pts
D.	Remote observation only	1 pts
E.	Remote observation and control	3 pts
F.	Non owned active witnessing	-2 pts
G.	Non owned no involvement	-3 pts
H.	Safety systems not required	10 pts

- Material selection

The evaluator looks for evidence that proper materials were identified and specified with due consideration to all stresses reasonably expected. Here the scoring is done on a qualitative scale by verifying the design documents and comparing them with the operation documents. For proposed lines the experience of the designer is evaluated by using data of an operating pipeline designed by him.

b) Construction : (20%)

The following variables are used to score incorrect construction activity previously done to the pipeline. The same procedure can be used on proposed pipelines also.

Table 3.10 score for construction

A. Inspection	10 pts
B. joining	2 pts
C. Materials	2 pts
D. Backfilling	2 pts
E. Handling	2 pts
F. Coating	2 pts

c) Operation : (35%)

The table given below can be used to score operations part of incorrect operations index. This table only partially applies to proposed facilities.

Table 3.11 score on operation

Procedures	7 pts
SCADA/ Communication system	3 pts
Drug test	2 pts
Safety programs	2 pts
Surveys/Maps/Records	5 pts
Training	10 pts
Mechanical error	6 pts

Using the above given table the evaluator assesses each component of pipeline system separately. The effectiveness of each sub system is assessed and a score is assigned as a part of the total using the weight of each component.

A qualitative score of 15 pts for maintenance covering documentation(2), schedule(3), procedures(10) is given after assessing maintenance records.

The potential for pipeline failure caused by corrosion is perhaps the most familiar and most common hazard. The different causes analyzed here are:

- Susceptible facilities
- Atmospheric corrosion
- Painting/coating/inspection
- Product corrosivity
- Cathodic protection
- Presence of corrosive environment

Table 3.12

Scoring Variables for Corrosion Index

Parameter	Percent Contribution
Atmospheric corrosion	10
Internal corrosion	20
Buried pipe corrosion	10
Coating condition	15
Cathodic protection	15
Interference	15
Mechanical corrosion	5
ILI	10
Corrosion Index	100

A. Atmospheric corrosion: (10%)

A possible evaluation scheme for atmospheric corrosion is given below. This may not be consistent with the muhlbauer model, but has been modified to suit the present day requirement. This is bearing in mind that subsurface corrosion is the major problem in tropical environments like India. Here careful weights are to be assigned and this process is complex.

- 50% weight is given to score using the table below.

Table 3.13 score for at. Weight corrosion

Air water interface	0 pts
Casings	1 pts
Insulation	2 pts
Supports	2 pts
Ground air interface	3 pts
Other exposure	4 pts
None	5 pts
Multiple occurrence detractor	-1 pts

- 50% weight of atmospheric corrosion assigned to score of table given below

Table 3.14 score at.type corrosion

Chemical and marine	0 pts
Chemical and high humidity	0.5
Marine swamp	0.8
High humidity and temperature	1.2
Chemical and low humidity	1.6
Low humidity and temperature	2
No exposure	2

B. Internal Corrosion (30%)

B1. Product corrosivity (20%)

This is an assessment of the aggressiveness of the product being carried in the line. Given below is the scoring pattern.

Mildly corrosive 3 pts

Strongly corrosive 0 pts

Corrosive only under special conditions 7 pts

Never corrosive 10 pts

These points are obtained by assessing the velocity profile and flow profile.

B2. Prevention activities: (70%)

It is prudent to take action against the damage caused by internal corrosion. Thus it is completely necessary to assess the actions based on the following given pattern.

Table 3.15 score for corrosion prevention

Anti corrosion activities	Points
none	0
Internal monitoring	2
Inhibitor injection	4
Not needed	10
Internal coating	5
Operational measure	3
pigging	3

C. Subsurface or buried metal corrosion (10%)

Soil corrosivity is only scored under this topic. Each sub variable is assigned points on high, medium and low scale. The net result is obtained using the following equation.

Soil corrosivity score= soil resistivity + PH + MIC +Steel corrosion.

E.Cathodic protection: (15%)

The CP effectiveness is purely scored on experience and qualitative models. This is done in this project by using a scale of good, fair and poor by assigning 15 points, 10, and 5 points respectively. 0 pts are assigned if cp is not present.

The following factors are also considered.

1. age of the cathodic system
2. frequency of surveys

3. test lead spacing.

4. CIS and polarization tests.

The equation followed is :

Maximum points * (survey age* years)^5 = score for CP. – (E 3.6)

G. Interference potential: (15%)

Corrosion is an electrochemical process and it is assessed using interference potential. The following pattern is used to assign scores using the inference from interference potential obtained by surveys conducted over the line.

AC related interference	2 pts
Shielding	1 pts
DC related interference	7 pts
Telluric currents	1%
Dc rail/OHE	50%
Foreign lines	49%

H. Mechanical corrosion: (5%)

For this a negative of one point is given if any of the following is found in the pipeline. But these are likely events in many pipelines.

- Operating stress > 60% of SMYS
- Operating temperature >100 °C .
- Age > 10 years
- Coating system other than fusion bonded epoxy.

J. Coating: (20%)

The following pattern is adopted to score coating:

- Fitness 10 pts
- Condition 10 pts

Quality of coating:

GOOD – a high quality coating designed for the environment- 0.0003 mA/sqft 20pts

(CP current requirement is given in brackets)

FAIR- an adequate coating but not specifically designed.- 0.003 mA/sqft 15 pts

POOR – a coating in place but not suitable.- 0.1 mA/sqft 5 pts

ABSENT- no coating is present- 1.0 mA/sqft 0 pts

The score obtained from above is given 50% weightage for coating

Coating condition parameters are assessed by the following pattern:

Coating selection 20 pts

Application 30 pts

Inspection 20 pts

Defect correction 30 pts

The obtained from above is given 10% weightage which makes up for 50% of coating.

K. Internal inspection instruments : (5%)

Based on a qualitative scale the presence of ILI facility, the frequency of ILI surveys, and effectiveness and accuracy of analysis of results of ILI are all scored for the above 5 pts. A probable method used is assigning 2 pts to analysis and 1 each to others.

Index sum: This is of all the contributors to risk and is calculated out of 400 for the Muhlbauer model. But in this project the index sum is extended to include process safety features and the model for process safety follows. The index sum will later be calculated.

3.2 HAZOP Matrix

Table 3.16 RBI Matrix development: frequency and severity codes

Matrix	Code	Occurrence
Frequency	0	Once in 1000 years
	1	Once in 100 years
	2	Once in 10 years
	3	Once in a year
	4	Once in a month
Hazard category	1	Personnel injury
	2	Equipment damage
	3	Production loss
	4	Environmental impact
	5	External reaction
Severity	0	Minor
	1	Appreciable
	2	Major
	3	Severe
	4	Catastrophic

Using the above given table the risk based index matrix is constructed for the above proposed pipeline project and the results are interpreted. This constitutes the first step in the Indian model of risk assessment.

3.3 Failure mode effect analysis (FMEA)

In the failure mode and effect analysis the effects of failure of each component/ part of the system could be considered to identify failure mode, causes of failure and remedial action. A FMEA generates a qualitative, systematic reference list of equipment, failure modes and effects. The results must generally consider the system and all equipment used in the process. The FMEA can consider only the major hazards or may be also deep, considering every component in detail. But the later causes unnecessary loss of time. Thus only the major hazards of a pipeline system have been depicted using a single fault tree. This process also consists of determining the failure rate of equipment either from relevant available data or through experience and experiments. These frequencies are used to calculate risk probability using fault tree.

3.3.1 Fault tree analysis:

Fault tree analysis seeks to relate the occurrence of an undesired event to one or more antecedent events. The desired event is called the top event and the antecedent events are called basic events. The top event may be and usually is, related to the basic events via certain intermediate events. The fault tree diagram exhibits the casual chain linking the basic events to the intermediate event and the latter to the top events. In this chain, logic gates illustrate the logical connection between events. The principal logic gates are:

AND Gate (the output event occurs if and only if all input event occurs) ----(A)----

OR Gate (the output event occurs even if any on of the input event occurs) ------®-----

3.3.2 Consequence and risk: A comparison of MUHLBAUER and OISD models.

As mentioned earlier, risk is defined as LIKELIHOOD * CONSEQUENCE. All through we have been talking about failure and its occurrence but it seems undeniable that the consequence is of more importance. The Indian model does very little to assess failure and its occurrence in case of pipelines. Therefore we have tried to analyze failure likelihood using the muhlbauer model. But added with that we have determined the failure rate of general pipeline components using some chemical data books or experience in the industry. But never is the Indian process specific to that particular pipeline being analyzed. Thus the basic aim has been to utilize the Indian model to assess consequences, where the results are very specific to the particular pipeline being assessed and even to the location being assessed. For the purpose of failure assessment, which the western model emphasizes, the Muhlbauer model has been used. Also the consequence id necessary can be quantified to suit the scale of index sum or vice versa. This may not be necessary as the risk scale for inference is only a relative one and this model can develop a scale for its own through experience if extensively used.

3.4 Estimation of consequence:(consequence analysis)

3.4.1 DOW index:

The hazard classification guide developed by the DOW chemical company and published by the American institute of chemical engineers provides a method for estimating the potential loss as a result of a fire explosion in petro-chemical plant or refinery process. A step by step objective evaluation of the realistic fire or explosion potential of processing or storage equipment. It is based on the empirical analysis of actual events and is widely used in the industry. The purpose of evaluation is to quantify fire and damage expected, identify contributors, and to communicate F&E risk to management.

The DOW INDEX is calculated guided by the following flow chart and formulae:

GPH subfactor $SF = 1 + GPH(t) * mf$ -(E 3.7)

Fire and explosion index $F = mf * (1+GPH(t))(1+SPH(t))$ -(E 3.8) [Manual of EHS Management 2004]

Toxicity index $= T_H + T_S/100(1+GPH(t)+SPH(t))$

Where GPH is general process hazard factor

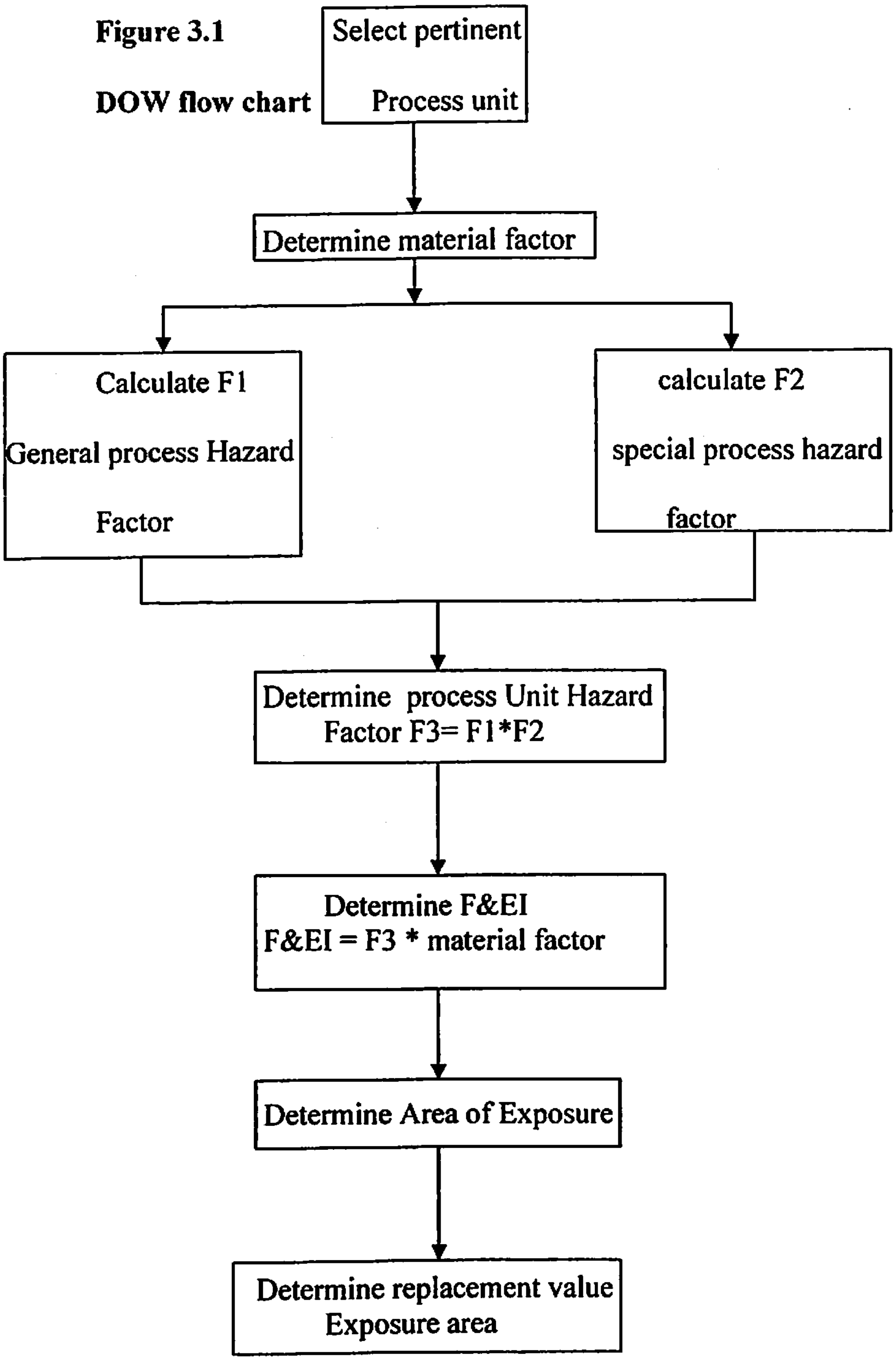
Where ……

SPH is Special process hazard factor

T is the toxicity index values as per NFPA guidelines.

Figure 3.1

DOW flow chart



3.5 Leak frequency estimation

The estimation of leak frequency of liquid leaks of different severity for piping pumps valves and flanges are to be modeled. For this purpose estimation of leak frequency from historical data are necessary. From this one can estimate the probability of ignition of a particular leak so that mitigation measures can be planned out.

Also the frequency of leak/ rupture for that particular pipeline can be estimated if data is available for the that diameter of the pipe (ie; frequency/m of the pipe of particular diameter). The mass flow rate of liquid through the leak/rupture can also be estimated by using the formula:

Mass flow rate = $ACo \sqrt{(\rho g P)}$

Where

A -area of leak (sq m)

Co-Coefficient of discharge

ρ- density (kg/cu m)

g- acceleration due to gravity (m/sq s)

P- gauge pressure (kPa)

3.6 Fire hazard analysis:

3.6.1 Modeling for estimation of the characteristics of liquid pool fire:

Calculation of heat release rate $Q = m''\Delta H_{C,eff}(1-e^{-k}\beta^{D})A_{dike.}$ –(E 3.8)(NFPA 2006)

Calculation of burning duration $t_b = 4V/\rho D^2$ --(E 3.9)[[NFPA 2006]

Calculation of pool fire flame height calculation(H_f)

Method of Heskestead, $H_f = 0.235\ Q^{2/5} - 1.02\ D$ --(E3.10)[DoT USA 1996]

Method of Thomas, $H_f = 42D\ [m''/\rho_a \sqrt{(gD)}]^{0.61}$ --(E3.11)[DoT USA 1996]

Where,

Q = pool fire heat release rate (kw)

m"= mass burning rate fuel per unit surface area (kg/m^2–s)

ΔH_c= effective heat of combustion (kJ/kg)

$A_f = A_{dike.}$ Surface area of pool fire (area involved in vaporization)

$k\beta$ = empirical constant (m^{-1})

D = Diameter of pool fire $\sqrt{4\ A_{dike}/\Pi}$

t_b = burning duration of pool fire (s)

V = Volume of liquid (m^3)

ν = regression rate (m/s)

Calculation of plume centerline temperature

$T_{p\ (centerline)} - T_a = 9.1(T_a/g\ C_p^2\ r_a^2)^{1/3}\ Q^{2/3}(Z-Z_a)^{-5/3}$ --(E3.12)[EHS Manual 2004]

Calculation of convective heat release

$Q_C = \chi_C\ Q$ --(E3.13)[Dr.Hamsagar's 2004]

Calculation of hypothetical virtual origin

$Z_O/D = -1.02 + 0.083(Q^{2/5})/D$ --(E3.14)[EHS Manual 2004]

Where

$T_{p\,(centerline)}$ - plume centerline temperature (C)

Q_C - Convective portion of heat transfer (kW)

T_a - Ambient air temperature (C)

.g - acceleration due to gravity.

C_p - Specific heat of air (kJ/kg-K)

r_a - Ambient air density

χ_C - convective heat release fraction

solid flame radiation model in presence of wind

q" =EF1->2 --(E3.15)[WB technical paper]

flame emissive power calculation

$E = 58\ (10^{-0.00823})$ --(E3.16)[WB-U.N. technical paper]

Distance from center of the pool fire to edge of the target calculation

R= L + r --(E3.17)[WB –U.N. technical paper]

Non dimensional wind velocity calculation

$U^* = U_w/(g\ m''\ D/\ r_a)^{1/3}$ --(E3.18)[WB –U.N. technical paper]

Where,

.q"- incident irradiative heat flux on the target (Kw/sqm)

E- Emissive power of the pool fire flame (kW/ sqm)

F1->2 – view factor between target and flame.

D – diameter of pool fire

L – distance between target and fire

R – radius of pool fire

U – non-dimensional wind velocity

Prediction of temperature Tjet and Velocity Vjet of the ceiling jet.

Alpert's ceiling jet correlations predict the temperature and velocity of a ceiling jet if the fire size, ceiling height, and radial distance from the fire are known. These correlations are useful for sprinkler and heat detector response applications.

$Tjet-Tamb = 16.9Q'^{2/3}/H^{5/3}$ for $r/H <= 0.18$ -(E3.19)[empirical safety relations manual

$Tjet- Tamb = 5.38(Q'/r)^{2/3}/H$ for $r/H >0.18$ –Royal Safety Research Institute London]

$Ujet = 0.96 (Q'/H)^{1/3}$ for $r/H<=0.15$

$Ujet = 0.195 Q'^{1/3}H^{1/2}/r^{5/6}$ for $r/H>0.15$

Where,

T = Ceiling jet gas temperature (C or F)

T amb = ambient temperature (C or F)

Q' = heat release rate of fire (kW)

H = ceiling height (m or ft)

R= radial distance from fire(m or ft)

Ujet = ceiling jet velocity (gas m/s or ft/s)

3.7 Probabilities

The relationship between leak frequency and probability is expressed in terms of a Poisson probability distribution function. For pipeline and pump station equipment failures, the following equation relating the probability of a spill ("spill" will refer to any release, regardless of size) to the spill frequency applies:

$P(X)SPILL = [(f*t)^X / X!] * e^{(-f*t)}$

where: P(X)SPILL = probability of exactly X spills

f = the average spill frequency for a segment of interest, spills /year

t = the time period for which the probability is sought, years

X = the number of spills for which the probability is sought, in the pipeline segment of interest.

The probability for one or more spills is evaluated as follows:

P(probability of one or more)SPILL = 1 - P(X)SPILL; where X = 0.

3.7 ALOHA model:

Aloha (Areal locations of hazardous atmospheres) model predicts how a hazardous gas cloud disperses in the atmosphere after accidental chemical release. ALOHA can predict rates of chemical release from broken pipes, leaking tanks and evaporating puddles, can model the dispersion of both neutrally and heavier than air gases. ALOHA is based on a continuous point source with a Gaussian plume distribution.

ALOHA considers the following:

a) Emergency response planning guidelines(ERPG1, ERPG2, ERPG3)

b) Temporary emergency exposure limits (TEELS)

c) Immediately dangerous to life of health (IDLH)

d) Boiling liquid vapour cloud explosion (BLEVE)

e) Vapour cloud explosion

f) Jet fire

g) Upper explosive limit

h) Lower explosive limit

i) Flammable level of concentration.

As mentioned earlier all the models of the OISD process risk plan have been done to assess the consequence part of risk assessment. Though the physical multiplication of likelihood and consequence are not carried out, inferences can be made directly by assessing them based on the previously explained models. The assessment of likelihood is done using the Muhlbauer model. Finally mitigation measures and inferences are suggested as a conclusion of this project, which can be implemented on the ATF pipeline to reduce the risk involved. The calculation of risk indices using the mentioned theoretical methodology, their results and discussion are explained in the following chapters.

Chapter 4
Risk: Computation and Estimation

This chapter describes in detail the computation of the risk values using the model described in the previous chapter. The data of the CPCL-Chennai AFSATF pipeline have been utilized for this. This pipeline has been chosen for the following reasons:

a) easier to apply the model to maximum possible length of the line as the line is 97KM long.

b) Familiarity of the evaluator with the pipeline construction project, and thereby its terrain and features.

c) Availability of required data with M/S Projects Development India Ltd, was best for this line as they had been the risk consultants for pre project assessment.

For the sake of comparison, ie; to evaluate the effectiveness of the given model, the data of Chennai Bangalore pipeline has been used wherever suitable data was available.

4.1 Evaluation of likelihood using Mulhbauer Model and FMEA.

4.1.1 Third party damage index.

a)The line here is dived to 10 segments equally from chain-age 22 to 42 km.

The respective covers at the ten segments were: (measured depth of cover)

Table 4.1

Chain-age (km)	Cover (")	Points
22.00-23.99	40.1	14
24.00-25.99	38.3	13
26.00-27.99	32.9	11
28.00-29.99	36.8	12
30.00-31.99	40.4	14
32.00-33.99	39.6	14
34.00-35.99	45.2	16
36.00-37.99	42.3	15
38.00-39.99	38.9	13
40.00-41.99(42)	37.0	12

The values are calculated using the previously described formula. The values of depth for crossings in this chain-age is taken separately.

4+4 =8 " of concrete at Manali marsh land is equal to 16" of earth = 6 pts

There were totally 8 river crossings of which 3 were of < 5ft depth – 0 pts

Five crossings are of 5 to 27 ft depth carrying 3 pts each.

Crossing cover = 15 + 6 = 21 for 6 crossings which carry points.

∴ value for depth of cover = 14(avg for earth cover) +21/6 =17.5 = 18 pts.

b) Again the same chain-age division to 10 segments was followed for calculating **Activity level**. Out of the given areas the following was the trend of area classification.

Table 4.2 class classification trend for 22-42 (activity level)

Chain-age (km)	Class location	Points
22.00-23.99	3	0
24.00-25.99	2	8
26.00-27.99	2	8
28.00-29.99	2	8
30.00-31.99	2	8
32.00-33.99	1	15
34.00-35.99	1	15
36.00-37.99	1	15
38.00-39.99	1	15
40.00-41.99(42)	3	0
Average points activity level = 10 pts (9.2)		

c) for consistently 6 segments of the line of ten, there were no **Above Ground Facilities.** So these segments were given 10 points each.

In case of the other segments above ground facilities with warning signs, vehicles more than 200ft away and tress on the rail protection was present. Thus these features add upto : 0 + 5 + 4 + 1 = 10 pts

So the average score for above ground facilities = 100/10 =10 pts

d) **Line location scores:**

• Effectiveness	5 pts
• Proven record of efficiency and reliability	2 pts
• Widely known in the community and advertised	0 pts
• Meets minimum OISD standards	1 pts
• Appropriate reaction to calls / records	0 pts
• Maps and records of the line available	2 pts
Total score for line location =	**10 pts**

e) **Public education score:**

These factors were validated to score public education:

• Mail outs	0 pts
• Meetings with local contractors/excavators per year	2 pts
• Meetings with public officials once a year	1 pts
• Regular education programs for community groups	0 pts
• Door to door contact with adjacent residents	0 pts
• To suit Indian scenario public education through News papers were considered	2 pts
• Education of village people through panchayats	4 pts

Total for public education: 9 pts

f) **ROW condition score:**

since the pipeline is new one which can be considered as a proposed one we assume even if the score in not excellent a nominal score of good, which gives 3 pts can be assigned to the ROW.

Final score of ROW condition = 3pts

g) **Patrol frequency:**

normally in the Indian scenario the patrolling is done less than once a month. But since the line is new and it requires less patrolling as the area where the line passes is comparatively one which high literacy rate, we have considered patrolling as less than four but more than once a month.

The final score for patrolling = 4 pts

Total score for third party damage index is given in the following table:

Table 4.3 score of third party damage

Field of investigation	**Points**
Depth of cover	18
Activity level	10
Above ground facilities	10
Line location	10
Public education	9
ROW condition	3
Patrol frequency	4
Total score for third party damage index	**64/100**

4.1.2 Design index

a) **Safety factor:**

This is evaluated using the equation design to maop ratio -1 * 35 points.

The safety factor mentioned here is considered apart from the one safety factor considered for SMYS etc. It does not include all the technical safety factors. In the Indian case no such separate safety factor is considered. Thus the MAOP =274 psi is about 0.72 times the design pressure. From the table given for design pressure the **score safety factor can be given as 14 pts.**

b) **Fatigue :**

The fatigue stress caused by load cycles(increase from start -to peak- back to start) in the line could be calculated as **2cycles/ week * 52 weeks * 0.5 year << 1000 cycles.** This value is low due the fact that the pipeline is newly commissioned.

Thus the stress caused by the load cycles = 4psi = less than 2% of MAOP.

∴ Score for fatigue = 14 pts. (from table)

c) The **surge potential** in this line is low as the station discharge pressure for the line is around 250 psi. The has considerable safety systems incorporated to assess surge situations. But since a safety condition is being assessed the probability for surge is considered to be medium. **Thus a score of 5pts is assigned for surge potential.**

d) **Integrity Verification:**

Since the pipeline is a new one the 10 segments as mentioned earlier were tested hydrostatically.

All the ten sections passed the test at test pressure = 1.35 times MAOP

So the final score for integrity verification would only consist of pressure test and no age verification would be required as the pipeline is a newly commissioned one.

∴The score for integrity verification = 10 pts

e) **Earth movements:** According to records of the meteorological survey of India , the ROW of the pipeline falls under seismic zone one which is roughly about 1000 km from the epicenter north – north west of Chennai, centered at Sholapur in Maharashtra. Thus, the region may not experience significant land movements due to quakes in the near future. But since it lies on south coastal Tamil Nadu which is prone to cyclones and also has a history of quake and tsunami(quake –70 yrs ago and tsunami + quake 3 yrs ago) a zone two value is considered. That is, the score for low land movement capabilities is assigned. **Score for earth movements = 10 pts**.

The final score for design index is given the table below

Table 4.4 Design index score

Field of investigation	**Points**
Safety factor	14
Fatigue	14
Surge potential	5
Integrity verification	10
Earth movements	10
Total score for design index =	**53/100**

4.1.3 Incorrect Operations Index.

a) Design:

1.The **hazard identification** process is practically very menial and does not consider all hazards so the **score for hazard identification is 2 pts.**

2.The possibility of exceeding the MAOP potential is extremely unlikely . Thus from the table given previously the **score for MAOP potential is 10 pts.**

3.The safety systems in the pipeline are only one level safety systems but have facilities for remote observation and control. So the **score for safety systems is 3 + 3 = 6 pts.**

4.Material selection for the pipeline has been done after deep analysis of the stresses induced etc. But the process was not fully satisfactory and company was not able to produce the necessary documents to support their claim. It was more on "tradition ", that the material selection parameters were finalized. So 2 pts were reduced from the maximum to make **final score of material selection as 2 pts.**

∴ **Thus the total score for design component = 20 pts**

b) Incorrect construction activities:

The table below carries the average score for ten segments from chain-age 22 to 42 km.

Table 4.5 Score for construction

A. Inspection	7 pts
B. joining	1 pts
C. Materials	1 pts
D. Backfilling	1 pts
E. Handling	0 pts
F. Coating	1 pts

Reasons

- Well experienced and trained people undertook radiography film reading and inspection. Thus 7 pts for inspection.
- There were pronounced weld defects with the same welders, reduce 1 point from joints.
- Materials used were satisfactory and upto standard so 1 pt assigned.
- Back filling was not satisfactory with respect to sand padding and rock shield in rocky areas. So 1 point of the 2 pts were reduced from this feature.
- The handling of pipes after welding was very poor. Even the engineers could not foresee the implications of stresses induced in the joints during pipe lifting. People were observed to state their own theory that "pipes are very very flexible". Thus a 0 pts were assigned for handling during construction(lowering).
- Coating , specially the joint coating was unsatisfactory, with pathetically bad sand blasting and surface preparation. So only 1 pt was assigned.
- **Thus the final score for the construction component is 11 pts**

c) Operations component:

The score of operations component of incorrect operations index is given below.

Table 4.5A Score for incorrect operations component

Procedures	5 pts
SCADA/ Communication system	2 pts
Drug test	0 pts
Safety programs	1 pts
Surveys/Maps/Records	5 pts
Training	8 pts
Mechanical error	6 pts

. Reasons

- Procedures adhered to are satisfactory but only 'taken for granted' theories prevail more.
- Scada communication system is fair enough for 2 pts
- Drug testing on employees (history) is null and void.
- Minimal safety programs only are ensured and operators less familiar with safety issues.
- Poor up keep and access to survey records/ maps.
- Training is satisfactory for normal operations.
- Mechanical error is slightly higher than acceptable.
- **Thus the total score for operations component is 27**

d) Maintenance component:

The documentation procedures are strictly followed but log of failures and errors is altogether not present. **Thus documentation has been assigned half the maximum score =1 pt.**

Procedures from manuals are followed only upto the level of motor memory, but some important manuals for maintenance and associated activities are not present at the site or they are not accessible to the required person. So **a score of 5 pts has been assigned for procedures.**

Schedules are followed and devised in an appreciably good manner. They are logged and kept up strictly. These constitute schedules like pigging, routine preventive maintenance etc. but the quality of the activity carried out is out of scope of this feature. So a full score of 3 pts has been assigned to schedules.

The total score for maintenance component is 9 pts.

The total score for in correct operations index is given in the following table. These scores were taken only for the average of chain -age 0 to 6 km around the mother station. All other features were assessed at the mother station terminal at Chennai petroleum corporation's premises.

Table 4.6 Score for Incorrect Operations index

Field of investigation	Points
Incorrect Design	20
Incorrect constructions	11
Incorrect operations	27
Maintenance	9
Total score for incorrect operations index = 67/100	

4.1.4 Corrosion Index

a)An evaluation scheme for corrosion and estimated values are given below. These may not be consistent with the Muhlbauer model, but has been modified to suit the present day requirement. This is bearing in mind that subsurface corrosion is the major problem in tropical environments like India. Here careful weights have been assigned and this process is complex. The line from chain-age 22 to 42 was divided into ten sections of equal length as previously. The score given below is the average of ten sections considering the apt features eg: casing for crossings only, air water interface for marshes .

- 50% weight was given to score using the table that follows and 50% to the next.

Table 4.7 Score for atmospheric Weight corrosion

Air water interface	0 pts
Casings	1 pts
Insulation	2 pts
Supports	0 pts
Ground air interface	3 pts
Other exposure	4 pts
None	0 pts
Multiple occurrence detractor	0 pts
Total score for atmospheric corrosion = 10 pts	

Table 4.8 Score at.type corrosion

Chemical and marine	0 pts
Chemical and high humidity	0.5
Marine swamp	1.8
High humidity and temperature	1.2
Chemical and low humidity	0
Low humidity and temperature	0
No exposure	0
Total score for atmospheric type corrosion = 3.5 pts	

<u>The final score for atmospheric corrosion = 10/2 + 3.5/2 = 6.75</u>

b) Internal corrosion:

B1. Product corrosivity.

This is an assessment of the aggressiveness of the product being carried in the line. The product carried in this pipeline is jet fuel which is not very aggressive. The product is mildly corrosive under normal conditions but under condition for exceeding MAOP and velocity beyond 3.5m/s the product becomes more aggressive. Hence <u>3+ 3 =6 pts</u> are assigned.

B2. Prevention activities.

Table 4.9 Score for corrosion prevention

Anti corrosion activities	Points
none	0
Internal monitoring	2
Inhibitor injection	4
Not needed	0
Internal coating	0
Operational measure	3
pigging	3
Total score for corrosion prevention = 12 pts	

C) **Sub-surface buried metal direct corrosion.**

Average soil resistivity for the 20 km chain- age = 2000 ohm/m

PH value of the soil = 4.5

MIC found = 0.032 of total

Steel corrosion = 0.02

Final score for sub surface corrosion (direct) = 2000/1000 + 4.5+ 0.032 +0.02 = 6.552

D) **Cathodic protection:**Based on the age and test lead spacing the PSP values were taken at several places in the 20 km chain-age. The result was found to be very satisfactory. Since the system is a new one a very optimistic value of 15 pts is assigned considering the system to be good.

The survey age ie, the survey has been conducted less than one year ago . thus the score becomes **15*1^5* 0.5 = 7.5 pts.**

E) **Interference potential**

AC related interference	1pts
Shielding	0 pts
DC related interference	2 pts
Telluric currents	1%
Dc rail/OHE	50%
Foreign lines	49%

Reason:

The DC related interference was found in case of 6 railway crossings in the chain-age between 22 and 42 km. Practically telluric currents were not assessable and were ignored. Shielding was not a problem as the line is a new one.

Score for interference potential is therefore = 3 pts.

I) **mechanical corrosion** which normally carries negative points, here **carries 0 pts** , because here operating stress does not exceed 60% SMYS. Temperature of operation is less than 100 C, line age less than ten years and finally the coating material is FBE.

J) **coating**

The fitness of the coating DFBE was fair enough. Hence it is capable of earning 7/10 pts. This was due to proper yard coating of the pipe. But during handling of the pipes, coating damage was heavy. This was not patched up properly and holiday testing was also poor. All yhis was due to inexperience in handling DFBE coating as Indian oil normally uses CTE coated pipes. **Score obtained = 7 + 5= 12 pts.**

The score obtained from above is given 50% weightage for coating. Coating condition parameters were assessed by the following pattern:

Table 4.10: score for coating condition

Coating selection	**10 pts** (proper documents not produced to risk consultant)
Application	**15 pts** (yard coated good. But joint coating – pathetic)
Inspection	**10 pts** (not enough personal to check quality during coating)
Defect correction	**10 pts** (correction of coating defects was very poor due to lack of experience in handling the solvent and base for patch work of Fusion Bonded Epoxy).

The total score for coating = 0.1 *45 + 0.5 *12 = 10.5 pts.

K) **Internal inspection tools and pigging.**

- Presence of ILI facility carries 1 pt
- The frequency of ILI surveys quarterly basis (good) carries 1 pt
- Effectiveness and accuracy of analysis of results of ILI carries zero as no real ILI survey has been carried out.
- **The final score for ILI and Pigging = 2 pts.**

The score for the corrosion index evaluated with the right weights is given in the table below:

Table 4.10A score for corrosion index

Field of investigation	Points
Atmospheric corrosion	6.75
Internal corrosion +subsurface corrosion	10.2552
Cathodic protection	7.5
Interference potential	3
Mechanical corrosion	0
Coating	10.5
ILI and pigging features	2
Total score for corrosion index = 40.52/100	

4.2. The index sum of risk, of the pipeline being assessed is calculated for 400 points by adding the four main indices ie, third party damage index, design index, incorrect operations index, and the corrosion index.

The final score for index sum for the pipeline is given in the table below, but the inferences and implication of the estimated value, as compared with the industry average and minimum recommended requirement are discussed in the next chapter.

Table 4.11 score of Index sum as average for the ten segments (regulations also) .

	Index Sum	Third party Damage Index	Design Index	Incorrect Operations Index	Corrosion Index
Overall Average	224.52	64.00	53.00	67.00	40.52
Highest probability Area	188.22	60.20	47.18	52.82	28.02
Regulatory requirement	180.00	52.00	44.00	50.00	34.00

The Muhlbauer model has previously been used, to determine the failure probability specific to the pipeline system. Now as part of the Indian process safety model the failure probability of the various components are estimated using historical data. They are organized by the FMEA and their consequences classified under the HAZOP matrix.

4.3 Failure mode and effect analysis.(referring to mode of failure)

The following tables give the equipment failure data which has been obtained from guidelines for process equipment failure data available with Oil Industries Safety Directorate. These values are used to estimate a consequence in case of an accident.

The data is also very important to determine exposure frequency and make a quantified fault tree or event tree.

Table 4.12: failure rates of piping and valves.

Item	Failure rate (occ/plant year)
Piping systems: metal sections	2.350E-04
Piping systems: metal connections	4.990E-03
Piping systems: lined pipe sections	3.870 E-03
Piping systems: rigid plastic	7.750 E-03
Hoses	4.990 E-03
Valves: non operated check	2.786 E-02
Valves: manual	1.330 E-03
Valves: operated motor	1.191 E-02
Valves: operated pneumatic	3.145 E-02
Valves: operated solenoid	4.266 E-01

Table 4.13 failure rates of vessels

Item	Failure rate (occ/plant year)
Atmospheric metallic	8.629E-03
Atmospheric non metallic	1.060E-02
Pressurized metallic	9.550E-05

Table 4.14 failure rates of rotating equipment

Item	Failure rate (occ/plant year)
Compressors engine driven	1.253E+01
Compressors electric motor driven	2.164E+01
Motor driven fans	7.963E-03
Pumps centrifugal motor driven	2.558E-00
Pumps turbine driven	7.805E-01

Table 4.15 failure of pressure storage

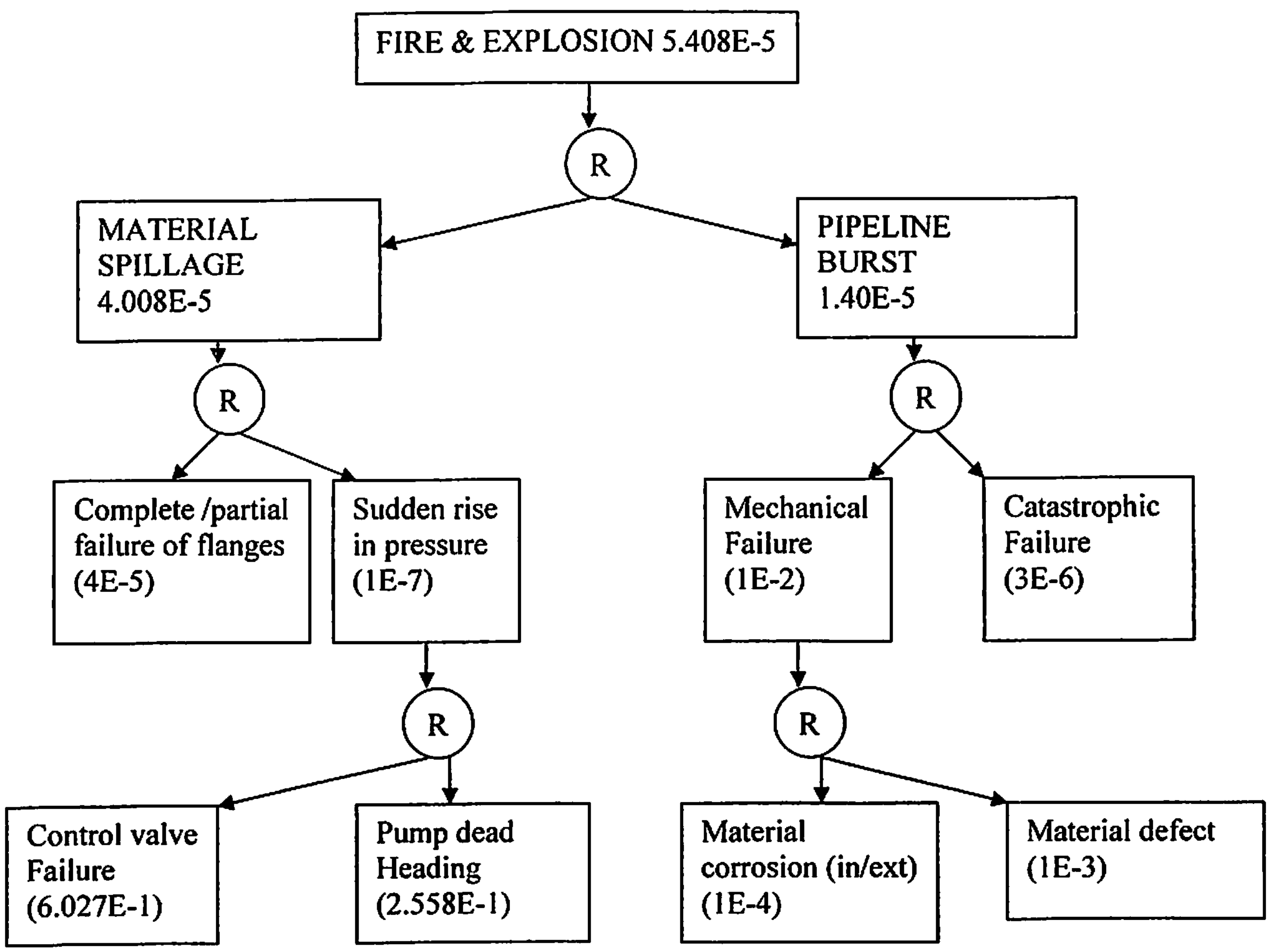
Event	Probability
Crack in pipe	P=1E-4
Gasket failure	P= 5E-5
Flange failure	P= 4E-5
Valve sealing failure	P= 3E-2
Drainage/ sampling valve not shut	P= 1E-4

The other values of failure rates were found not completely pertaining to the subject of study. Examples of these were electrical equipments, instruments, and refrigeration equipments, fire protection system. Some values of the failure rates of the previously mentioned equipments have been used. But care has been taken to mention only the required value of failure rate, wherever necessary.

4.4 Fault tree analysis.

The fault tree given below describes the events leading to fire/explosion.

FIGURE 4.1 Event tree probability chart



4.5 Risk Based Investigation Matrix (RBI)

Table 4.16 RBI Matrix development: frequency and severity codes

Matrix	Code	Occurrence
Frequency	0	Once in 1000 years
	1	Once in 100 years
	2	Once in 10 years
	3	Once in a year
	4	Once in a month
Hazard category	1	Personnel injury
	2	Equipment damage
	3	Production loss
	4	Environmental impact
	5	External reaction
Severity	0	Minor
	1	Appreciable
	2	Major
	3	Severe
	4	Catastrophic

RISK MATRIX CODE

F = Frequency code

S = Severity code

U: unacceptable level of risk

R: risk reduction required

C: Does not warrant high Risk, but can be reduced.

F4	2R	**3R**	**4R**	**3U**	**4U**
F3	1R	2R	**3R**	**4R**	**3U**
F2	2C	1R	2R	**3R**	**4R**
F1	1C	2C	1R	2R	**3R**
F0	0	1C	2C	1R	2R
	S0	S1	S2	S3	S4

Estimation of consequences:

The calculations that follow from now, estimate the consequence part of risk involved in the pipeline. This allows us to foresee the measures required to taken, to reduce risk.

4.6 Fire and explosion indices (DOW INDEX) estimation:

The hazard classification guide developed by the DOW chemical company and published by the American institute of chemical engineers provides a method for estimating the potential loss as a result of a fire explosion in petro-chemical plant or petroleum process.

Step 1: selection of the material, which appropriately represents fuel/explosion hazard.

This is used to estimate the material factor of the hazardous material. In this case the material carried by the pipeline is jet fuel or ATF.

Material factor =16.

Step2: estimation of general process hazard factor.

Here a penalty of 0.1 to 0.6 can be assigned to the presence of any of the following type of reactions or hazards. The evaluator decides the scale and it is to be followed uniformly throughout the process.

a) Exothermic reactions: Table 4.17

Exothermic chemical reactions	**Likelihood of occurrence in process of study**
Hydrogenation	**N**
Hydrolysis	**N**
Isommarization	**N**
Sulfonation	**N**
Alkylation	**N**
Oxidation	**N**
Polymerization	**N**
Halogenation	**N**
Nitration	**N**

b) **Endothermic reaction : Table 4.18**

Endothermic chemical reaction	Likelihood of occurrence in process of study
Energy source NOT combustion	N
Energy source IS combustion	Y

c) **Materials handling and transfer: Table 4.19**

Material handling & transfer option	Most probable representation
Loading/Unloading flammable liquids	Y
Centrifuges, batch reactors, mixing in semi- open containers.	N

Materials handling and transfer: Table 4.20

Material handling & transfer option	Most probable representation
Class I	N
Combustible solids.	N
Class II	Y

d) **Ventilation Assessment: Table 4.21**

Applicability to the given process	Most probable representation.
No problem	N
Sight problem	Y
Significant problem	Y

e)**Access Assessment: Table 4.22**

Applicability in the given process	Most probable representation.
No problem	Y
Significance problem	N

f) **Drainage Style: Table 4.23**

Applicability in the given process	Most representation.
To basin	N
Diking around process unit	Y

Step-3 :Select special process hazard factor:

(a) Process temperature: Table 4.24

Following could appropriately represent the process temperature:

Applicability in the given process	Most probable representation
Are process temperature	N
Not problem	Y
Above flash point	N
Above boiling point	N
Above auto ignition temperature	N

(b) Operation Near flammable Mixture Range

The potential for a flammable mixture of air and fuel to form in the given system could be best represented by following:

Table 4.25

Applicability in the given process	Most appropriate representation
Sub atmospheric pressure could result in air leakage to flammable substance.	Y
Tank storage of flammable substance can breathe in air at certain conditions	Y
Instrument, equipment or purge system failure could result in a flammable mixture	Y
Cannot avoid operating process in flammable range	Y

(c) Dust explosion:

Dust explosion near the project area could be best represented by: **Table 4.26**

Applicability in the given process	Most probable representation
Not a problem	Y
Large particles>175μm	N
Medium particles <175μm & >100μm	N
Smaller particles<100μm	N

(d) **Valve pressure:**

Input system pressure in kPa:

Table 4.27

Input	
Flow rate (volume basis)	1417 l/min
Density	800 kg/cu.m
Viscosity	8 cP
Pipe length	95 km
Pipe outside/ equivalent diameter	8.625 "
Pipe condition	New / clean

Output	
Pressure drop	1962.372 kPa
Head loss	250.133 m of fluid
Reynolds number	13725.7 turbulent flow
Fanning friction factor	0.0072052
Velocity	0.627 m/s
Percent of erosion velocity	14.5

(c) **Quantity of flammable materials:**

Because large quantities of flammable material pose a greater hazard, the quantity of flammable material in the system is one of the significant input for the assessment of hazard.

Table 4.28

Capacity of pipeline	0.18 MMTPA
Input liquid per day	493151kg

(f) **Corrosion and erosion:**

Keeping in view of design and specification of the pipeline, following option appropriately represents the given system:

Table 4.29

Corrosion Rate	Most Probable Representation.
<0.5 mm per year	Y
0.5 –1mm per year	N
1 mm per year	N
Risk of cracking	N

(g) Leakage joints and packing:

Table 4.30

Leakage –joints and packaging in the given Process.	Most probable representation
Minor problem	Y
Major problem	N

(h) Use of fired heaters:

Table 4.31

Applicability in the given process	Most probable representation.
No problem	Y
<10m	N
10-20m	N
20-30m	N
>30m	N

(i) rotating equipment- pumps, compressors:

Table 4.32

Applicability in given process	Most probable representation
No problem	Y
Problem	N

(j) **Hot oil exchange system:**

Table 4.33

Applicability in the given process	Most probable representation.
No problem	Y
<19000	N
19000-38000	N
38000-95000	N
>95000	N

Step-4: Results of DOW.

The process hazard factor and special process hazard factor are calculated by the previously given methodology. The DOW index is calculated using the formulae given in last chapter. The implications of the results obtained are discussed in the next chapter.

Table 4.34: results of DOW index

The material factor is:	16
The general process hazard factor is:	3.25
The special process hazard factor is:	12.502060
The unit hazard factor is:	8
The fire and explosion index is:	128
The radius of exposure is:	32.772096
The damage factor is:	0.5801638
The consequence	1E+1* 128 =1280

4.7 Leak frequency estimation

Using the previously estimated failure frequency one can do the estimation of leak frequency of liquids of different severity for piping, pumps, valves and flanges. These have been calculated and given in the following tables. In addition, the tables provide estimates of the probability of ignition and the associated probability of fire for a flammable liquid leak and explosion for a flammable gas leak.

Table 4.35: leak frequency data estimation.

Equipment	Type of leak	Frequency (occurrence per year)
Pipe diameter =25mm	Rupture	1E-6 Per metre
	Major leak	1E-5 Per metre
	Minor leak	1E-4 Per metre
Pipe diameter = 100 mm	Rupture	3E-7 Per metre
	Major leak	6E-6 Per metre
	Minor leak	3E-5 Per metre
Pipe diameter =300mm	Rupture	1E-7 Per metre
	Major leak	3E-6 Per metre
	Minor leak	1E-5 Per metre
Flanges	Section leak	1E-4
	Minor leak	1E-3
Valves	Rupture	1E-5
	Major leak	1E-4
	Minor leak	1E=3
Pumps	Rupture	3E-5
	Major leak	3E-4
	Minor leak	3E-3

For pipe work, valves and pumps the definition of hole sizes are (A is the cross sectional area of the pipe)

- Rupture leak =A
- Major leak = 0.1 A
- Minor leak = 0.01A

Section area = A

Minor leak area = 0.1 A

Using the above tables the probability of ignition and corresponding probability of fire for Aviation Turbine Fuel(ATF) are given below in the table. These were calculated, from probability of leak/rupture etc * probability of flash/ source of ignition. Fire fire the probability of fire to sustain is also considered.

Table 4.36:probability of ignition or fire

Type of leak	Probability of ignition		Probability of fire	
	ATF(liquid)	Gas	ATF(liquid)	Gas
Minor (<1 kg/s)	**0.01**	0.01	1	0.04
Major (1-50kg/s)	**0.03**	0.07	1	0.12
Massive(>50kg/s)	**0.06**	0.6	1	0.3

4.7.1 Fire and explosion frequency calculation:

The frequency of rupture/leak for the pipeline is calculated and given in the following scenario tables. They have been calculated by values from general leak frequency data.

Scenario –1 Rupture leak

Leak scenario (closest diameter of pipe)	300mm
Severity	Rupture
Leak type	Liquid
The pipeline length (m)	95000
The accurate diameter of pipe(mm)	224
The pipe pressure (kPa)	1962

The frequency of a vapour cloud explosion/ fire is (occ/1000yr) = 0.76

The mass flow rate of the liquid through leak in kg/s = 54.0842

Scenario –2 Major leak

Leak scenario (closest diameter of pipe)	300mm
Severity	Major
Leak type	Liquid
The pipeline length (m)	95000
The accurate diameter of pipe(mm)	224
The pipe pressure (kPa)	1962

The frequency of a vapour cloud explosion/ fire is (occ/1000yr) = 8.55
The mass flow rate of the liquid through leak in kg/s = 5.40842

Scenario -3 Minor leak

Leak scenario (closest diameter of pipe)	300mm
Severity	Minor
Leak type	Liquid
The pipeline length (m)	95000
The accurate diameter of pipe(mm)	224
The pipe pressure (kPa)	1962

The frequency of a vapour cloud explosion/ fire is (occ/1000yr) = 9.5

The mass flow rate of the liquid through leak in kg/s = 0.540842.

4.8 Estimation of characteristics of liquid pool fire

The characteristics of the liquid pool fire present risk analysis study, has been estimated by applying variable inputs to construct different scenarios, as illustrated.

Table 4.37: input parameters for pool fire modeling

Input parameters	Fuel type	
	(ATF)JP-4	**(ATF)JP-5**
Mass burning rate of fuel (m")	0.051 kg/m^2-s	0.054 kg/m^2-s
Effective heat of combustion	43500 kJ/ kg	43000 kJ/ kg
Fuel density	760 kg/m^3	810 kg/m^3
Empirical constant	3.6 m^{-1}	1.6m^{-1}
Gravitational acceleration	9.81 m/s^2	
Ambient air density	1.13- 1.18 kg/m^3	
Fuel spill volume	5-50 gallons	
Fuel spill area or dike area	10-100 ft^2	
Ambient air temperature	77-104°F (25-40 °C)	

4.8.1 Construction of scenarios:

Four scenarios were considered for modeling of burning characteristics of liquid pool fire to be caused by spillage of ATF and estimated heat release rate (HRR), burning duration and flame height.

Table 4.38: various scenarios of pool fire

Parameter	Scenario-1	Scenario-2	Scenario-3	Scenario-4
Fuel spill volume	5 gallons	10 gallons	25 gallons	50 gallons
Fuel spill area or dike area	10 sq ft	20 sq ft	50 sq ft	100 sq ft
Ambient air temperature	86-104°F (30-40 °C)			

Table 4.39: Various scenarios of pool fire

Area		Dia	Scenario -1				Scenario -2			
ft^2	m^2	Dia (m)	Q(kW)	$T_{b(sec)}$	H_f (ft) Heskestad	H_f (ft) Thomas	Q(kW)	T_b	H_f (ft) Heskestad	H_f (ft) Thomas
1	0.09	0.34	202.00	3035.96	5.29	4.85	205.29	6071.93	5.34	4.85
5	0.46	0.77	1009.99	607.19	9.69	8.49	1026.47	1214.39	9.77	8.49
10	0.93	1.09	2019.97	303.60	12.55	10.80	2052.94	607.19	12.65	10.80
15	1.39	1.33	3029.96	202.40	14.58	12.43	3079.41	404.80	14.70	12.43
20	1.86	1.54	4039.94	151.8	16.21	13.74	4105.88	303.60	16.35	13.74
25	2.32	1.72	5049.93	121.44	17.60	14.84	5132.35	242.88	17.75	14.84
50	4.65	2.43	10099.8	60.72	22.68	18.89	10264.6	121.44	22.88	18.89
75	6.97	2.98	15149.7	40.48	26.27	21.75	15397.0	80.96	26.51	21.75
100	9.29	3.44	20199.7	30.36	29.15	24.03	20529.3	60.72	29.42	24.03

Table 4.40: various scenarios of pool fire

Area		Dia	Scenario -3				Scenario -4			
ft^2	m^2	Dia (m)	Q(kW)	T_b	H_f (ft) Heskestad	H_f (ft) Thomas	Q(kW)	T_b	H_f (ft) Heskestad	H_f (ft) Thomas
1	0.09	0.34	206.07	15179.8	5.35	4.85	206.10	30359.6	5.35	4.85
5	0.46	0.77	1030.36	3035.96	9.79	8.49	1030.52	6071.93	9.79	8.49
10	0.93	1.09	2060.73	1517.98	12.68	10.80	2061.05	3035.96	12.68	10.80
15	1.39	1.33	3091.09	1011.99	14.73	12.43	3091.57	2023.98	14.73	12.43
20	1.86	1.54	4121.46	758.99	16.38	13.74	4122.09	1517.98	16.38	13.74
25	2.32	1.72	5151.82	607.19	17.79	14.84	5152.62	1214.39	17.79	14.84
50	4.65	2.43	10303.6	303.60	22.92	18.89	10305.2	607.19	22.92	18.89
75	6.97	2.98	15455.4	202.40	26.57	21.75	15457.8	404.80	26.57	21.75
100	9.29	3.44	20607.2	151.80	29.48	24.03	20610.4	303.60	29.48	24.03

4.8.2 Estimation of centerline temperature of a buoyant fire plume.

Table 4.41 Inputs for the estimation of center line temperature of plume.

Heat Release Rate of the Fire (Q)	2000-750 kW
Elevation Above the Fire Source (z)	10-15 ft
Area of Combustible Fuel (A_c)	15-25 ft^2
Ambient Air Temperature (T_a)	77-104°F (25-40°C)
Specific Heat of Air (c_p)	1.00 kJ/kg-k
Ambient Air Density (r_a)	1.13-1.18 kg/m^3
Acceleration of Gravity (g)	9.81 m/sec^2
Convective Heat Release Fraction (x_c)	0.70

The centerline temperature of the plume, in the previous four scenarios; are listed in the following tables. These values have been calculated using the formulae for centerline temperature mentioned in the previous chapter.

Table 4.42 Scenario – 1 for centerline temperature

Heat release rate of fire (Q)		2000 kW	2500 kW	3000 kW	6000 kW	7500 kW
Elevation above the fire source		15 ft	15 ft	15 ft	15 ft	15 ft
Area of combustible		25 sq ft	25 sq ft	25 sq ft	25 sq ft	25 sq ft
Ambient air temperature		104 °F	104 °F	104 °F	104 °F	104 °F
T_P	°C	302.95	363.96	426.49	847.89	1096.56
	°F	577.30	687.12	799.67	1558.21	2005.80

Table 4.43 Scenario – 2 for centerline temperature

Heat release rate of fire (Q)		2000 kW	2500 kW	3000 kW	6000 kW	7500 kW
Elevation above the fire source		15 ft	15 ft	15 ft	15 ft	15 ft
Area of combustible		20 sq ft	20 sq ft	20 sq ft	20 sq ft	20 sq ft
Ambient air temperature		104 °F	104 °F	104 °F	104 °F	104 °F
T_P	°C	321.63	387.86	456.02	599.44	1200.55
	°F	610.93	730.15	852.83	1110.99	2193.00

Table 4.44 Scenario – 3 for centerline temperature

Heat release rate of fire (Q)		2000 kW	2500 kW	3000 kW	6000 kW	7500 kW
Elevation above the fire source		10 ft	10 ft	10 ft	10 ft	10 ft
Area of combustible		15 sq ft	15 sq ft	15 sq ft	15 sq ft	15 sq ft
Ambient air temperature		104 °F	104 °F	104 °F	104 °F	104 °F
T_P	°C	688.38	875.11	1080.37	1556.98	557.31
	°F	1271.09	1607.20	1976.66	2834.57	1035.17

Table 4.45A Input for the model of radiant heat flux from fire to a target fuel

Input parameters	**Fuel type**	
	(ATF)JP-4	**(ATF)JP-5**
Mass burning rate of fuel (m")	0.051 kg/m^2-s	0.054 kg/m^2-s
Effective heat of combustion	43500 kJ/ kg	43000 kJ/ kg
Fuel density	760 kg/m^3	810 kg/m^3
Empirical constant	3.6 m^{-1}	1.6m^{-1}
Gravitational acceleration	9.81 m/s^2	
Ambient air density	1.13- 1.18 kg/m^3	
Fuel spill volume	5-50 gallons	
Fuel spill area or dike area	10-100 ft^2	
Ambient air temperature	77-104°F (25-40°C)	
Wind speed or velocity (Uw)	250-600 ft/min	
Distance between fire and target (L)	5-10 ft	

Table 4.45: Output for the model of radiant heat flux from fire to a target fuel.

		Scenario-1				Scenario-2			
Fuel spill area or dike area sq ft		10	10	10	10	15	15	15	15
Wind speed ft/min		200	350	500	600	200	350	500	600
Distance between target and fire		5	5	5	5	5	5	5	5
Flame radiation q"	Kw/m^2	13.18	19.14	22.82	24.70	14.43	21.36	25.46	27.54
	Btu/ft^2	1.16	1.69	2.01	2.18	1.27	1.88	2.24	2.43

		Scenario-3				Scenario-4			
Fuel spill area or dike area sq ft		10	10	10	10	15	15	15	15
Wind speed ft/min		200	350	500	600	200	350	500	600
Distance between target and fire		5	5	5	5	5	5	5	5
Flame radiation q"	Kw/m^2	15.17	22.84	27.18	29.35	15.62	23.92	28.42	30.64
	Btu/ft^2	1.34	2.01	2.39	2.58	1.38	2.11	2.50	2.70

Table 4.45.......

		Scenario-5				Scenario-6			
Fuel spill area or dike area sq ft		10	10	10	10	15	15	15	15
Wind speed ft/min		200	350	500	600	200	350	500	600
Distance between target and fire		10	10	10	10	10	10	10	10
Flame radiation q"	Kw/m²	5.92	7.46	7.65	7.47	7.11	9.83	10.82	11.03
	Btu/ft²	0.52	0.66	0.67	0.66	0.63	0.87	0.95	0.97

Table 4.45.......

		Scenario-7				Scenario-8			
Fuel spill area or dike area sq ft		10	10	10	10	15	15	15	15
Wind speed ft/min		200	350	500	600	200	350	500	600
Distance between target and fire		10	10	10	10	10	10	10	10
Flame radiation q"	Kw/m²	7.90	11.54	13.20	13.81	8.44	12.84	15.01	15.94
	Btu/ft²	0.70	1.02	1.16	1.22	0.74	1.13	1.32	1.40

Table 4.45....

		Scenario-9				Scenario-10			
Fuel spill area or dike area sq ft		10	10	10	10	15	15	15	15
Wind speed ft/min		200	350	500	600	200	350	500	600
Distance between target and fire		15	15	15	15	15	15	15	15
Flame radiation q"	Kw/m²	2.99	3.00	2.62	2.38	3.88	4.37	4.07	3.78
	Btu/ft²	0.26	0.26	0.23	0.21	0.34	0.39	0.36	0.33

Table 4.45......

		Scenario-11				Scenario-12			
Fuel spill area or dike area sq ft		10	10	10	10	15	15	15	15
Wind speed ft/min		200	350	500	600	200	350	500	600
Distance between target and fire		15	15	15	15	15	15	15	15
Flame radiation q"	Kw/m²	4.53	5.58	5.46	5.19	5.02	6.63	6.75	6.56
	Btu/ft²	0.40	0.49	0.48	0.46	0.44	0.58	0.59	0.58

4.8.3 Prediction of temperature jet (T jet) and velocity (U jet) of ceiling jet:

Alpert's ceiling jet correlations predict the temperature and velocity of a ceiling jet if the fire size, ceiling height, and radial distance from the fire are known. These correlations are useful for sprinkler and heat detector response applications

The correlations are based on experimental data collected for fuel with heat release rates ranging from 668Kw to 98MW and ceiling heights ranging from 4.6 to 15.5m.

Table 4.46: input parameters for temperature and velocity of jet modeling

Input parameters	
Mass burning rate of fuel (m")	0.051 kg/m^2-s
Effective heat of combustion	43500 kJ/ kg
Fuel density	760 kg/m^3
Empirical constant	3.6 m^{-1}
Gravitational acceleration	9.81 m/s^2
Ambient air density	1.13- 1.18 kg/m^3
Fuel spill volume	5-50 gallons
Fuel spill area or dike area	10-100 ft^2
Ambient air temperature	77-104°F (25-40 °C)
Heat release rate (Q')	5000-10000 kW
Radial distance from fire(r)	1-5 m
Ceiling height	2-10 m

Table 4.47: output for temperature and velocity jet

Scenario	Input					Output	
	Heat release (Q')	Radial distance of fire (r) m	Ceiling height (H) m	r/H	Ambient temp. T_{amb} (°C)	Ceiling jet gas velocity (m/s)	Ceiling jet gas temperature T (°C)
Scenario-1	5000	0.8	4	0.20	30	8.03	486
	5000	1	4	0.25	30	6.66	423
	5000	2	4	0.50	30	3.74	277
	5000	3	4	0.75	30	2.66	219
	5000	4	4	1.00	30	2.10	186
Scenario-2	5000	0.8	5	0.16	30	8.97	367
	5000	1	5	0.20	30	7.45	344
	5000	2	5	0.40	30	4.18	288
	5000	3	5	0.60	30	2.98	181
	5000	4	5	0.80	30	2.34	154

Scenario-3	10000	0.8	5	0.16	30	11.31	566
	10000	1	5	0.20	30	9.39	529
	10000	2	5	0.40	30	5.27	344
	10000	3	5	0.60	30	3.76	270
	10000	4	5	0.80	30	2.95	228
Scenario-4	10000	0.8	6	0.13	30	11.38	425
	10000	1	6	0.17	30	10.29	425
	10000	2	6	0.33	30	5.77	292
	10000	3	6	0.50	30	4.11	230
	10000	4	6	0.67	30	3.24	195

Provided that an ample supply of oxygen is available, the amount of surface area of the given liquid becomes the defining parameter. The diameter of the pool fire depends upon the release modes, release quantity and burning rate. Liquid pool fires with a given amount of fuel can burn for long periods of time if they have a small surface area, or for short periods of time over a large spill area.

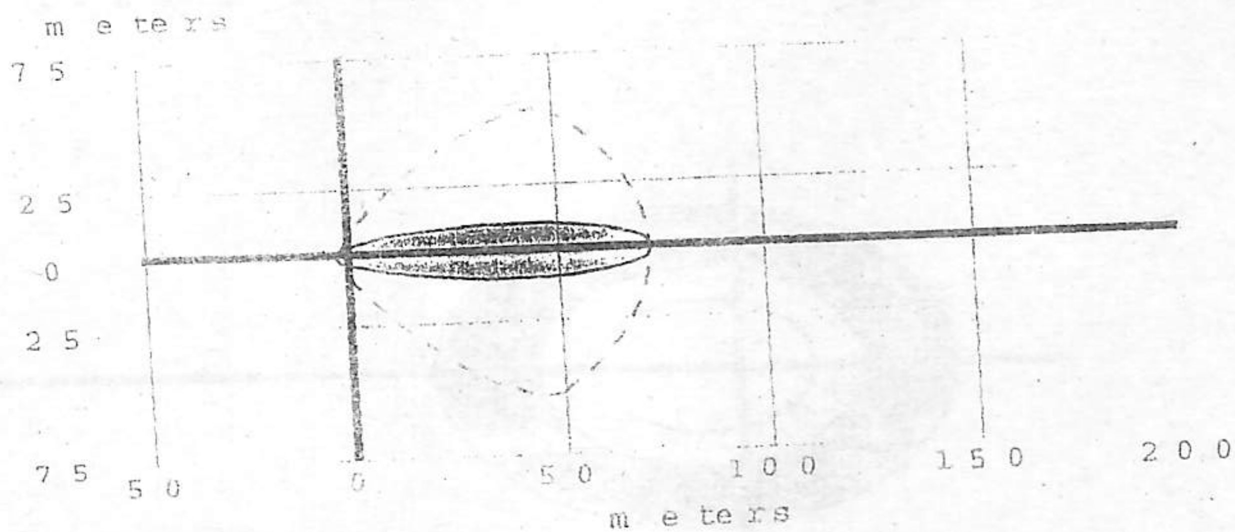
4.9 Results of ALOHA (Arial Locations of Hazardous Atmosphere) model :

The results of the ALOHA model, which was analyzed using a software; specially made for ALOHA model. These are given in the next few pages for different chemical presence in the atmosphere. The results computed in this chapter are discussed in the next chapter.

Component of ATF : BENZENE

Leak from hole in horizontal cylindrical tank (Considering the 30 feet segment of pipeline); Flammable chemical escaping from tank (not burning)

THREAT MODELED : TOXIC AREA OF VAPOR CLOUD (GAUSSIAN)



>= 1000 ppm = ERPG-3 (not drawn)

>= 150 ppm = ERPG-2 (not drawn)

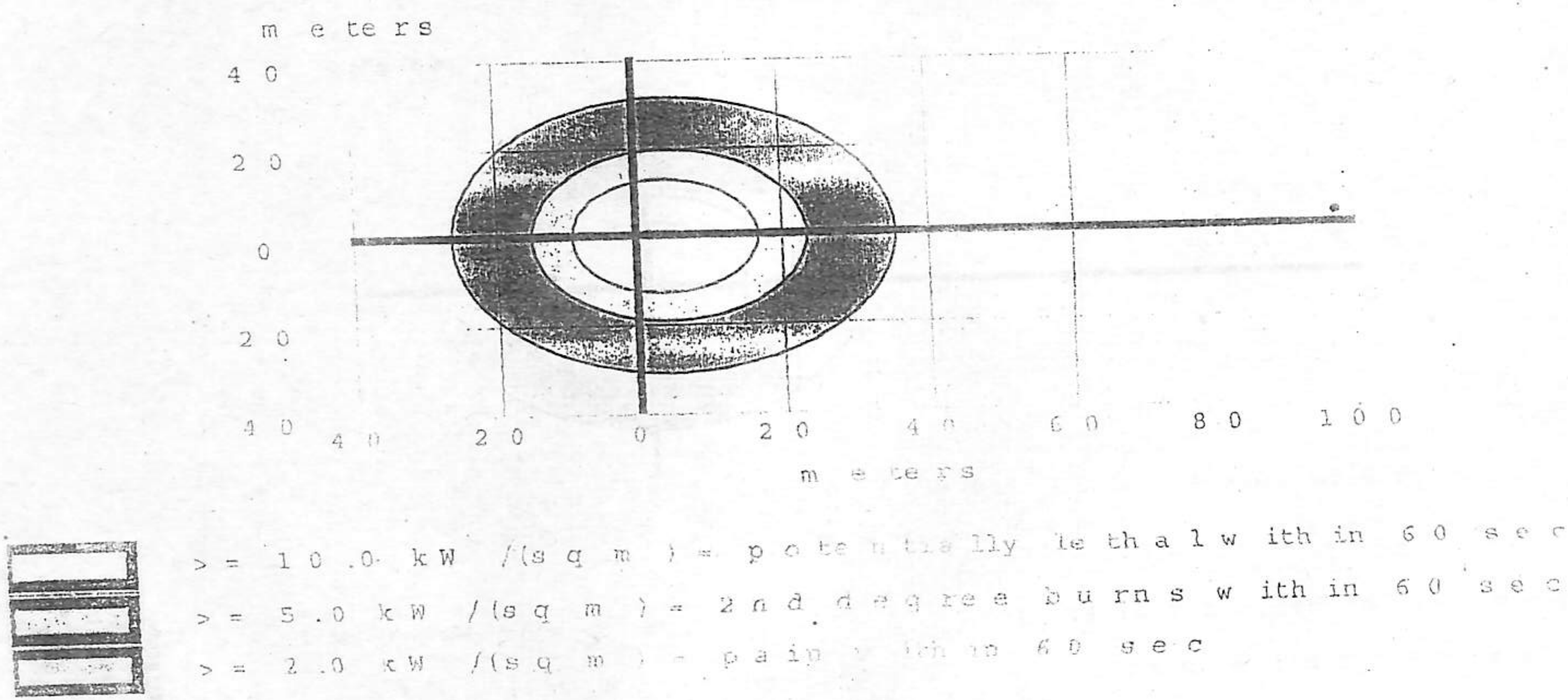
>= 50 ppm = ERPG-1

Confidence Lines

Component of ATF : n-Octane

Thermal Radiation from pool fire (Horizontal cylindrical tank considering the 30 feet long segment of pipeline)

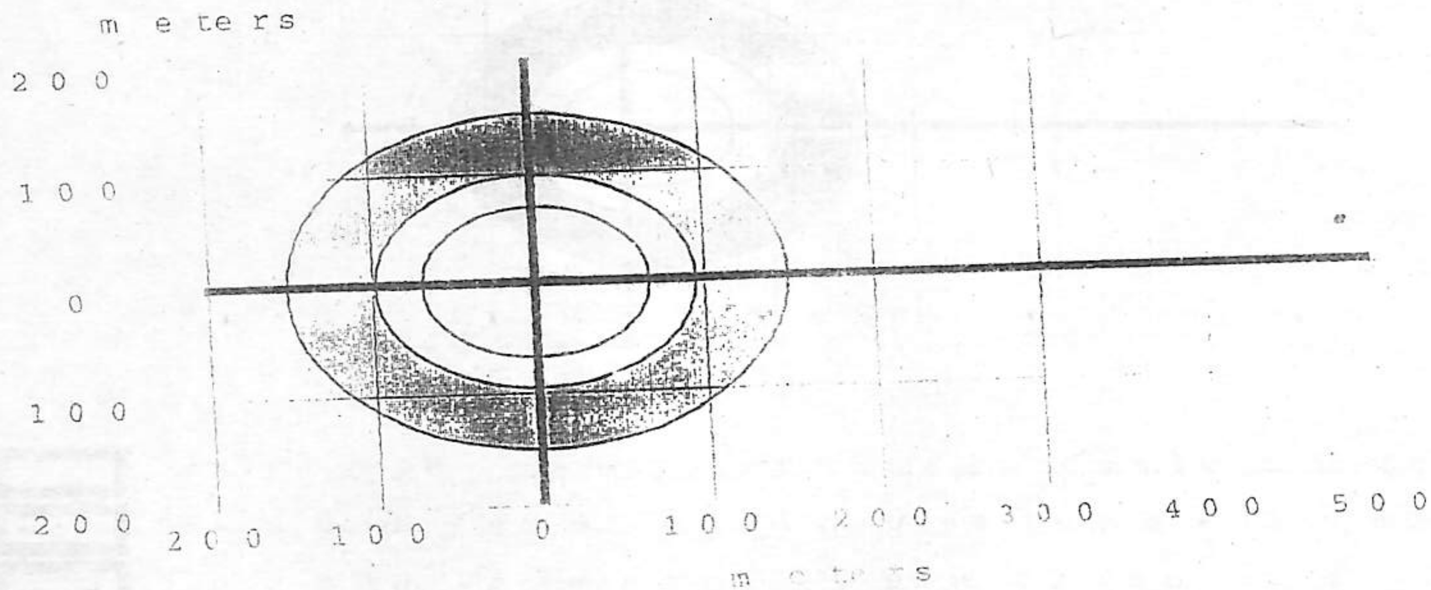
THREAT MODELED : THERMAL RADIATION FROM POOL FIRE (GUASSIAN)



Component of ATF : n-Octane

BLEVE of flammable liquid (Horizontal cylindrical tank considering 30 ft long segment of pipeline)

THREAT MODELED : THERMAL RADIATION FROM FIREBALL (GUASSIAN)



>= 10.0 kW /(sq m) = potentially lethal within 60 sec

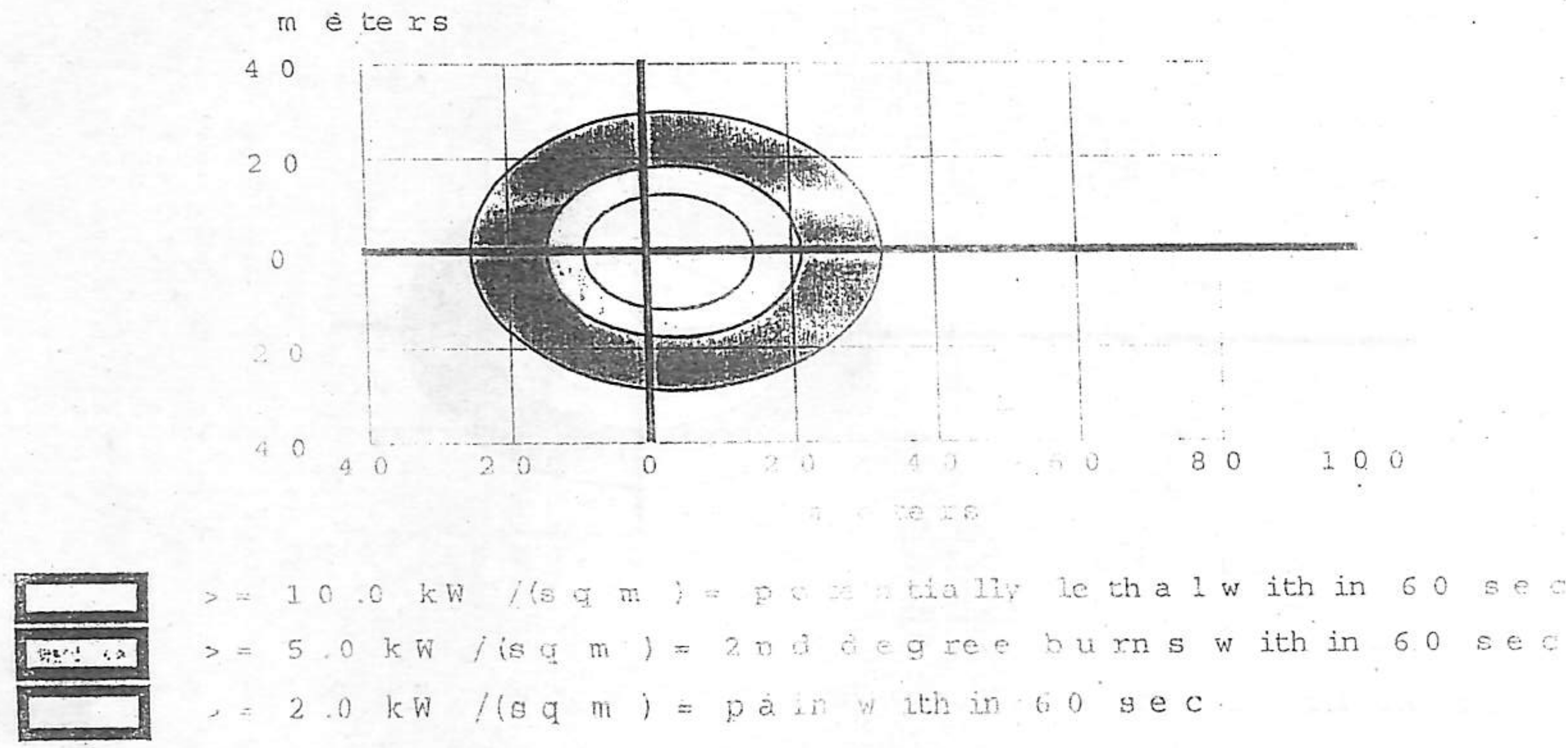
>= 5.0 kW /(sq m) = 2nd degree burns within 60 sec

>= 2.0 kW /(sq m) = pain within 60 sec

Component of ATF : ETHYLBENZENE

Thermal Radiation from pool fire (Horizontal cylindrical tank considering the 30 feet long segment of pipeline)

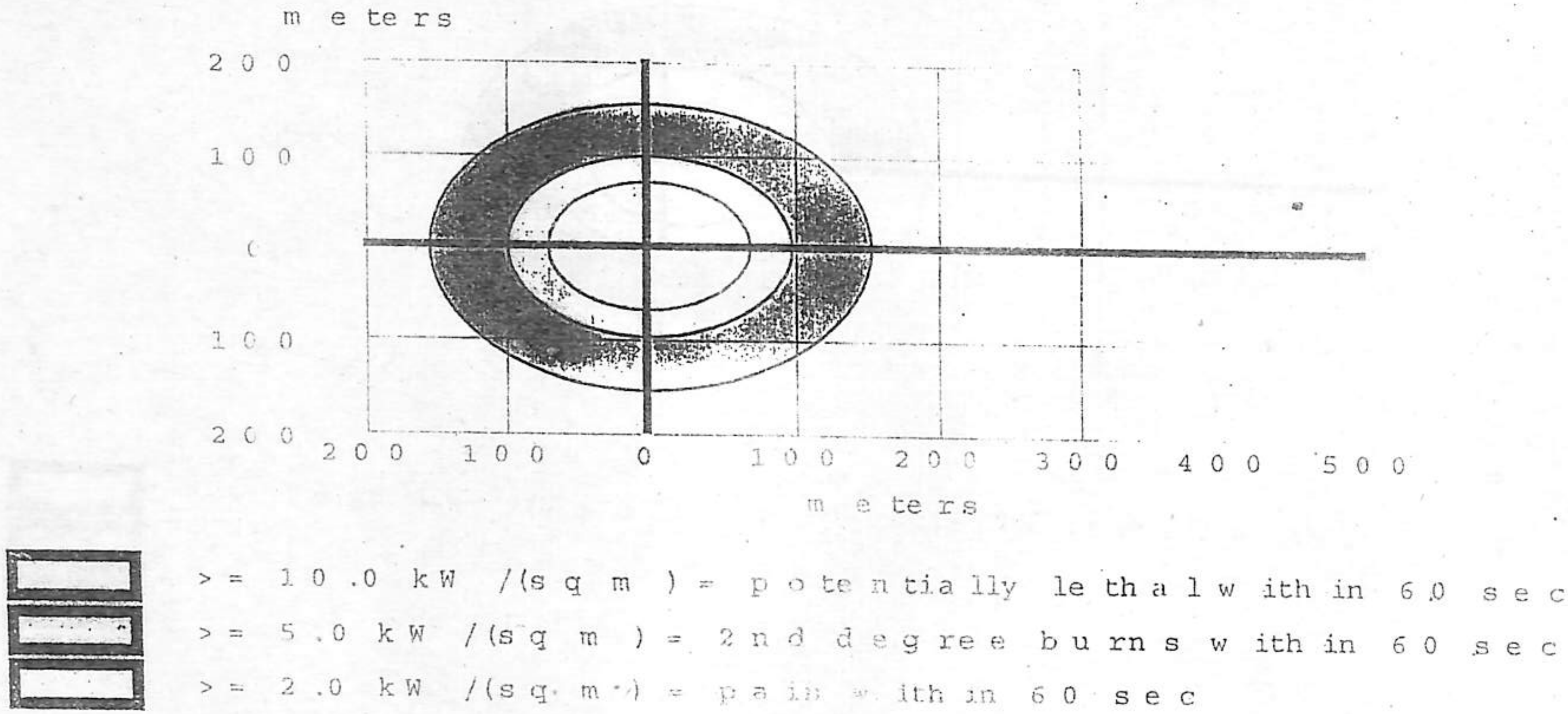
THREAT MODELED : THERMAL RADIATION FROM POOL FIRE (GUASSIAN)



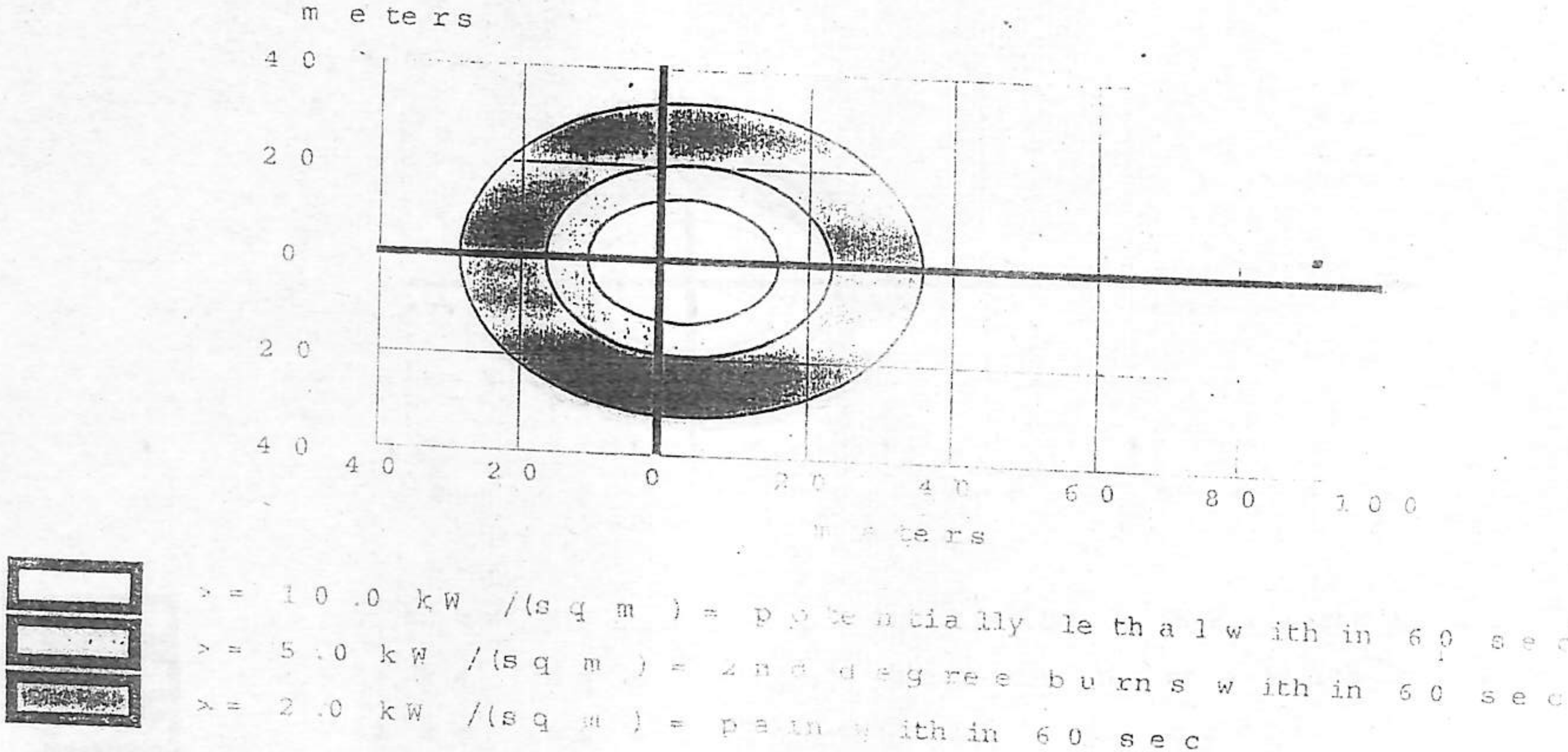
Component of ATF: **ETHYLBENZENE**

BLEVE of flammable liquid (Horizontal cylindrical tank considering 30 ft long segment of pipeline)

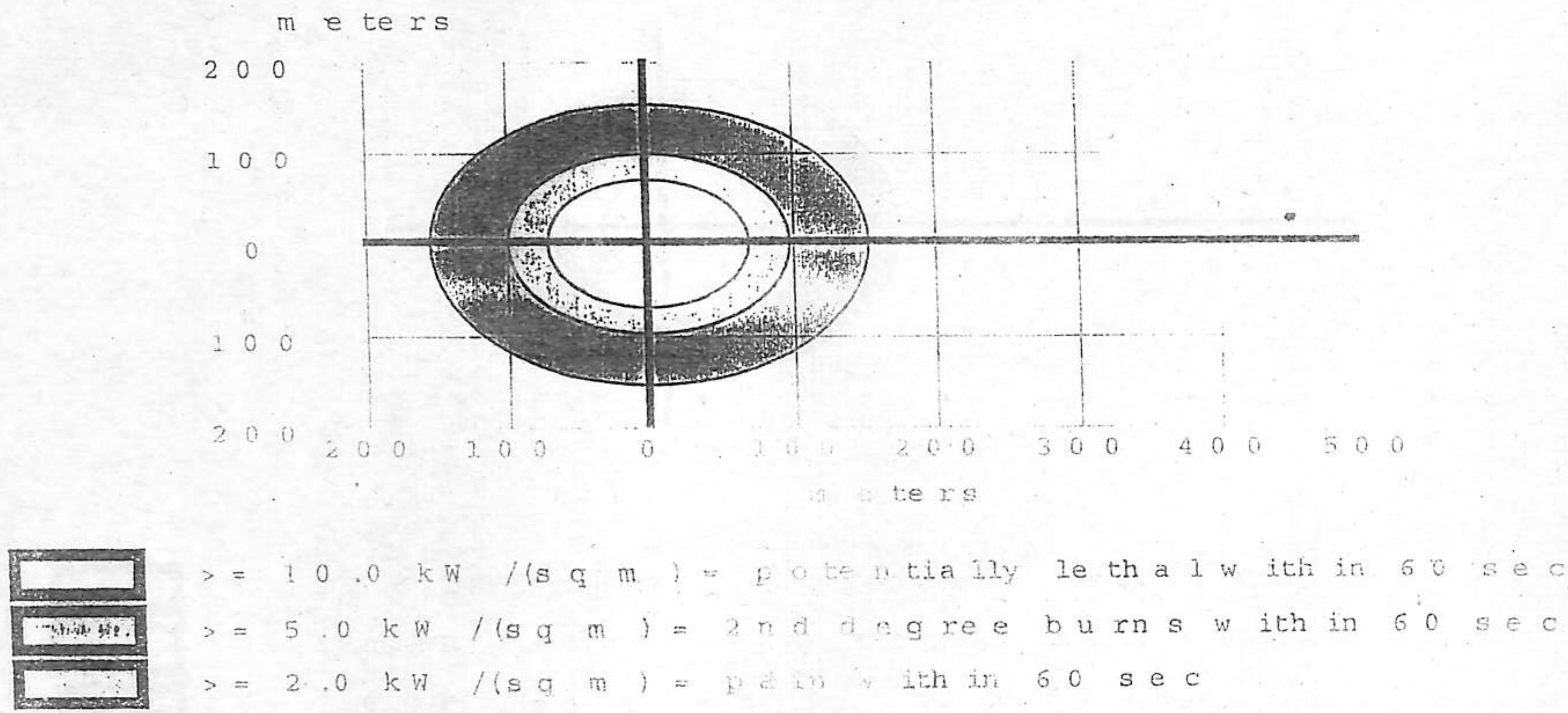
THREAT MODELED : THERMAL RADIATION FROM FIREBALL (GUASSIAN)



Component of ATF : METHYLCYCLOHEXANE
Thermal Radiation from pool fire (Horizontal cylindrical tank considering the 30 feet long segment of pipeline)
THREAT MODELED : THERMAL RADIATION FROM POOL FIRE (GUASSIAN)



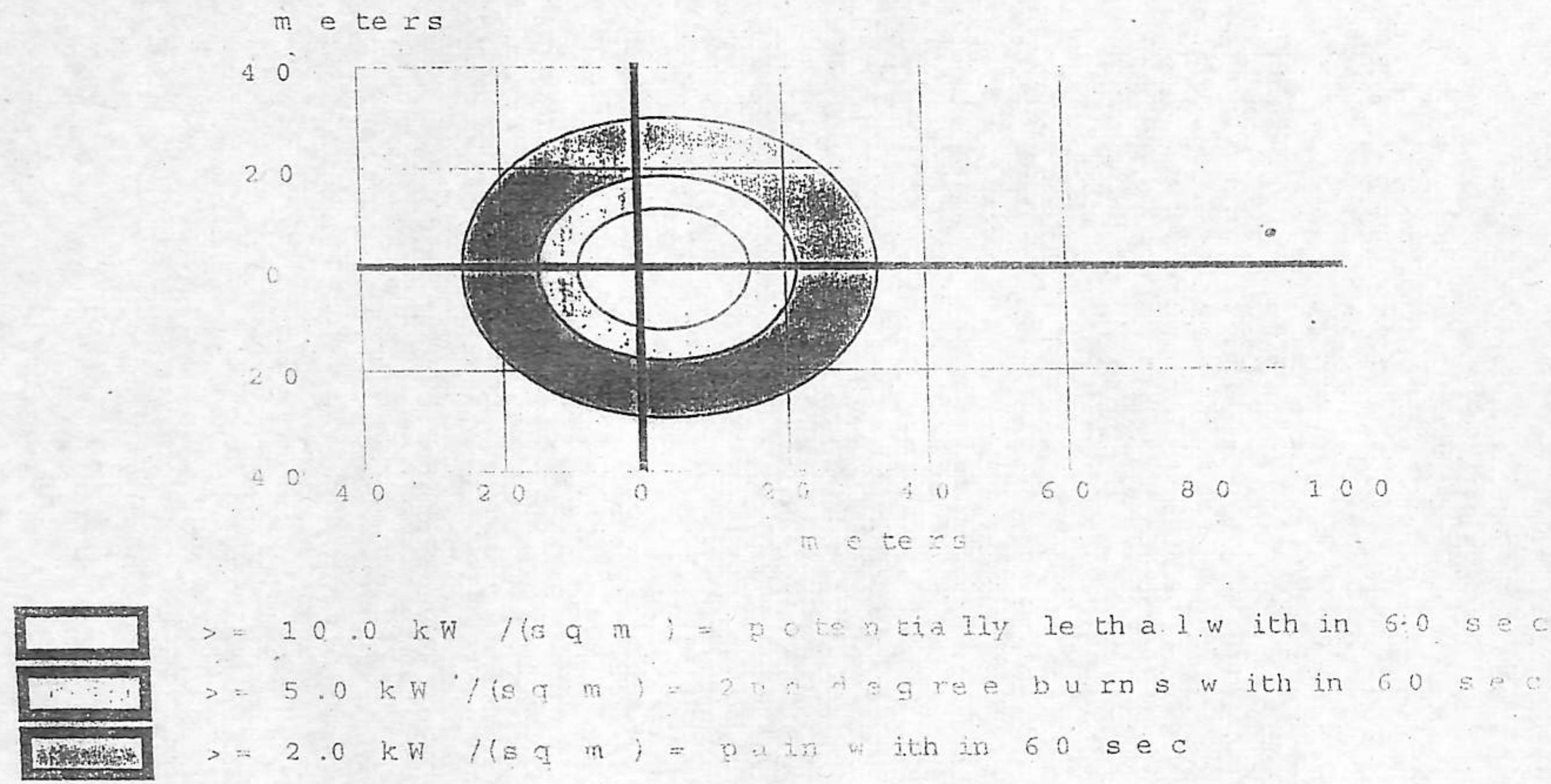
Component of ATF : METHYLCYCLOHEXANE
BLEVE of flammable liquid (Horizontal cylindrical tank considering 30 ft long segment of pipeline)
THREAT MODELED : THERMAL RADIATION FROM FIREBALL (GUASSIAN)



Component of ATF : BENZENE

Thermal Radiation from pool fire (Horizontal cylindrical tank considering the 30 feet long segment of pipeline)

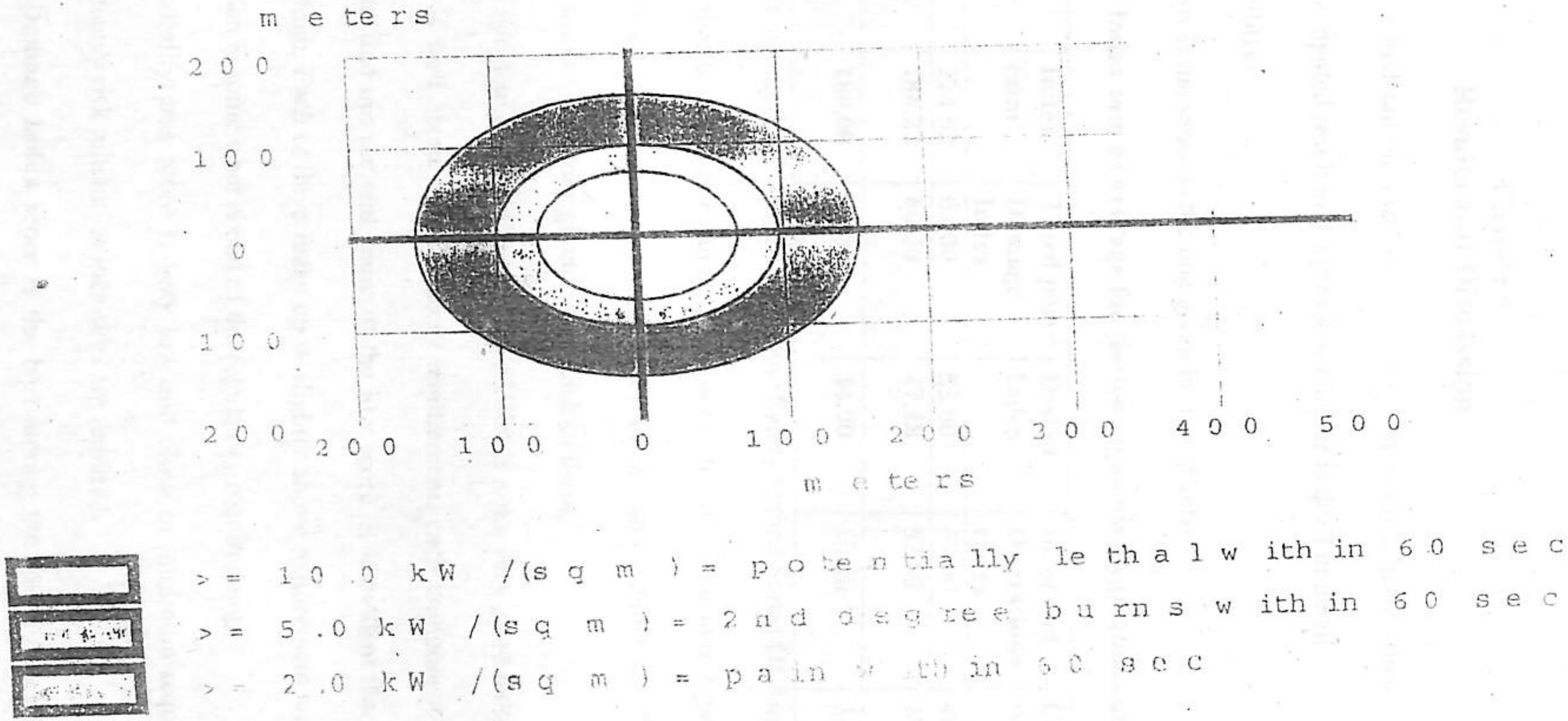
THREAT MODELED : THERMAL RADIATION FROM POOL FIRE (GUASSIAN)



Component of ATF : **BENZENE**

BLEVE of flammable liquid (Horizontal cylindrical tank considering 30 ft long segment of pipeline)

THREAT MODELED : THERMAL RADIATION FROM FIREBALL (GUASSIAN)



Chapter 5
Results and Discussion

This chapter discusses in detail the various inferences from the results and their implications. Each computed result in the previous chapter is dealt in detail.

5.1 Index sum of failure:

The table given below is the same as the one given in last chapter.

Table 4.11 score of Index sum as average for the ten segments (regulations also)

	Index Sum	Third party Damage Index	Design Index	Incorrect Operations Index	Corrosion Index
Overall Average	224.52	64.00	53.00	67.00	40.52
Highest probability Area	188.22	60.20	47.18	52.82	28.02
Regulatory requirement	180.00	52.00	44.00	50.00	34.00

(Requirements as per standards of Office Of Pipeline Safety United States Of America)

It is not only important to make inferences and observe trends in an investigation, but also reasoning the trend observed is a necessity. From the above table the following inferences can be made (with reasons given below each of them)

1)a. **The index sum** is calculated for 400 and 224.52/400 is not a very good indication of safety. Though this is well above the regulatory requirement, each component must be studied thoroughly to find out the real cause of the low score. It is evident that none of the other scores are high. Each of them make up to slightly above requirement and finally add upto a score which is some what ahead of the regulatory requirement.

b. The highest probability area score is very low and close to minimum requirement, indicating that very heavy risk mitigation measures are required.

2) a. **Third party Damage Index** score is the best among the four indices found to compute the index sum. This is because of the fact that the pipeline has been laid few

months before, and the **ROW** is free of any over growth, encroachments etc. the score does not any where match close to the score of a new pipeline(avg 78) meaning that; the ROW has not been prepared aptly for the new pipeline.

b. The score of **depth of cover** is good, but that of **activity level** is low; due to more of class 2&3 locations. This means it is more of a burden to carry out operations in case of an emergency and the impact would be high.

c. **Line location** scores are low due to lack of immediate response (response time = 1 week avg) for calls on the pipeline and damage. Also public are unaware of line location and presence, which may lead to heavy damage in case of uninformed digging etc.

d. **Public education** in general is very poor and the company does not seem to bother much about it. Even the presence of mango trees, were located right on the pipeline in some places. This explains the poor status of the public education score.

e. Finally the poorest part of third party index comes from the **frequency of patrolling.** With lack of awareness among public, the patrolling of the must be done frequently. But it is carried out once a month or even once in two months or more. In developed nations where frequent patrolling is not necessary it is carried out once a week. The score has been given by assuming an optimistic frequency of once a month, even this does not seem practical to Indian oil.

3) **Design index:** The score of the design index is relatively the most pathetic of the four indices. Though the score as seen is well higher than the minimum requirement, and is a very good score; but for the fact that the pipeline is new. This is because a line, which has just been commissioned, must get the closest score to cent percent in design, as its parameters have just been analyzed. But the score says something else.

a. The **safety factor** that has been assumed on the SMYS (0.75 of SMYS) is merely a technical safety factor and is not considered to be of any value from safety point of view. This is the case with most of the third world countries, which want to reduce cost of pipes heavily. The safety factor must allow for a design pressure of 1.5 to 2 times of MAOP. There is also a wrong idea with the design agency of the pipeline owner (IOC itself) that heavy walled pipe leads to more stress and creep, leading to pipe fracture.

b. The score of fatigue is high as the line has hardly gone through any of the fatigue –load cycles. The **surge potential** score is also high due the fact that surge is a rare probability is a line of design pressure of 250Psi, having practically on difference in static head between sending and receiving ends.

c. The score for **integrity verification** is also high as the hydrostatic tests on the different sections being assessed, was carried out very recently before commissioning. The **earth movements** have been assigned a mediocre score, bearing in mind the large distance from the epicenter of geographical movement in southern Maharashtra (Sholapur) and also the history of a quake and the tsunami that have hit the region.

4) **Incorrect Operations Index:** The score of the incorrect operations index is good and acceptable as compared to the regulatory standards. This also can be attributed to the fact that a new pipeline has very little history of mal-operations and accidents/failures. Still reasons for the relatively unsatisfactory score is follows:

a. **Design** of the line is not carried out with deep analysis every for every new line, which makes the design lack features suit the particular line being designed. It is more of tradition and monotony of formulae used in the design of every line without acquiring formal data, which is vital for the production of a fool proof and robust design. Also the design documents are never made available to many of the personnel who requires the vitally. Even the risk consultant had to make up it's own estimate of design of the design for assessment.

b. In the case of **construction activities**, which score the lowest in the index, the following were the problems:

- Pronounced **weld defects** of same type has been found from same welder, but has been ignored as the person certified radiographic films was an amateur and not aware of a particular problem, though well versed with others.
- **Back filling** was not done properly. Sand padding was just a ritual; rock shield was not given in all rocky area. Also roots of trees found in the trench were not removed. Even very big trees which were so close that, most of their roots were near the pipe (inside trench) were not bothered to be removed as the permission of forest department was necessary.
- The **handling** of pipes after welding was very poor. Even the engineers could not foresee the implications of stresses induced in the joints during pipe lifting. People were observed to state their own theory that "pipes are very very flexible".
- **Coating**, specially the **joint coating** was unsatisfactory, with pathetically bad sand blasting and surface preparation.

c. The **operations and maintenance** part was highly satisfactory; but for bad up keep and availability of records, maps, manuals at the right place. Also some events are not logged properly to avoid acceptance of responsibility from operator's side. Also employees are not aware of even minimal programs on safety and risk.

5) **Corrosion index:** The score of corrosion index is also an acceptable one. Normally the score is lower pipelines under operation. But for this pipeline, which can barely be considered to be operating, the low score has to attributed to the right reason to prevent failures, for which corrosion is the best-known cause in the industry.

a. The scores indicate that chances for atmospheric corrosion is high due to presence of marine climatic influence. Also the assessed stretch has a marine swamp having high salt concentration. The humidity in the region is also high.

b. Major weightage has been given to subsurface corrosion, as this the major contributor to failure. This is not consistent with the Muhlbauer model but may be an extension of it. This assumes significance, as the soil score is not satisfactory because of the fact that the soil is wet and salty for a major chunk of the length on the CPCL side. This makes the soil highly conductive on top through the bottom, making the pipe prone to corrosion. Also the water table in this region is high.

c. The score for cathodic protection is high because the line is new and enough time is required to assess the real capability of the system. But presently it provides a very good picture. Only the fact that the telluric currents at railway crossings (6 numbers) were not assessed during design, but have been found during risk analysis is a matter which requires to be looked into.

d. The product corrosivity is very low, leading to a high internal corrosion score. But externally the coating has obtained a bad score because of poor know-how about the new DFBE coating. The handling has caused heavy damage to coating but lack of training in using the repair fluid has resulted in defects being left behind. Also the holiday testing was done very poorly as the joints, which were coated by CTE (Ray chem. Sleeve) required 12KV but the pipe coating required 5KV. This was practically difficult to implement, as applying 12KV on the pipe would damage coating. Also in some places lack of training must have damaged the coating due to holiday detection, as wrong voltages were applied around the pipe; but these were left undetected. These facts may come to light after a few years of coating service.

As we have discussed the implications of the various indices the counter action necessary to reduce risk is to be decided. These have been suggested in the last section of this chapter.

5.2 Failure mode and effect analysis (FMEA):

The FMEA analysis provides very little scope for discussion on results, as it is basically data estimation for failures from historical records. Only they help in failure probability calculations and they indicate the frequency. The analysis in our case has resulted in tables 4.12 to 4.15. They indicate that failure frequency is independent of the pipeline as a whole. But they can be associated with the failure frequency of different equipment in the system and their numbers.

5.2.1 Fault tree analysis:

The fault tree given in diagram 4.1 indicates that the maximum probability of failure rests with the control valve. But the failure rates of flanges, etc are low. Hence we can infer that material spillage probability is low because it is most probable that the hazard is detected by the safety/detector system.

Also it indicates that a pipeline burst (very low probability) may not lead to a catastrophic failure (probability extremely low) but it would be under control as it may be attributed to a material defect (low probability) or corrosion (high probability).

5.3 RBI matrix:

The RBI matrix classifies the hazards related to pipelines on 3 different hazard scales. This matrix can be used to fit in any type of identified hazard with the help of the consequence table (4.16). The results of the matrix indicate that the areas in bold pose a major hazard and they require immediate attention. Also we can understand that if the matrix considers the whole project, then there are always some parts of the project which constitute high risk areas.

5.4 Estimation of consequences:

The discussions that follow from now, discuss the consequence part of risk involved in the pipeline. This allows us to foresee the measures required to taken, to reduce risk.

5.5 DOW index & fire and explosion indices.

The results of the DOW index calculation are a material factor, general process hazard factor, the fire and explosion index and the damage radius.

The material factor is:	**16**
The general process hazard factor is:	**3.25**
The special process hazard factor is:	**12.502060**
The unit hazard factor is:	**8**
The fire and explosion index is:	**128**
The radius of exposure is(m)	**32.772096**
The damage factor is:	**0.5801638**
The consequence	**1E+1* 128 =1280**

The inference from the DOW index is given in the following table:

Table 5.1: DOW index- degree of hazard. (courtesy: DOW Chemicals Ltd)

Degree of hazard	Fire and explosion index
Light	0-60
Moderate	61-96
Intermediate	97-127
Heavy	128-158
Severe	>159

The results of DOW index analysis indicate that the degree of hazard involved in the pipeline is heavy. The radius of exposure of the consequence suggested by the result (32 m) is very large as it covers up an area of almost 2000 sq m. This warrants the need of fire hazard analysis and also heavy mitigation measures to reduce risk due to fires in this area. In case of a pipeline, these areas may constitute any type class location. So enough planning of emergency is highly important. Also the various causes specific to fire and their consequences need to be studied in detail. The following is a description of the result of the pipeline leak scenario, which is the most major contributor to fire hazard. The consequence contributors of DOW were analyzed and their results are presented below.

Table 5.2: summarization of vapor cloud explosion & mass flow.

Fire & explosion parameters	**Type of leak**		
	Rupture	Major	Minor
The frequency of a vapor cloud explosion for gases or fire for liquids is (occ/yr)	0.76	8.55	9.5
The mass flow rate through the leak is (kg/s)	54.08	5.408	0.5408

The table given above gives us an idea of the probable consequence of fire caused by the most probable types of leaks. The results clearly indicate that as the magnitude of the leak increases the mass flow rate increases but the frequency of occurrence and also the probability decreases.

5.6 Discussion on various scenarios(burning characteristics of pool fire).

Refer various scenarios in table 4.38.

Scenario-1:

Say the fuel spill volume is 5 gallons and fuel spill area is 10 sq ft and ambient temperature is in the range of 86-104 °C.

Pool fire diameter is calculated as 1.09 sq m., heat release rate is 2019.97 kW (1914.57 Btu/s); burning during is estimated as 303.60s and pool fire flame height is calculated as 12.55ft by Heskestad method & 10.80ft by Thomas method.

Scenario-2:

Say the fuel spill volume is 10 gallons and fuel spill area is 20 sq ft and ambient temperature is in the range of 86-104 °C.

Pool fire diameter is calculated as 1.54 sq m., heat release rate is 4105.88 kW (3891.63 Btu/s); burning during is estimated as 303.60s and pool fire flame height is calculated as 16.35 ft by Heskestad method & 13.74 ft by Thomas method.

Scenario-3:

Say the fuel spill volume is 25 gallons and fuel spill area is 50 sq ft and ambient temperature is in the range of 86-104 °C.

Pool fire diameter is calculated as 2.43 sq m., heat release rate is 10303.64 kW (9766.00 Btu/s); burning during is estimated as 303.60s and pool fire flame height is calculated as 22.92.55ft by Heskestad method & 18.89 ft by Thomas method.

Scenario-4:

Say the fuel spill volume is 50 gallons and fuel spill area is 100 sq ft and ambient temperature is in the range of 86-104 °C.

Pool fire diameter is calculated as 3.44 sq m., heat release rate is 20610.45 kW (19535.0 Btu/s); burning during is estimated as 303.60s and pool fire flame height is calculated as 29.48 ft by Heskestad method & 24.03 ft by Thomas method.

These can be summarized as follows:

HRR as well burning duration is dependent on the on the surface area of fuel spillage. Higher the volume and area, higher is the HRR.

For a given amount of fuels spills with a large surface area burn with a high HRR for a short duration, and spills with a smaller surface area burn with a lower HRR for a long duration.

5.6.1 Estimation of centerline temperature

The pulsating behavior of a flame affects its temperature. The temperature varies across the width and height of the flame and temperature at a fixed position will fluctuate widely, particular around the edges and near the top of the flame. Therefore, any discussions of flame temperature, usually involved reporting the centerline temperature or average flame temperature, which is determined by determined by measuring the temperature at different times and different times and different locations within the flame. Refer table 4.40 for values of centerline plume temperature. Consider the HRR between 200-700kW; elevation above the fire source is 10-15ft and area of combustible fuel is 15-25 Sq ft. ambient temperature is 104 F. As indicated, the centerline temperature of buoyant fire plume, it is clear that for lesser height and lesser area, the temperature is higher even if HRR is low. In case of wider area and more height, centerline temperature is less even if HRR is more.

5.7 Radiant heat flux from fire to a target fuel.

Fire normally grows and spreads by direct burning, which results from impingement of the flame on combustible materials or from heat transfer to other combustibles by means of conduction, convection, or radiation. All three of these modes of heat transfer may be significant, depending on the specifics of a given scenario. Conduction is particularly important in allowing heat to pass through a solid barrier to ignite material on the other side. Nevertheless, most of the heat transfer in fires typically occurs by means of convection and/ or radiation. Refer table 4.42. The following are clearly evident from the table:

Radiant flux (Btu/ sq ft.)

- Increases with the increase in fuel spill area.
- Increases with the increase in wind speed.
- Decrease if the distance between fire and target increases.

5.8 ALOHA model:

The ALOHA model signifies the hazard caused by different components present in the hazardous liquids and there by tries to estimate their consequences separately, to rank them in their order of hazard. Aloha (Arial locations of hazardous atmospheres) model predicts how a hazardous gas cloud disperses in the atmosphere after accidental chemical release. ALOHA can predict rates of chemical release from broken pipes, leaking tanks and evaporating puddles, can model the dispersion of both neutrally and heavier than air gases. ALOHA is based on a continuous point source with a Gaussian plume distribution. The results of ALOHA show that the maximum consequence area can be even roughly 50m radius and more. This is almost an area of more than 7500 sq m. The population in this area is going to suffer at least pain or lateral health effects. This analysis can be helpful in predicting where extra isolation valves are required.

The transmission pipeline safety record has been improving over time. Liquids pipelines have the best safety record of any mode, where transport options exist, for moving petroleum and other hazardous liquid products. Human casualties, property loss, and environmental damage resulting from pipeline incidents are infrequent, but when they do occur the consequences can be significant. For example, a 2002 liquids pipeline incident In Agumbe, Karnataka (MHBPL – HPCL & Petronet) resulted in the release of 2000 kL of SKO into a field in the middle of the town. The diesel ignited, killing three, injuring eight, and causing roughly RS 45 million in property damage. Such incidents, along with population growth, urbanization, a growing demand for energy, and increased public opposition to the siting of new pipelines, have combined to focus greater attention on the need for increased land use controls in the vicinity of pipelines and led to this study.

The purpose of this scoping study is to consider the feasibility of developing risk-informed guidance as one means of minimizing or mitigating hazards and risk to the public, pipeline workers, property, and the environment near existing and future transmission pipelines.

5.9 Confidence Limits

Confidence limits or intervals are commonly used in association with statistical calculations. Available data are a sample used to estimate characteristics of the overall population—all possible data including future measurements. The sample data can be used to calculate a point estimate, such as a mean value or the average leak rate in leaks per Km per year. A point estimate approximates the value for the entire population of data, termed the "true" value. However, this approximation is affected by the uncertainty in the sample data set. A confidence interval bounds the uncertainty associated with the point estimate. For example, a 95 percent confidence interval for the leak rate has a 95 percent probability of including the true leak rate.

When the number of data points available is small, the confidence limits are wide, indicating that there is not enough information available to be confident that all future data will be close to the small data set already obtained. Data on pipeline failure rates are limited. Hence, the use of upper limits of statistical confidence intervals, especially at a high, 95 percent confidence level, would not present meaningful representations of true failure potential. It will present unrealistically large predictions, strictly as a result of the small number of data points available. Such predictions do not represent best estimates of failures. It may be theoretically correct to say, for example, that "one can be 95 percent confident that there is no more than a one in ten chance of a spill in this area" as a result of a statistical confidence calculation on limited spill data. However, the *best* estimate of spill probability might be only one chance in a thousand. In the EA, the future leak probabilities are estimated using the mean historical leak frequencies. In most engineering calculations, the mean values of those factors that have been derived from historical data are most often chosen as being the most likely to be predictive of future performance. An alternative to the normal calculation of confidence intervals or bounds about the mean leak frequency is available for instances where the data set is very small.

Case study(examples of confidence level calculation)

Confidence Intervals about the Leak Frequency, f

Case A: Last 10 years of Operation
Pipeline Length = 449.67 miles
Number of Leaks = 8

n = pipeline mile-year combinations
= 4496.7

for 8 occurrences, values of G from Table A.25 in Hahn & Meeker are:

G for 95% lower confidence bound = 3.454
G for 95% upper confidence bound = 15.76

Upper confidence bound = G (upper) / n
Lower confidence bound = G (lower) / n

Applying this method to Case A gives

Leak frequency	=	0.00178 leaks/mile/year
Lower 95% confidence limit	=	0.00077 leaks/mile/year
Upper 95% confidence limit	=	0.00350 leaks/mile/year

Case B: Last 29 years of Operation
Pipeline Length = 449.67 miles
Number of Leaks = 26

n = pipeline mile-year combinations
= 13040.43

for 26 occurrences, values of G from Table A.25 in Hahn & Meeker are:

G for 95% lower confidence bound = 16.98
G for 95% upper confidence bound = 38.10

Upper confidence bound = G (upper) / n
Lower confidence bound = G (lower) / n

Applying this method to Case B gives

Leak frequency	=	0.00199 leaks/mile/year
Lower 95% confidence limit	=	0.00130 leaks/mile/year
Upper 95% confidence limit	=	0.00292 leaks/mile/year

5.10 Quantitative Analysis of a suggested risk mitigation methodology:

We can get the probability of fatality $\frac{r}{\sqrt{Q}} = e^{\frac{12.73 - P_r}{6.8}}$ and check the corresponding death probability P from the probability unit P_r using Table 2[8]. The relation between $\frac{r}{\sqrt{Q}}$ and P is shown in Fig.2.

Table 5.3: Relationship of probability unit and probability of death

Death	0	1	2	3	4	5	6	7	8	9
0	—	2.67	2.9	3.1	3.2	3.3	3.4	3.5	3.5	3.6
10	3.7	3.77	3.8	3.9	3.9	3.9	4.0	4.0	4.0	4.1
20	4.1	4.19	4.2	4.2	4.2	4.3	4.3	4.3	4.4	4.4
30	4.4	4.50	4.5	4.5	4.5	4.6	4.6	4.6	4.6	4.7
40	4.7	4.77	4.8	4.8	4.8	4.8	4.9	4.9	4.9	4.9
50	5.0	5.03	5.0	5.0	5.1	5.1	5.1	5.1	5.2	5.2
60	5.2	5.28	5.3	5.3	5.3	5.3	5.4	5.4	5.4	5.5
70	5.5	5.55	5.5	5.6	5.6	5.6	5.7	5.7	5.7	5.8
80	5.8	5.88	5.9	5.9	5.9	6.0	6.0	6.1	6.1	6.2
90	6.2	6.34	6.4	6.4	6.5	6.6	6.7	6.8	7.0	7.3
99	7.3	7.37	7.4	7.4	7.5	7.5	7.6	7.7	7.8	8.0

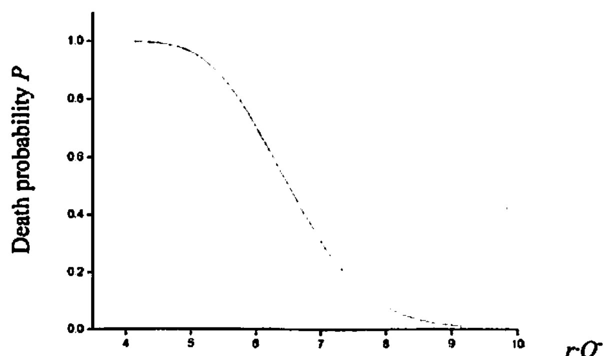


Fig 5.1 Death probability from fire of petroleum product

Death probability from jet fire depends on the distance from fire and gas release rate, and individual risk can be got by multiplying the pipeline failure probability and the death probability at a specified location. To social risk, the number of death can be computed by the number of people in the death zones and the corresponding death probability. As shown in figure.2, the death zones can be divided into three zones with the death probability ranging from 1% to 50%, 50% to 99%, 99% to 100%[9], the number of death $N_{a\text{-}b}$ in each zone can be multiplied by the average death probability and the number of people in the area with the radius r_{99}, r_{50}, r_1 and pipeline failure point as the origin. The radius of fatality 99, 50, 1% can be got from equation (3), the corresponding probability unit P_r is 7.33, 5, 2.67.

$$r_{i,99}=\sqrt{21.3Q} \qquad r_{i,50}=\sqrt{42.3Q} \qquad r_{i,1}=\sqrt{83.9Q} \qquad \text{(E5.1)}$$

Where $N_{a\text{-}b}$ is the number of death in the zone corresponding to the a%-b% death probability, the average death probability in three death zones are shown in Fig.2.

$$\frac{\int_0^{\sqrt{21.3}} P d\bar{r}}{\int_0^{\sqrt{21.3}} d\bar{r}} \approx 1 \qquad \frac{\int_{\sqrt{21.3}}^{\sqrt{42.3}} P d\bar{r}}{\int_{\sqrt{21.3}}^{\sqrt{42.3}} d\bar{r}} \approx 0.804 \qquad \frac{\int_{\sqrt{42.3}}^{\sqrt{83.9}} P d\bar{r}}{\int_{\sqrt{42.3}}^{\sqrt{83.9}} d\bar{r}} \approx 0.154 \qquad \text{(E5.2)}$$

$$\text{N}=N_{100-99}+N_{99-50}+N_{50-1}\approx\rho(A_{100-99}+0.804A_{99-50}+0.154A_{50-1}) \qquad \text{(E5.3)}$$

Where $A_{a\text{-}b}$ is area of the three zones with death probability from a% to b%.

The computation procedure of individual risk and societal risk is shown in Fig.5.2.

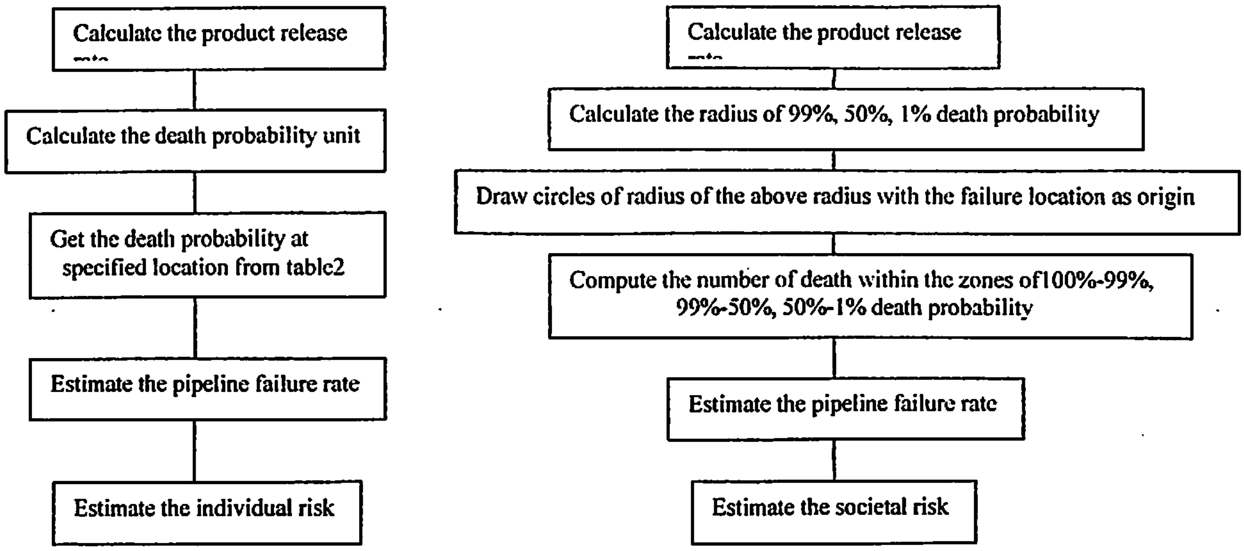


Fig.5.2 Procedure to calculate individual risk and social risk of a LP pipeline

Case study of

There is a pipeline in the city of Hingoli (NW Andhra Pradesh) with diameter 500 mm, operating pressure 0.3 MPa, cover depth 100 mm passing through a area with area 1 km×1 km, population density 2500 persons/km^2 in a city. Product leaks from a hole with diameter 60 mm and the failure is due to the third party interference.

$$P_0/P=1.01325\times10^5/0.3\times10^6=0.34$$

$$(\frac{2}{\gamma+1})^{\frac{\gamma}{\gamma-1}} = (\frac{2}{1.32+1})^{\frac{1.32}{1.32-1}} = 0.542$$

$$\frac{P_0}{P} \le (\frac{2}{\gamma+1})^{\frac{\gamma}{\gamma-1}},$$

$$Q = C_d A P \sqrt{\frac{M\gamma}{RT}(\frac{2}{\gamma+1})^{\frac{\gamma+1}{\gamma-1}}} \square 60.29(\text{kg/s})$$

$$r_{99} = \sqrt{21.3Q} = 35.84,\ r_{50} = \sqrt{42.3Q} = 50.50,$$

$$r_1 = \sqrt{83.9Q} = 71.12$$

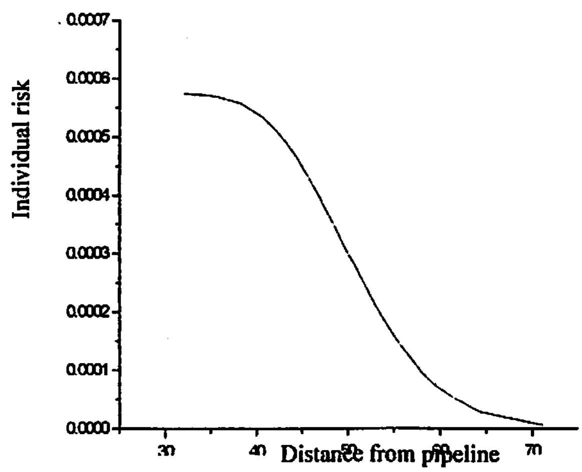
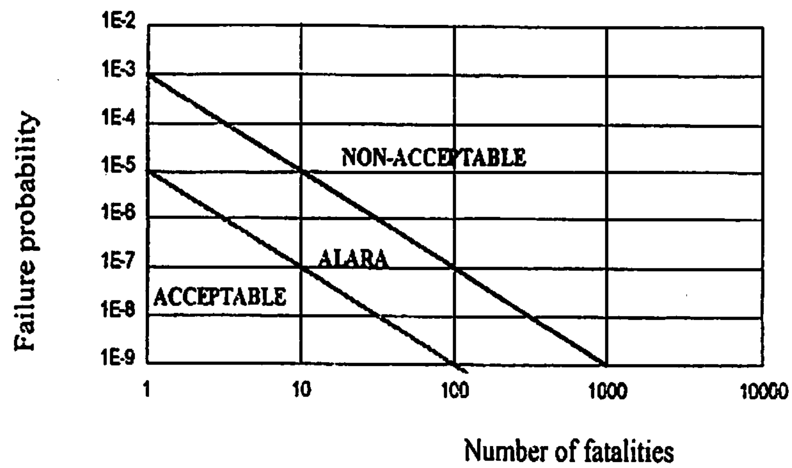


Fig.5.3 Calculation outcome of individual

From the computation outcome in Fig.3, we can determine the corresponding safety distance to protect people from injury when the pipeline failures to bring fire or explosion. The pipeline safety distance can be seen as 72 m according to the acceptable criteria of individual risk 10^{-6}.

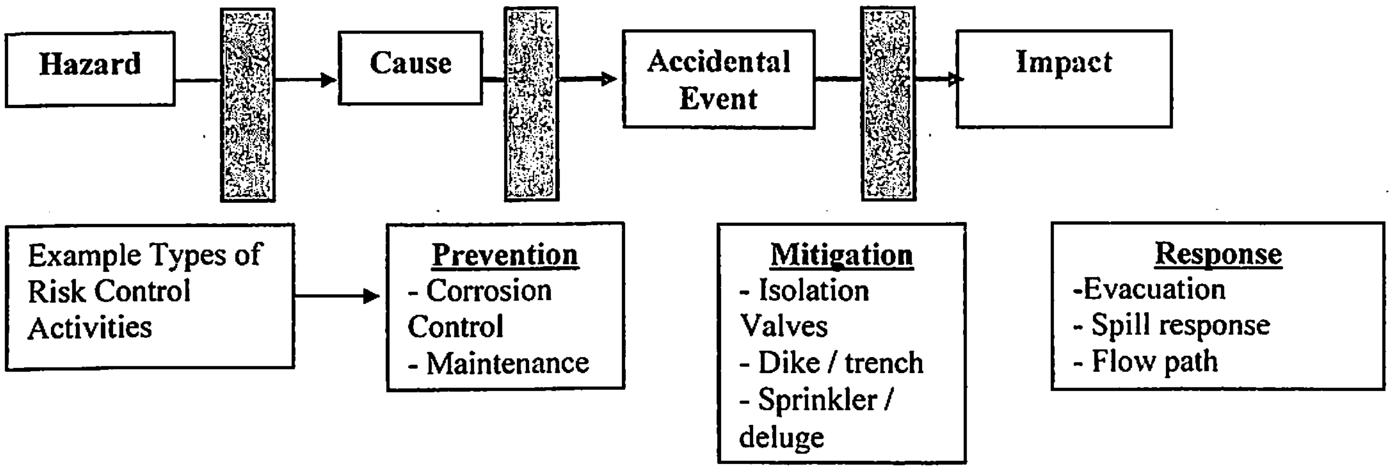
$N=N_{100\text{-}99}+N_{99\text{-}50}+N_{50\text{-}1}=\rho(A_{100\text{-}99}+0.804A_{99\text{-}50}+0.154A_{50\text{-}1})=21.1$; $F/N=1.8\times10^{-5}$. The social risk of the pipeline can be seen as ignorable due to social risk criterion as shown in Fig.5.4.



Hence this curve called FN curve can be used to mitigate risk by identifying the areas of high fatality accident rate and also determining the level of acceptability of fatalities. This has been used as the best-known method of risk mitigation by many consultants and companies world over.

The suggested graphical representation has been previously covered under the results of the ALOHA model(refer.).

Figure 5.5 General risk mitigation and performance Measures Associated with Stages of a Pipeline Incident



Health risk to pipeline construction workers

Table 5.4: health risk to construction workers.

Summary of Stack Parameters

Activity	Acute Risks		HARP Output: 70-Year Cancer Risk[b]	Duration of Activity (days)	Risk Adjustment Factor[c]	Long-Term Risks	
	Acute Risk Hazard Index	Significance Level[a]				Adjusted Cancer Risk[d]	Significance Level[a]
Trenching	0.246	1.0	4.55E-05	180	0.0070	3.2E-07	1.0E-06
Pipelay	0.265	1.0	1.49E-05	180	0.0070	1.0E-07	1.0E-06
Shore Crossing	0.241	1.0	7.53E-05	60	0.0023	1.8E-07	1.0E-06
Drilling	0.070	1.0	9.57E-06	30	0.0012	1.1E-08	1.0E-06

Given above is a table providing the risk associated with workers. This is a standard followed in western countries. Hardly any assessment towards health risk was carried out before getting clearances. Hence nothing has ever been done to mitigate the risk.

5.11 Findings

Finding 1. Pipeline incidents have potential for significant impact on life, property, and the environment.

According to Ministry of Environment and Forests data, during the 6-year period 1999 through 2004, an annual average of 14 reportable hazardous liquids transmission pipeline incidents1 occurred, resulting in 2 deaths, 11 injuries, and RS 97 million in property damage. During the same time period, an annual average of 33 reportable natural gas transmission pipeline incidents occurred, resulting in 6 deaths, 10 injuries, and RS 20 million in property damage. In the 1990s it was estimated that more than 620 kL of oil and other hazardous liquids have been released into the environment. Although no comprehensive studies have yet estimated the environmental damage caused by pipeline spills in India, there are numerous examples of the effects of individual spills on the environment.

Finding 2. Just as transmission pipelines pose a risk to their surroundings, so does human activity in the vicinity of pipelines pose a risk to pipelines. These risks increase with growth in population, urban areas, and pipeline capacity and network.

The demand for natural gas and petroleum is projected to increase by 36 percent between 2010 and 2015. Thus, more pipelines will be required to serve growing as well as mature areas. With increasing urbanization and land development activity near transmission pipelines as well as the addition of new facilities to serve growing populations, the probability that pipelines will be damaged by human activities in the pipeline rights-of-way may also increase. In addition, if there is an incident, more people may be affected because more people may be living and working near the pipeline who have the potential to be injured or killed. This will exacerbate the consequences of an incident.

Finding 3. Land use decisions can affect the risks associated with increased human activity in the vicinity of transmission pipelines.

Finding 4. Pipeline safety and environmental regulation have generally focused on (*a*) the design, operation, and maintenance of pipelines and (*b*) incident response. They have not directed significant attention to the manner in which land use decisions can affect public safety and the environment.

Finding 5. For the most part, state and local governments have not systematically considered risk to the public from transmission pipeline incidents in regulating land use.

Transmission pipelines generally are not subject to any local land use regulation. In most instances, the width, configuration, and control of pipeline rights-of-way are established without local input. Provisions with regard to the widths of rights-of-way are often established for laying and inspecting the pipeline rather than for public safety or prevention of environmental damage.

Finding 6. Risk-informed approaches are being used effectively in other domains (e.g., natural hazard mitigation, industrial hazard mitigation, nuclear reactor and waste disposal programs, tanker safety). These techniques are also being used to address other aspects of pipeline safety (e.g., pipeline integrity), but they have not been used to make informed land use decisions.

Given the relatively small number of incidents and the geographically dispersed nature of the pipeline system, the data to predict pipeline failures at a specific location with confidence are insufficient. Risks cannot be eliminated, but a risk-informed approach can help provide guidance to minimize the probability of pipeline failures occurring and to mitigate the consequences of failures when they do occur.

Finding 7. Currently, decision makers lack adequate tools and information to make effective land use decisions concerning transmission pipelines.

Guidance concerning development that incorporates the risk from transmission pipelines is not available to local government officials. As indicated previously, the few communities that have adopted setbacks have not had access to reliable data, risk analysis, or model ordinances by which they could reasonably determine appropriate separation distances between transmission pipelines and buildings. For example, a proposal was made that included a 1,000-foot setback using the theoretical impact radius of a major natural gas transmission line explosion. This approach, however, considers the potential consequences of an event without accounting for its probability, is based on a natural gas pipeline failure rather than a liquids pipeline failure, and does not attempt to weigh the risk-reduction benefits of such a measure against the considerable cost that such a provision would entail.

Finding 9. Encroachments and inappropriate human activity within the right-of-way can adversely affect pipeline safety. There appears to be variability in the quality and extent of inspections, maintenance, and enforcement of rights-of-way.

Finding 10. Technically the Indian process model lacks particularity to the specific pipeline being assessed and relies greatly on historical data.

Finding 11. A major feature like third party damage index is being ignored in the model, which challenges the validity of the model to the pipeline scenario.

Finding 12. Of all the risk assessment techniques followed only the third party damage index and coating assessment of Muhlbauer model and the process safety model together could stand alone to make a good estimate of risk involved in a pipeline.

Finding 13. The fire and explosion indices show that the hazard rating is heavy, but the industry does very little to mitigate risk in India.

Finding 14. The flame height calculations and consequence radii indicate about 12m and 50m respectively.

It must be ensured that this area for the specified distance and height is devoid of any fire enhancing factors like flammable materials, process units, buildings etc. to reduce the consequences of failure.

Finding 15. The probability of failure and accident it very low, but a reportable leak may be frequent.

Finding 16. The radiant flux received from a fire is capable enough of causing good fatality rate.

5.11.1 Summary of Findings:

The overall findings of this risk assessment show that risk of a spill is highly variable along the length of the pipeline. It shows that these variations occur because of different system and geographic characteristics along the route.

The probability of explosion arising from a leak on an ATF pipeline is statistically very remote. If a pipeline spill and subsequent ignition occurs, a flash fire and/or pool fire is possible.

However, 96 percent of pipeline jet fuel spills do not ignite. The areas potentially impacted by heat effects along the pipeline show ranges in distances from the pipeline from a few hundred feet up to approximately 2,000 ft from the pipeline, depending on the size of a spill and site-specific drainage conditions. ATF fires affect distances about 20 percent farther than crude oil fires.

A corridor of 2,500 ft, 1,250 ft either side of the pipeline centerline, was generally used as the impacts zone to identify sensitive receptors.

Chapter 6
Conclusion

6.1 Conclusions of the study:

Conclusion 1:Presently available model of process safety focuses only on consequence and not risk.

A review of four recent studies showed a broad range of results, due to variations in models, approaches, and assumptions. The four studies are not consistent and focus only on consequences rather than both risks and consequences. While consequence studies are important, they should be used to support comprehensive, risk-based management and planning approaches for identifying, preventing, and mitigating hazards to public safety and property from potential spills.

Conclusion 2:Pipelines though good for the nations growth, are a great hazard as consequences are heavy.

Though it is evident that the pipeline has obtained clearance of statuary bodies, the study clearly shows that this is a result of the need for energy highways to stimulate growth in the form of pipelines.

The results of the fire indices indicate high level of hazard consequence. This has to be borne in mind by operators.

Conclusion 3:Only hazard consequences are heavy; but the likelihood provides some comfort, as it is only slightly more than acceptable limit.

The failure mode and effect analysis and the vent tree calculation with the index sum model have clearly shown that pipeline failures and accidents are within acceptable limits. This has justified the statuary clearances of pipelines.

Conclusion 4:Lack of safety professionals specialized to pipelines.

Pipeline safety has to be free from influence of chemical engineers and process safety people. This is the ultimate cause for the persistence of process safety model in the pipeline scenario in India. The industry has to develop self sufficient safety professionals specialized in pipelines out of existing pipeline engineers.

Conclusion 5:Lack of openness obstructs risk identification.

Risk identification and risk management processes should be conducted in cooperation with appropriate stakeholders, including public safety officials and elected public officials. Considerations should include site-specific conditions, available intelligence, threat assessments, safety and security operations, and available resources. It should not be a separate process on paper as it would not really identify hazards. The documents related to design and construction must be made available to all the people to whom it is required. It must at least be made available to the consultant. Also care must be taken to log previous occurrence of untoward incidents.

Conclusion 6:Health risk to employees and construction workers during construction is never assessed.

Conclusion 7. Judicious land use decisions can reduce the risks associated with transmission pipelines by reducing the probabilities and the consequences of incidents.

Pipeline safety is a shared responsibility. Land use decisions and control of activities and development near transmission pipelines may be undertaken by the pipeline operator; safety regulators; national, state, and local officials; and the property owners. Appropriate land use measures taken by local governments could bolster and complement a pipeline company's efforts to protect the right-of-way and preclude uses that could pose a public safety risk.

Conclusion 8. It is feasible to use a risk-informed approach to establish land use guidance for application by local governments.

The probability of failure of any transmission pipeline is a function of many distinct factors including materials of construction, fabrication, exposure to corrosion, pressurization, and depth of cover. Data and models are lacking for making precise predictions about specific lines, but estimates can be developed at an aggregate level and adjusted to account for local conditions. The possible consequences of an event could be estimated on the basis of the product carried, degree of pressurization, depth of cover, surrounding development, and other considerations. The appropriateness and acceptable cost of various measures to reduce probability and consequence could be derived from local values. Although such an approach may be somewhat simplistic initially, it could be improved over time to a sufficient degree to help government officials regulate land use. The committee envisions an ongoing process that would involve risk assessment experts and stakeholders in the development, ongoing refinement, and application of such information.

Conclusion 9. There is clear evidence that guidelines can be developed that would assist in preserving habitat while maintaining rights-of-way in a state that facilitates operations and inspection.

As an adjunct to its main charge, the committee was asked to consider the problem of habitat loss when rights-of-way are initially cleared and subsequently maintained to allow for inspection, which is required by federal law. Right-of-way maintenance facilitates such inspection, usually conducted by aerial surveillance, and reduces the potential for tree roots to interfere with pipelines, which is another possible cause of failure. Rights-of-way can provide useful and functional habitat for plants, nesting birds, small animals, and migrating animals. In developed or urban areas, the ecological function of such rights-of-way may be useful but marginal, in large part because of the narrowness of the right-of-way and the already extensive habitat fragmentation. There is an overriding environmental benefit in effective inspection of pipelines to avoid incidents with consequent releases and environmental damage.

Conclusion 10: the risk assessment procedures in India lack pertinence to environmental hazards. Hencc practically nothing is done to mitigate risk to nature.

6.2 Recommendations:

The following are the recommendations emerging out of the study.

- Regular patrolling of the pipelines should be carried out especially when the transfer operation is in progress. This will help in identifying any activity that have the potential to cause pipeline damage or to identify small leaks whose effects are too small to be detected by instruments. The frequency of patrolling must be increased to at least twice a month.
- Pipeline failures due to third party activity can be reduced by ensuring that the members of the public, surrounding population, and the district administration are aware of the pipeline.
- Education of public on pipeline facilities must be seriously thought over by Indian pipeline owners

- The entire stretch of the underground pipeline is to be cathodically protected. Regular readings of pipe to soil potentials should be taken to ensure that rapid corrosion is not taking place locally. These surveys must be frequent and analysis of the results and counter measures must be speeded up using proper software support.
- Prior to the transfer of hydrocarbons from the port to the storage terminal, water draw off should be done to minimize internal corrosion.
- Positive blinding of the lines may be carried out by using spectacle blinds at both the ends.
- At locations where the pipelines / pipe racks are close to traffic movement, adequate crash guards may be provided.
- The pipelines should be subjected to hydrotest at least once in 5 years.
- The coating chosen must be effectively used with technical know how. If modern coatings are used they must assessed once a year.
- The design safety factor must be increased to consider a risk safety factor. This would reduce the risk phenomenally.
- Proper mitigation measures, concentrated to land use pattern must be ensured to bring down the risk. This is because the best known mitigation procedure is always associated with land use pattern.
- The use of the suggested model is recommended to assess pipeline risks. The use of process safety model only been found to be a useless risk assessment process.

- Education on pipeline safety principles for employees is important. Presently the risk assessment document is only a scripture and the process merely a ritual, followed only by few people who have understood the value of the ritual.
- Finally though all these are being followed, it is followed only on paper or partially. Everything has to be put into practice.
- The inferences from flame height model must be seriously considered in designing terminals. The results of ALOHA are to be applied in choosing land measures.
- An emergency management plan must be made from the risk results by the company itself and it should contain the DMP and should be the holy book of employees more than manuals etc. But as of now it is being prepared, to be given to the collector, to meet some statuary requirement.
- Pre mitigation and post mitigation risk assessments must be carried out once in 5-7 years, in it must be ensured that risk is brought under acceptable level.
- OISD should develop risk-informed land use guidance for application by stakeholders. The guidance should address

  A. Land use policies affecting the siting, width, and other characteristics of new pipeline corridors;

  B. The range of appropriate land uses, structures, and human activities compatible with pipeline rights-of-way;

  C. Setbacks and other measures that could be adopted to protect structures that are built and maintained near pipelines; and

  D. Model local zoning ordinances, subdivision regulations, and planning policies and model state legislation that could be adopted for land uses near pipelines.

Such a risk-informed guidance system should include three interrelated components:

1. A decision framework informed by risk analysis,

2. Guidelines based on the analysis, and

3. Alternative actions that could be taken on the basis of the guidelines.

- The process for developing risk-informed land use guidance should

  (a) Involve the collaboration of a full range of public and private stakeholders (e.g., industry and federal, state, and local governments);

  (b) Be conducted by persons with expertise in risk analysis, risk communication, land use management, and development regulation;

  (c) Be transparent, independent, and peer reviewed at appropriate points along the way; and

  (*d*) incorporate learning and feedback to refine the guidance over time.

- The transmission pipeline industries should develop best practices for the specification, acquisition, development, and maintenance of pipeline rights-of-way. In so doing, they should work with other stakeholders. With regard to the specific maintenance issue of clearing rights-of-way to allow for inspection, the federal government should develop guidance about appropriate vegetation and environmental management practices that would provide habitat for some species, avoid threats to pipeline integrity, and allow for aerial inspection.

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Appendix 1

MSIHC RULES 1989
& SCHEDULES
MINISTRY OF ENVIRONMENT AND FORESTS
GOVT. OF INDIA

5.17 MANUFACTURE, STORAGE AND IMPORT OF HAZARDOUS CHEMICAL RULES, 1989

MINISTRY OF ENVIRONMENT AND FORESTS

(Department of Environment, Forest and Wildlife)

NOTIFICATION

New Delhi, the 27th November, 1989

S.O. 966(E).-In exercise of the powers conferred by Section 6, 8 and 25 of the Environment (Protection) Act, 1986 (29 of 1986), the Central Government hereby makes the following rules, namely .-

1. Short title and commencement.
(1) These rules may be called the Manufacture, Storage and import of Hazardous Chemical Rules, 1989.
(2) They shall come into force on the date of their publication in the official Gazette.

2. Definitions.
In these rules, unless he context otherwise requires.-
(a) "Act" means the Environment (Protection) Act, 1986 (29 of 1986);
(b) "Authority" means an authority mentioned in Column 2 of Schedule 5;
(c) "export" with its grammatical variations and cognate expression, means taking out of India to a place outside India;
(d) "exporter" means any person under the jurisdiction of the exporting country and includes the exporting country who exports hazardous chemical:
(e) "hazardous chemical" means-
(i) any chemical which satisfies any of the criteria laid down in Part I of Schedule I and is listed in Column 2 of Part II of this Schedule:
(ii)any chemical listed in Column 2 of Schedule 2;
(iii) any chemical listed in Column 2 of Schedule 3;
(f) "import" with its grammatical variations and cognate expression, means bringing into India from a place outside India;
(g) "importer" means an occupier or any person who imports hazardous chemicals;
(h) "industrial activity" means-
(i) an operation of process carried out in an industrial installation referred to in Schedule 4 involving or likely to involve one or more or hazardous chemicals and includes on-site storage or on-site transport which is associated with that operation or process, as the case may be; or
(ii) isolated storage; or
(iii) pipeline;
(i) "isolated storage" means storage of a hazardous chemical, other than storage associated with an installation on the same site specified in Schedule 4 where that storage involves atleast the quantities of that chemical set out in Schedule 2;
(j)"major accident" means an occurrence including any particular major emission, fire or explosion involving one or more hazardous chemicals and resulting from uncontrolled developments in the course of an industrial activity or due to natural events leading to serious effects both immediate or delayed, inside or outside the installation likely to cause substantial loss of life and property including adverse effects on the environments;
(k) "pipeline" means a pipe (together with any apparatus and works associated therewith) or system of pipes (together with any apparatus and work associated therewith) for the conveyance of a hazardous chemical other than a flammable gas as set out in Column 2 of Part II of Schedule 3 at a pressure of less than 8 bars absolute: the pipeline also includes inter-state pipe
(l) "Schedule" means Schedule appended to these rules;
(m) "site" means any location where hazardous chemicals are manufactured or processed, stored, handled, used, disposed of and includes the whole of an area under the control of an occupier and includes pier, jetty or similar structure whether floating or not;
(n) "Threshold quantity" means,-
(i) in the case of a hazardous chemical specified in Column 2 of Schedule 2, the quantity of that chemical specified in the corresponding entry in Columns 3 & 4;
(ii) in the case of hazardous chemical specified in Column 2 of Part I of Schedule 3, the quantity of that chemical specified in the corresponding entry in Columns 3 & 4 of that part;
(iii) in the case of substances of a class specified in Column 2 of Part II of Schedule 3, the total quantity of all substances of that class specified in the corresponding entry in Column 3 & 4 of that part

3. Duties of authorities.
Subject to the other provisions of these rules, the authority shall perform duties as specified in Column 3 of Schedule 5.

4. General responsibility of the occupier during industrial activity.
(1) This rule shall apply to.-
(a) an industrial activity in which a hazardous chemical, which satisfies any of the criteria laid down in Part I of Schedule 1 and is listed in Column 2 of Part II of this Schedule is or may be involved; and
(b) isolated storage in which there is involved a threshold quantity of a hazardous chemical listed in Schedule 2 in Column 2 which is equal to or more than the threshold quantity specified in the Schedule for that chemical in Column 3 thereof.
(2) An occupier who has control of an industrial activity in term of sub-rule (1) shall provide evidence to show that he has.-
(a) identified the major accident hazards; and
(b) taken adequate steps to -
(i) prevent such major accidents and o limit their consequences to persons and the environment;
(ii) provide to The persons working on the site with the information, training and equipment including antidotes necessary to ensure their safety.

5. Notification of Major accident.
(1) Where a major accident occurs on a site or in a pipe line, the occupier shall forthwith notify the concerned authority as identified in Schedule 5 of that accident, and furnish thereafter to the concerned authority a report relating to the accidents in installments, if necessary, in Schedule 6.
(2) The concerned authority shall on receipt of the report in accordance with sub-rule 1 of this rule shall undertake a full analysis of the major accident and send the requisite information to the Ministry of Environment and Forests through appropriate channel.
(3) Where an occupier has notified a major accident to the concerned authority under respective legislation, he shall be deemed to have compiled with the requirements as per sub-rule 1 of this rule.

6. Industrial activity to which rules 7 to 15 apply.
(1) Rules 7 to 15 shall apply to.-

(a) an industrial activity in which there is involved a quantity of hazardous chemical listed in Column 2 of Schedule 3 which is equal to or more than the quantity specified in the entry for that chemical in Columns 3 & 4 (Rules 10-12 only for Column 4) and

(b) isolated storage in which there is involved a quantity of a hazardous chemical listed in Column 2 of Schedule 2 which is equate to or more than the quantity specified in the entry for that chemical in Column 3

(2) For the purposes of rules 7 to 15, or

(a) "new industrial activity" means an industrial activity which-

(i) commences after the date of coming into operation of these rules; or

(ii) if commenced before that date is an industrial activity in which a modification has been made which is likely to cover major accident hazards and that activity shall be deemed to have commenced on the date on which the modification was made;

(b) an "existing industrial activity" means an industrial activity which is not a new industrial activity

7. Notification of sites.

(1) An occupier shall not undertake any industrial activity unless he has submitted A written report to the concerned authority containing the particulars specified in Schedule 7 at least 3 months before commencing that activity or before such shorter time as the concerned authority may agree and for the purpose of this paragraph an activity in which subsequently there is or is liable to be a threshold quantity or more of an additional hazardous chemical shall be deemed to be a different activity and shall be notified accordingly

(2) No report under sub-rule (I) need to be submitted by the occupier if he submits a report under rule 10(1)

8. Updating of the site notification following changes in the threshold quantity.

Where an activity has been reported in accordance with rule 7(1) and the occupier makes a change in it (including an increase or decrease in the maximum threshold quantity of a hazardous chemical to which this rule applies which is or is liable to be at the site or in the pipeline or at the cessation of the activity, which affects the particulars specified in that report or any subsequent report made under this rule the occupier shall forthwith furnish a further report to the concerned authority.

9. Transitional provisions.

Where-

(a) at the date of coming into operation of these rules an occupier is in control of an existing industrial activity which is required to be reported under rule 7(1); or

(b) within 6 months after that date an occupier commence any such new industrial activity; it shall be a sufficient compliance with that rule if he reports to the concerned authority as per the particulars in Schedule 7 within 3 months after the date of coming into operation of these rules or within such longer time as the concerned authority may agree in writing.

10. Safety reports.

(1) Subjects to the following paragraphs of this rule, an occupier shall not undertake any industrial activity to which this rule applies, unless he has prepared a safely report on that industrial activity containing The information specified in Schedule 8 and has sent a copy of that report to the concerned authority at least ninety days before commencing that activity.

(2) In the case of a new industrial activity which an occupier commences, or by virtue of sub-rule (2) (a) (ii) of rule 6 is deemed to commence, within 6 months after coming into operation of these rules, it shall be sufficient compliance with sub-rule (I) of this rule if the occupier sends to the concerned authority a copy of the report required in accordance with that sub-rule within ninety days after the date of coming into operation of these rules.

(3) In The case of an existing industrial activity, until five years from the date of coming into operation of these rules, it shall be a sufficient compliance with sub-rule (I) of this rule in the occupier on or before ninety days from The date of the coming into operation of These rules sends to the concerned authority in information specified in Schedule 7 relating to that activity.

11. Updating of reports under rule 10.

(1) Where an occupier has made a safety report in accordance with sub-rule (I) of rule 10 he shall not make any modification to The industrial activity to which that safely report relates which could materially affect the particulars in that report, unless the has made a further report to take account of those modifications and has sent a copy of that report to The concerned authority at least 90 days before making those modifications.

(2) Where an occupier has made a report in accordance with rule 10 and sub-rule (I) of this rule and that industrial activity is continuing the occupier shall within three years of the dale of the last such report, make a further report which shall have regard in particular to new technical knowledge which has affected the particulars in the previous report relating to safely and hazard assessment and shall within 30 days or in such longer lime as the concerned authority may agree in writing, send a copy of the report to the concerned authority

12. Requirements for further information to be sent to the authority.

(1) Where, in accordance with rule 10, an occupier has sent a safely report relating to an industrial activity to the concerned authority, the concerned authority may, by a notice served on the occupier, requires him to provide such additional information as is specified in the notice and the occupied shall send that information to the concerned authority within such lime as is specified in The notice or within such extended lime as the authority may subsequently specify

13. Preparation of on-site emergency plan by the occupier.

(1) An occupier shall prepare and keep up-to-date an on-site emergency plan detailing how major accidents will be dealt with on the site on which the industrial activity is carried on and that plan shall include the name of The person who is responsible for safety on the site and the names of those who are authorised to take action in accordance with the plan in case of an emergency

(2) The occupier shall ensure that the emergency plan prepared in accordance with sub-rule (I) takes into account any modification made in the industrial activity and that every person on the site who is affected by the plan is informed of its relevant provisions.

(3) The occupier shall prepare the emergency plan required under sub-rule

(a) in the case of a new industrial activity before that activity is commenced;

(b) in the case of an existing industrial activity within 90 days of coming into operation of these rules.

14. Preparation of off-site emergency plan by the authority.

(1) It shall be the duty of the concerned authority as identified in Column 2 of Schedule 5 to prepare and keep up-to-date an adequate off-site emergency plan detailing how emergencies relating to a possible major accident on that site will be dealt with and in preparing that plan the concerned authority shall consult the occupier, and such other persons as it may deem necessary.

(2) For the purpose of enabling The concerned authority to prepare the emergency plan required under sub-rule (1), the occupier shall provide the concerned authority with such information relating to the industrial activity under his control as the concerned authority may require, including the nature, extent and likely effects off-site of possible major accidents and the authority shall provide the occupier with any information from the off-site emergency plan which relates to his duties under rule 13.

(3) The concerned authority shall prepare its emergency plan required under sub-rule (1).-

(a) in the case of a new industrial activity, before that activity is commenced;

(b) in the case of an existing industrial activity, within six months of coming into operation Of these rules

15. Information to be given to persons liable to be affected by a major accident.

(1) The occupier shall take appropriate steps to inform persons outside the site either directly or through District Emergency Authority who are likely to be in an area which may be affected by a major accident about-

(a) the nature of the major accident hazard; and
(b) the safety measures and the "Do's" and 'Don'ts" which should be adopted in the event of a major accident
(2) The occupier shall take the steps required under sub-rule (1) to inform persons about an industrial activity, before that activity is commenced, except, in the case of an existing industrial activity in which case the occupier shall comply with the requirements of sub-rule (1) within 90 days of coming into operation of these rules.

16. Disclosures of information.
(1) Where for the purpose of evaluating information notified under rule 5 or 7 to 15, the concerned authority discloses that information to some other person that other person shall not use that information for any purpose except for the purpose of the concerned authority disclosing it, and before disclosing the information the concerned authority shall inform that other person of his obligations under this paragraph.

17. Collection, Development and Dissemination of Information.
(1) This rule shall apply to an industrial activity in which a hazardous chemical which satisfies any of the criteria laid down in part I of Schedule I and is listed in Column 2 of Part II of this Schedule is or may be involved.
(2) An occupier, who has control of an industrial activity in term of sub-rule 1 of this rule, shall arrange to obtain or develop information in the form of safety data sheet as specified in Schedule 9. The information shall be accessible upon request for reference.
(3) The occupier while obtaining or developing a safety data sheet as specified in Schedule 9 in respect of a hazardous chemical handled by him shall ensure that the information is recorded accurately and reflects the scientific evidence used in making the hazard determination. In case, any significant information regarding hazard Of a chemical is available, it shall be added to the material safety data shet as specified in Schedule 9 as soon as practicable.
(4) Every container of a hazardous chemical shall be clearly labelled or marked to identify.-
(a) the contents of the container,
(b) the name and address of manufacturer or importer Of the hazardous chemical;
(c) the physical, chemical and toxicological data as per the criteria given at Part I of Schedule 1.
(5) In terms of sub-rule 4 Of this rule where it is impracticable to label a chemical in view of the size of the container or the nature of the package, provision should be made for other effective means like tagging or accompanying documents.

18. Import of hazardous chemicals.
(1) This rule shall apply to a chemical which satisfies any of the criteria laid down in Part I of Schedule I and is listed in Column 2 of Part II of this Schedule.
(2) Any person responsible for importing hazardous chemicals in India shall provide at the time of import or within thirty days from the date of import to the concerned authorities as identified in Column 2 of Schedule 5 the information pertaining to-

(i) the name and address of the person receiving the consignment in India;
(ii) the port of entry in India;
(iii) mode of transport from the exporting country to India
(iv) The quantity of chemical(s) being imported; and
(v) complete product safety information.

(3) If the concerned authority at the State is satisfied that the chemical being imported is likely to cause major accident, it may direct the importer to take such steps including stoppage of such imports as the concerned authority at the State may deem it appropriate.
(4) The concerned authority at the State shall simultaneously inform the concerned Port Authority to take appropriate steps regarding safe handling and storage of hazardous chemicals while off-loading the consignment with the port premises.
(5) Any person importing hazardous chemicals shall maintain the records of the hazardous chemicals imported as specified in Schedule 10 and the records so maintained shall be open for inspection by the concerned authority at the State or the Ministry of Environment and Forests or any officer appointed by them in this behalf.
(6) The importer of the hazardous chemical of a person working on his behalf shall ensure that transport of hazardous chemicals from port of entry to the ultimate destination is in accordance with the Central Motor Vehicles Rules, 1989 framed under the provisions of the Motor Vehicles Act, 1988.

19. Improvement notices.
(1) If the concerned authority is of the opinion that a person has contravened the provisions of these rules, the concerned authority shall serve on him a notice (in this para referred to as "an improvement notice") requiring that person to remedy the contravention or, as the case may be, the matters occasioning it within such period as may be specified in the notice.
(2) A notice served under sub-rule (1) shall clearly specify the measures to be taken by the occupier in remedying said contraventions.

20. Power of the Central Government to modify the Schedule.
The Central Government may, at any-time, by notification in the Official Gazette, make suitable changes in the Schedules.

SCHEDULE -I

[See rule 2(c)(i), 4(1)(a), 4(2), 17 and 18]
Indicative Criteria and List of Chemicals
PART I

(a) Toxic Chemicals:

Chemicals having the following values of acute toxicity and which, owing to their physical and chemical properties, are capable of producing major accidents hazards.

S. No.	Degree of Toxicity	Medium lethal dose by the oral route (oral toxicity) LD50 (mg/kg) body weight of test animals	Medium lethal dose by the dermal route (dermal toxicity) LD 50 (mg/kg) body weight of test animals	Medium lethal concentration by inhalation route (four hours) LC 50 (mg/l) inhalation on test animals
1	Extremely toxic	1 – 50	1 - 200	0.1 - 0.5
2	Highly toxic	51 – 500	201 - 2000	0.5 - 2.0

(b) Flammable chemicals:

(i) **Flammable gases; chemicals which in the gaseous state at normal pressure and mixed with air become flammable and the boiling point of which at normal pressure is 20°C or below;**

(ii) **highly flammable liquids: chemicals which have a flash point lower than 23°C and the boiling point of which at normal pressure is above 20° C;**

(iii) **flammable liquids: chemicals which have a flash point lower than 65°C- and which remain liquids under pressure, where particular processing conditions, such as high pressure and high temperature, may create major accident hazards.**

(c) Explosives:

Chemicals which may explode under the effect of flame, heat or photo-chemical conditions or which are more sensitive to shocks or friction than dinitrobenzene.

SCHEDULE - 2

[(See rule 2(e)(ii), 4(1)(b), 4(2) (1) and 6(1)(b)]

Isolated storage at Installations other than those covered by Schedule 4

(a) The threshold quantities set out below relate to each installation or group of installations belonging to the same occupier where the distance between installation is not sufficient to avoid, in foreseeable circumstances, any aggravation of major accident hazards. These threshold quantities apply in any case to each group of installations belonging to the same occupier where the distance between the installations is less than 500 metres.

(b) For the purpose of determining the threshold quantity of hazardous chemical at an isolated storage, account shall also be taken of any hazardous chemical which is:-

(i) in that part of any pipeline under the control of the occupier having control of the site wh.ch is within 500 metres of that site and connected to it;

(ii) at any other site under the control of the same occupier any part of the boundary of which is within 500 metres of the said site; and

(iii) in any vehicle, vessel, aircraft or hovercraft, under the control of the same occupier which is used for storage purpose either at the site or within 500 metres of it; but no account shall be taken of any hazardous chemical which is in a vehicle, vessel, aircraft or a hovercraft used for transporting it.

Sl. No.	Chemicals	Threshold Quantities (tonnes)	
		For application of Rules 4, 5 and 7-9	For application of Rules 10 to 15
1	2	3	4
1	Acrylonitrile	350	5,000
2	Ammonia	60	600
3	Ammonium nitrate (a)	350	2,500
4	Ammonium nitrate fertilizers (b)	1,250	10,000
5	Chlorine	10	25
6	Flammable gases as defined in Schedule 1, paragraph (b) (i)	50	300
7	Highly flammable liquids as defined in Schedule 1, paragraph (b) (ii)	10,000	100,000
8	Liquid oxygen	200	2,000
9	Sodium chlorate	25	250
10	Sulphur dioxide	20	500
11	Sulphur trioxide	15	100

(a) This applies to ammonium nitrate and mixtures of ammonium nitrates where the nitrogen content derived from the ammonium nitrate is grater than 28 per cent by weight and to aqueous solutions of ammonium nitrate where the concentration of ammonium nitrate is greater then 90 per cent by weight

(b) This applies to straight ammonium nitrate fertilizers and to compound fertilizers where the nitrogen content derived from the ammonium nitrate is greater than 28 per cent by weight (a compound-fertilizer contains ammonium nitrate together with phosphate and/or potash).

SCHEDULE- 3

[See rule 2(e) (iii), 5 and 6(1) (a)]

List of Hazardous Chemicals for Application of Rules 5 and 7 to 15

(a) The quantities set-out-below relate to each installation or group of installations belonging to the same occupier where the distance between the installations is not sufficient to avoid, in foreseeable circumstances, any aggravation of major-accident hazards. These quantities apply in any case to each group of installations belonging to the same occupier where the distance between the installations is less than 500 metres.

(b) For the purpose of determining the threshold quantity of a hazardous chemical in an industrial installation, account shall also be taken of any hazardous chemicals which is:-

(i) in that part of any pipeline under the control of the occupier have control of the site, which is within 500 metres off that site and connected to it;

(ii) at any other site under the control of the same occupier any part of the boundary of which is within 500 metres of the said site; and

(iii) in any vehicle, vessel, aircraft or hovercraft under the control of the same occupier which is used for storage purpose either at the site or within 500 metres of it; but no account shall be taken of any hazardous chemical which is in a vehicle, vessel, aircraft or hovercraft used for transporting it.

S.No.	Chemical	Threshold Quantity		CAS Number
		for application of Rules, 5, 7-9 and 13-15	for application of Rules 10-12	
1	2	3	4	5
GROUP 5-FLAMMABLE CHEMICALS				
1	Flammable gases: Substances which in the gaseous state normal pressure and mixed with air become flammable and the boiling point of which at normal pressure is 20°C or below;	15 t	200 t	
2	Highly flammable liquids: Substances which have a flash point lower than 23°C and the boiling point Of which at normal pressure is above 20°C;	1000 t	50,000 t	
3	Flammable liquids: Substances which have a Rash point lower than 65ø C and which remain liquid under pressure, where particular processing conditions, such as high pressure and high temperature, may create major accident hazards.	25 t	200 t	

(a) This applies to ammonium nitrate and mixtures of ammonium nitrate where the nitrogen content derived from the ammonium nitrate is greater than 28% by weight and aqueous solutions of ammonium nitrate where the concentration of ammonium nitrate is greater than 90% by weight.

(b) This applies to straight ammonium nitrate fertilizers and to compound fertilizers where the nitrogen content derived from the ammonium nitrate is greater than 28% by weight (a compound fertilizer contains ammonium nitrate together with phosphate and/or potash).

SCHEDULE -7

[See rule 7(1)]

INFORMATION TO BE FURNISHED FOR THF NOTIFICATION OF SITES

PART-I

Particulars to be included in a notification of a site.

1. The name and address of the employer making the notification.
2. The full postal address of the site where the notifiable industrial activity will be carried on.
3. The area of the site covered by the notification and of any adjacent site which is required to be taken into account by virtue of b(ii) of Schedule 2 and 3.
4. The date on which it is anticipated that the notifiable industrial activity will commence, or if it has already commenced a statement to that effect.
5. The name and maximum quantity liable to be on the site of each dangerous substance for which notification is being made.
6. Organisation structure namely organisation diagram for the proposed industrial activity and set up for ensuring safety and health.
7. Information relating to the potential for major accidents, namely-
   (a) identification of major accident hazards;
   (b) the conditions or the events which could be significant in bringing one about;
   (c) a brief description of the measures taken.

Information relating to the site namely-

(a) a map of the site and its surrounding area to a scale large enough to show any features that may be significant in the assessment of the hazard or risk associated with the site,-

(i) area likely to be affected by the major accident.

(ii) population distribution in the vicinity.

(b) a scale plan of the site showing the location and quantities of all significant inventories of the hazardous chemicals;

(c) a description of the process or storage involving the hazardous chemicals and an indication of the conditions under which it is normally held;

(d) the maximum number of persons likely to be present on site.

9. The arrangement for training of workers and equipment necessary to ensure safety of such workers.

PART-II

Particulars to be included regarding pipeline-

1. The names and the address of the persons making the notification.
2. The full postal address of the place from which the pipeline activity is controlled addresses of the places where the pipeline starts and finishes and a map showing the pipeline route drawn to a scale of not less than 1: 400000
3. The date on which it is anticipated that the notifiable activity will commence, or if it is already commenced a statement to that effect.
4. The total length of the pipeline, its diameter and normal operating pressure and the name and maximum quantity liable to be in the pipeline of each hazardous chemical for which notification is being made.

SCHEDULE -8

[See rule 10(1)]

INFORMATION TO BE FINISHED INA SAFETY REPORT

1. The name and address of the person furnishing the information.
2. Description of the industrial activity, namely-
   (a) site,
   (b) construction design,
   (c) protection zones explosion protection, separation distances.
   (d) accessibility of plant,
   (e) maximum number of persons working on the site and particularly of those persons exposed to be hazard.
3. Description of the processes, namely-
   (a) technical purpose of the industrial activity,
   (b) basic principles of the technological process,
   (c) process and safety-related data for the individual process stages,
   (d) process description,
   (e) safety-related types of utilities.
4. Description of the hazardous chemicals, namely-
   (a) chemicals (quantities, substance data, safety-related data, toxicological data and threshold values).

(b) the form in which the chemical may occur on or into which they may be transformed in the event of abnormal conditions.
(c) the degree of purity of the hazardous chemical

5. Information on the preliminary hazard analysis, namely-
   (a) types of accident
   (b) system elements or events that can lead to a major accident,
   (c) hazards.
   (d) safety-relevant components.
6. Description of safety-relevant units, among others,
   (a) Special design criteria,
   (b) controls and alarms,
   (c) special relief systems,
   (d) quick-acting valves,
   (e) collecting tanks/dump tank,
   (f) sprinkler system.
   (g) fire-fighting etc.
7. Information on the hazard assessment, namely--
   (a) identification of hazards,
   (b) the cause of major accidents,
   (c) assessment of hazards according to their occurrence frequency,
   (d) assessment of accident consequences,
   (e) safety systems,
   (f) known accident history.
8. Description of information on organisational systems used to carry on the industrial activity safety, namely-
   (a) maintenance and inspection schedules,
   (b) guidelines for the training of personnel,
   (c) allocation and delegation of responsibility for plant safety,
   (d) implementation of safety procedures.
9. Information on assessment of the consequences of major accidents, namely-
   (a) assessment of the possible release of hazardous chemicals or of energy
   (b) assessment of the effects of the releases (size of the affected area, health effects, property damage)
10. Information on the mitigation of major accidents, namely-
   (a) fire brigade
   (b) alarm systems,
   (c) emergency plan containing system of organisation used to fight the emergency, the alarm and the communication rules, guidelines for fighting the emergency, information about hazardous chemicals, examples of possible accident sequences,
   (d) coordination with the District Emergency authority and its off-site emergency plan,
   (e) notification of the nature and scope of the hazard in the event of an accident,
   (f) antidotes in the event of a release of a hazardous chemical.

SCHEDULE-10

[See Rule 18(5)]

(Format for maintaining records of hazardous chemicals imported)

1. Name and address of the Importer:
2. Date and reference number of issuance of permission to import hazardous chemicals:
3. Description of hazardous chemicals:
   (a) Physical form:
   (b) Chemical form:
   (c) Total volume and weight (in kilogrammes/tonnes)
4. Description of purpose of import:
5. Description of storage of hazardous chemicals:
   (a) Date:
   (b) Method of storage:

Appendix 2

REQUIREMENTS OF ATF
PETROLEUM RULES 2002
CONSTITUTION OF INDIA

5.16 Annexure-1 :Requirement of Aviation Turbine Fuels (Kerosine Type), Jet A-1

Sl.	Characteristics	Requirements
i	Appearance	Clear, bright and visually free from solid matter and undissolved water at normal ambient temperature.
ii	Composition	
a	Acidity, total, mg KOH/g, max	0.015
b	Aromatics, % by vol, max	25[1]
c	Olefins contents, % by volume, max	5.0
d	Sulphur, total, % by mass, max	0.30[2]
e	Sulphur mercaptan, % by mass, max OR Doctor Test	0.0030 [3&4] Negative[4]
f	Refining component, at the point of manufacture: 1. Hydroprocessed component, % v/v 2. Severely hydroprocessed component, % v/v	 Report Report[5]
iii	Volatility	
a	Distillation 1. Initial boiling point °C 2. Fuel recovered 10 percent by volume, at °C, max 50 percent by volume, at °C 90 percent by volume, at °C 3. Final boiling point, °C, max 4. Residue, percent by volume, max 5. Loss, percent by volume, max	 Report 205 Report Report 300 1.5 1.5
b	Flash point (Abel) °C, min	38
c	Density at 15°C, kg/m3	775 to 840
iv	Fluidity	
a	Freezing point, °C, max	(-)47
b	Kinematic viscosity, mm2/s (at –20°C), max	8.0
v	Combustion	
a	Specific energy, MJ/kg, min OR Product of API gravity and aniline point, min	42.8 4800
b	Smoke point, mm, min OR Smoke point, mm, min AND Naphthalenes, percent vol, max	25 19 3.0
vi	Corrosion	
a	Copper strip corrosion for 2 h at 100°C	Not worse than No.1
b	Silver strip corrosion classification, max	Note 9
vii	Stability, Thermal stability (JFTOT)	
a	Filter pressure differential, mm Hg, max	25.0
b	Tube rating, visual	Less tha 3, No "Peacock" or "Abnormal" colour deposit (11)
viii	Contaminants	
a	Existent gum, mg/100 ml, max	7
b	Water reaction: Interface rating, max Separation rating, max	 Ib Sharp separation no emulsion or ppt within or upon either layer
c	Micro separometer rating at point of manufacture:	

	MSEP without SDA, min OR MSEP with SDA, min	85[14] 70
ix	Conductivity: Electrical conductivity ps/m (at the point, time and temperature of delivery to the purchaser)	50, min 450, max
x	Lubricity, mm, max	0.85 [15&16]

1. Defence requirements to be met at 22 percent by volume maximum and at 20 percent by volume, max for defence aircrafts fitted with engine of Russian origin.
2. Defence requirements to be met at 0.25 percent by mass maximum for Russian Aircraft.
3. Defence requirements to be met at 0.002 percent mass maximum.
4. The alternative method ii(f) is a secondary requirement to ii(e). In the event of conflict between sulphur mercaptan ii(e) and Doctor Test ii(f) results, method ii(e) shall prevail.
5. Severely hydroprocessed components are defined as petroleum derived hydrocarbons that have been subjected to a hydrogen partial pressure of greater than 7000 kPa during manufacture. This requirement comes into effect on 1st December, 2000.
6. A condenser bath temperature of 0 to 4°C shall be used.
7. Specific energy by one of the calculation method listed in Table 2 will be acceptable. Where, a measurement of specific energy is deemed necessary, the method to be used shall be agreed between the purchaser and supplier.
8. Convert the aniline point determined in °C to °F. Also find out API gravity at 60°F from, density at 15°C using ASTM/IP Table 3. Alternatively calculate API gravity from the relative density in accordance with the following formula :

$$\text{Degree API} = \frac{141.5}{\text{RD } 15.6°\text{C}/15.6°\text{C}} - 131.5$$

9. For defence use, the requirement of silver strip corrosion test should be 'O' at refinery level and 1 Max at the delivery point. For civil Aviation use, the requirement is 1 Max at refinery level and 2 Max at the delivery point.
10. The test method to be followed at the refinery as well as at the delivery point shall be IP-227 (4 h at 50°C).
11. Examination of heater tube to determine the visual tube rating using the visual tuberator shall be carried out within 120 min of completion of the test.
12. While (P:29) requires use of steam for evaporation of Jet fuel, it is known that air is frequently substituted. This practice is accepted because data show that the use of air typically increases the level of existent gum determined by the method compared to the use of steam.
13. If the sample contains sediment or insoluble matter, it shall be allowed to stand and clear fuel decanted for testing. The sample shall not be filtered.
14. These MSEP requirements apply only at the point of manufacture. No precision data are available for fuels containing SDA, if MSEP testing is carried out during downstream distribution no specification limits apply and results are not be used as the sole reason for rejection of a fuel.
15. Under preparation. Till such time, the test method to be followed as per ASTM D 5001. The requirement to determine lubricity applies only to fuels containing more than 95 percent hydroprocessed material where at least 20 percent of this is severely hydroprocessed (see Footnote 5). The limits apply only at the point of manufacture.
16. Under preparation. Till such time, the test method to be followed as per ASTM D 5001. For Defence requirement irrespective of method of production of ATF, that is, Hydrotreated, Merox or mixed, lubricity in terms of WSD shall be reported. If 'as is' WSD of ATF is greater than 0.65mm at the point of production at the refinery, the desired WSD shall be obtained by the user after doping with the approved lubricity additive as mentioned in 4.2.4 before ATF is inducted into the aircraft in order to comply with the Original Engine Manufacturers (OEMs) recommendations of the aero engines / aircrafts / systems.

Appendix 3

HAZOP STUDY GUIDE WORD TABLE

Table-5.5 (b) HAZOP Approach for Risk Identification of Petroleum Product (ATF) Pipeline

Guide Word	Deviation	Cause (s)	Consequence	Scenario	Safeguard & Action
No	No Flow	♦ Pump suction valve closed ♦ No material inflow.	♦ Rapid damage to pump. ♦ With auto start of standby pump, the other pump would also be damaged.	Frequency [2] Category [2] [3] Severity [1] [2] Risk [1R][2R]	♦ To ensure the effectiveness of flow/ pressure/ leak detectors. ♦ The proposed SCADA system would ensure safeguards adequately.
Less	Less Flow	♦ Pump not functioning properly. ♦ Leakage from valve/ flanges/ joints etc.	♦ Residual head level falls. ♦ Can damage pump. ♦ Fire Hazard	Frequency [2] Category [1] [2] [3] Severity [1] [2] Risk [1R][2R]	♦ To ensure the effectiveness of flow/ pressure/ leak detectors. ♦ The proposed SCADA system would ensure safeguards adequately.
High	High Flow	♦ Sudden increase in pressure due to rise in SDH. ♦ Control Valve failure	♦ Rapid increase in pressure. ♦ Vessel rupture ♦ Leakage (severe/ major)	Frequency [2] Category [1] [2] [3] Severity [1] [2] Risk [1R][2R]	♦ To ensure the effectiveness of flow/ pressure/ leak detectors. ♦ The proposed SCADA system would ensure safeguards adequately.
Pressure	No	Covered under flow	Covered under flow	Covered under flow	Covered under flow
	Less	Covered under flow	Covered under flow	Covered under flow	Covered under flow
	High	Covered under flow	Covered under flow	Covered under flow	Covered under flow
Temperature	High	♦ Faulty pump left running on kick-back for long time. ♦ Pump failure-dead heading.	Pump may be damaged by high temperature.	Frequency [2] Category [2] [3] Severity [1] [2] Risk [1R][2R]	The proposed SCADA system would ensure effectiveness of the pump.
Corrosion	More	♦ External weather conditions. ♦ Internal matrix of the product. ♦ Friction due to flow, particularly at turning points and base.	♦ Potential for stress ♦ Corrosion cracking. ♦ Pipe rupture ♦ Leakage	Frequency [2] Category [2] [3] [4] [5] Severity [1] [2] Risk [1R][2R]	♦ Passive and active corrosion protection system would ensure protection from internal & external corrosion. ♦ Passive protection would consist of either coat tar enamel or 3 LPE coating. ♦ Active corrosion would be an impressed current cathodic protection system.
Scaling	More	♦ Deposits of corroded material etc,.	♦ Less flow ♦ Quality of product may be damaged	Frequency [2] Category [2] [3] Severity [1] [2] Risk [1R][2R]	♦ Pigging operation would ensure the cleaning of pipeline on regular basis.

Appendix 4

FORMAT FOR DOW INDEX ASSESSMENT

DOW Fire and Explosion Index:

The hazard classification guide developed by the Dow chemical company and published by the American Institute of Chemical Engineering provides a method for estimating the potential loss as a result of a fire or explosion in refinery or tank farm storages. The step-by-step objective evaluation of the realistic fire or explosion potential of processing or storage equipments. It is based on empirical analysis of actual events and widely used in many industries.

The purpose of evaluation is to:

- Quantify expected fire and explosion damage.
- Identify equipment likely to contribute.
- Communicate F&E risk to management.

It is a system of index in fire and explosion and toxicity so as to categorize plant sections in to different hazard zones involving fire, explosions and toxicity hazards. DOW Index assigns penalties for each operating, handling, processing and storage condition and nature of chemicals handled.

Penalties Are Of Two Categories:

1. General Process Hazards (GPH): These penalties related to:

a. Nature of reaction : exothermic / endothermic.

b. Handling and transfer of hazardous chemicals.

c. Units within buildings.

d. Miscellaneous.

2. Special Process hazards (SPH): These penalties related to:

a. High process temperature near flammable range.

b. Operating pressure.

c. Low operating temperature.

d. In-process quantity of hazardous chemicals.

e. Storage quantity of hazardous chemicals.

f. Leak hazard.

General Process Hazard (GPH):

Table 1: Penalty on exothermic reactions:

Sr.no	Exothermic Reaction	Max. Penalty	Penalty Given	Remarks
a.	Combustion	0.2		
b.	Hydrogenation	0.3		
c.	Alkylation	0.3		
d.	Isommarization	0.3		
e.	Sulfonation	0.3		
f.	Neutralization	0.3		
g.	Esterification	0.5*		
h.	Oxidation	1.0		
i.	Nitration	1.25		
j.	Polymerization	0.5		
k.	Condensation	0.5		
l.	Halogenation	1.0		
Total GPH – 1		6.75-8		
* Expect for highly reactive acid where penalty is 0.75 or 1.25				

Table 2: Penalty on Endothermic reaction: Penalty upto max.

Sr.No	Endothermic Reactions	Max. Penalty	Penalty given	Remarks
a.	Calcination	0.2		
b.	Electrolysis	0.2		
c.	Pyrolysis/Cracking	0.2		
d.	As in a/c with Combustion	2*		
Total GPH –2		0.8-10		

* Use 0.4 if combustion process leads to Calcination/Pyrolysis, Cracking

Table 3: Penalty for Handling and Transfer of Materials:

Sr.no	Handling and transfer of materials	Max. Penalty	Penalty given	Remarks
a.	Loading, Unloading Hazardous materials with Coupling/uncoupling.	0.5		
b.	Hazardous material in Drums below atm. B.pt	0.3		
c.	Hazardous materials in Drums above atm. B.pt	0.6		
Total GPH - 3		1.4		

Table 4: Penalty for units within building:

Sr. no	Units with in building	Max. Penalty	Penalty given	Remarks
a.	Flammable liquids above flash point but below atm. B.pt	0.3		
b.	Flammable liquids above atm. B.pt	0.6		
Total GPH – 4		0.9		

Table 5: Miscellaneous:

Sr. no	Miscllaneous	Max. Penalty	Penalty given	Remarks
a.	Flammable materials in drums Centrifuge/open batch mixing	0.5		
Total GPH – 5		0.5		

Special Process Hazards (SPH):

Table 6: Process temperature:

Sr. No	Process Temperature	Max. Penalty	Penalty given	Remarks
a.	Flammable Materials in drums centrifuge/open batch mixing	0.5		
b.	Above flash point	0.25		
c.	Above atm. B.pt	0.6		
d.	Chem. With auto-ignition	0.75		
Total SPH – 6		2.1		

Table 7: Low Pressure

Sr. No	Low Pressure	Max.Penalty	Penalty given	Remarks
a.	Fire/explo. Hazard by air Leak in vacuum system	0.5		
b.	Hydrogen collection system	0.5		
c.	Vacuum Dist. At less than 0.65 bar with air leak hazard	0.75		
Total SPH – 7		1.85		

Table 8: Operations in a near Flammable Range

Sr. No	Operations in a near Flammable Range	Max. Penalty	Penalty given	Remarks
a.	Outdoor tanks with vapour Phase> LFL> UFL	0.5		
b.	Operation close to flammable Limits with controls	0.75		
c.	Operation within flammable range	1.0		
Total SPH – 8		2.25		

Table 9: Penalty for Operating Pressure

Sr. No	Flammable & Combustible liquids under pressure	Max. Penalty	Penalty given	Remarks
a.	Flammable & comb. Liquids Under pressure in bars. Penalty (y)=0.435*log(p)			
b.	High viscous liquids under Pressure penalty=y*0.7			
c.	Pressurized liquefied flammable Gases penalty=y*1.3			
d.	Compressed non-flammable gases Penalty=y*1.2			
Total SPH – 9				

Table 10: Penalty for Low temperature

Sr. No	Operations in a near Flammable range	Max. Penalty	Penalty given	Remarks
a.	Operations<0>-30 deg.c	0.3		
b.	Operations<-30 deg.c	0.5		

Total SPH – 10	0.8

Table 11: Penalty for Quantity of Flammable Liquids in Storage

Sr. No	Penalty for quantity of flammable liquids in storage	Max. Penalty	Penalty given	Remarks
a.	In-storage Penalty (y) for Pressurized liquefied gas y=((185-(log(e*q*10^-9/700000))^2)^5-11.45 where, e=heat comb (kj/Kg) q=in-process quantity(kg)			
b.	In-storage penalty (y) for flammable liquids y=((55-log(e*q*10^-9)/270))^2)^5-6.4			
Total SPH – 11				

Table 12: In Process Penalty for Quantity of Flammable. Liquids

Sr. No	Operations in a near Flammable range	Max. Penalty	Penalty given	Remarks
a.	In process penalty(y) Y=10^(0.305*log(e*q)-2.965) Where, e= heat comb.(kj/kg) q= in-process quantity(kg)			
Total SPH – 12				

Table 13: Penalty for loss of material through corrosion & erosion

Sr. No	Penalty for loss of material through corrosion & erosion	Max. Penalty	Penalty given	Remarks
a.	Corrosion rate less 0.5 mm/yr With pitting or local erosion	0.1		
b.	Corrosion rate over 0.5mm/yr < 1 mm/yr	0.2		
c.	Corrosion rate > 1 mm/yr	0.5		
Total SPH – 13		0.8		

Table 14: Penalty for loss of Material through leaks of joints, etc.

Sr. No	Penalty for loss of Material through leaks of joints, etc	Max. Penalty	Penalty given	Remarks
a.	Packing & gland seals likely to Give some minor leakage	0.1		
b.	Regular leak problem in pumps & flange joints	0.2		
c.	Process fluids penetrating in nature, abrasive slurries	0.4		
d.	Sight glasses, expansions joints assemblies, bellows.	1.5		
Total SPH – 14		2.2		

Computation Of DOW Index:

1. Compute Total General Process Hazard (GPH):

Sr. No	1. General Process Hazards (GPH)	Max. Penalty	Penalty given
3.1	Exothermic Reactions	6.75-8	
3.2	Endothermic Reactions	0.8-1.0	
3.3	Handling and Transfer of Materials	1.4	
3.4	Units within building	0.9	
3.5	Miscellaneous	0.5	
Total GPH		10.35 – 11.8	

2. Compute Total Special Process Hazard (SPH):

Sr. No	2. Special Process Hazards (SPH)	Max. Penalty	Penalty given
3.6	Process Temperature	2.1	
3.7	Low Pressure	1.85	
3.8	Operation in a near Flammable range	2.25	
3.9	Penalty for Operating Pressure	Formulae	
3.10	Penalty for Low temperature	0.8	
3.11	Penalty for quantity of Flammable Liquids in storage	Formulae	
3.12	In Process Penalty for Quantity of Flammable. Liquids & Compressed Liquefied Gases	Formulae	
3.13	Penalty for loss of materials through Corrosion & erosion	0.8	
3.14	Penalty for loss of Material through leaks of joints, etc.	2.2	
Total SPH			

3. GPH subfactor (sf) = ((1+GPH)*MF)

4. Fire & explosion index (F) = MF* (1+GPH)*(1+SPH)

Where,
MF - Material factor.

GPH - Total General Process Hazard.

SPH - Total Special Process Hazard.