A REPORT

ON

CONSEQUENCE ANALYSIS

&

RISK ASSESSMENT OF PIPELINE NATURAL GAS

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CERTIFICATE

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This is certify that the major project report on ***"CONSEQUENCE ANALTSIS & RISK ASSESSMENT OF PNG"*** completed and submitted to the **University of Petroleum & Energy Studies, Dehradun** by **Mr. Arham Siddiqui & Mr. Alok Rawat** in partial fulfillment of the requirement for the award of the degree of Bachelor of Technology (Applied Petroleum Engineering), 2003-07, is a bonafide work carried out by them under my supervision and guidance.

To the best of my knowledge and belief the work has been based on investigations made, data collected and analyzed by them & their work have not been submitted anywhere else for any other university or institution for the award of any degree/diploma.

Dr N.A SIDDIQUI

DATE 7-5-07

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ABSTRACT

Unlike other hazardous plant, the transmission pipelines carrying natural gas are not within secure industrial site, but are routed across land out of owned by the pipeline company. If the natural gas is accidentally released and ignited, the hazard distance associated with these pipelines to people and property is known to over 300m for a larger one at higher pressure. Therefore, pipeline operators and regulators must address the associated public safety issues.

Though complete elimination of accidents is a mirage, but we can minimize its number through effective programmes. For this an idea about the possible hazards and their extent associated with the plant and process must be known, then only we can effectively prevent accidents or mitigate its effects during an emergency. There comes the importance of consequence analysis. It helps us to find the effect of an accident or their consequences and to provide preventive methods. A perfectly made risk analysis along with their consequence report and the implementation of its recommendations will surely contribute to the improvement of safety standards.

OBJECTIVES

- To know the industrial hazards.
- To know more about the safety practices of the industry.
- To study the fire fighting facilities of the industry.

CONTENTS OF THE PROJECT

INTRODUCTION TO NATURAL GAS AND ITS PROPERTIES

Natural gas is colorless, shapeless, and odorless in its pure form. Quite interesting, except that natural gas is combustible, and when burned it liberates a great deal of energy. Unlike fossil fuels, however, natural gas is clean burning and emits lower levels of potentially harmful byproducts in the air.

Natural gas is a combustible mixture of hydrocarbon gases. While natural gas is formed primarily of methane, it can also include ethane, propane, butane, and pentane. The composition of natural gas can vary widely, but below is a table outlining the typical makeup of natural gas it is refined.

Table 1-1

Typical Constituents of Natural Gas

Category	Components	Amount,%
Paraffinic HC's	Methane Ethane Propane Butane Pentane Hexane Heptane and higher	70-98% 1-10% Trace-5% Trace-2% Trace-1% Trace-0.5% None traces
Cyclic HC's	Cyclopropane Cyclohexane	Traces Traces
Aromatic HC's	Benzene and others	Traces
Non hydrocarbons	Nitrogen Carbon dioxide Hydrogen sulfide Helium Other sulphur and nitrogen compounds water	Trace-15% Trace-1% Trace occasionally Trace-5% Trace occasionally Trace-5%

Like all gases, natural gas is a homogeneous fluid of low density and viscosity. It is odorless; odor-generating additives are added to it during processing to enable detection of gas leaks. Natural gas is one of the more stable flammable gases. It is flammable within the limits of a 5-15% mixture with air, and its ignition temperature ranges from 1,100-1,300^{O}F. Typically natural gas has an energy content of 1,000 Btu/scf, which is an important parameter because gas these days is often priced in terms of its energy content, rather than mass or volume basis.

HEALTH RELATED DATA

The principal constituents of natural gas, methane, ethane, and propane are not considered to be toxic. The American Conference of Governmental Industrial Hygienist (ACGIH) considers those gases as simple *asphyxiate*, which are a health risk simply because they can displace oxygen in a closed environment.

- The effective TLV (THRESHOLD LIMIT VALUE) for an average natural gas composition as per ACGIH, considering all of these limits as about 10,500 ppm.
- The odor threshold of odorized natural gas is about 10,000 ppm. Therefore it is unlikely that personnel will be unknowingly exposed to the TLV concentration since they detect it by odor.
- Natural gas is neither toxic nor corrosive, and it can not contaminate ground water.

The natural gas being produced and transported through the network varies in composition from one section of pipeline to another, according to the gas produced from each well. However, all pipeline sections transport natural gas containing some hydrogen sulfide. The pipeline creates no hazards for persons near the pipeline or well sites as long as the sour natural gas is contained within the pipeline.

Accidental releases of sour natural gas from the well/pipeline network could create potentially life-threatening hazards to persons near the location of the release. Due to the presence of hydrogen sulfide in the natural gas, the vapor cloud created by a release of gas to the atmosphere would be toxic as well as flammable. Persons inhaling air containing toxic hydrogen sulfide vapor could be fatally injured if the combination of hydrogen sulfide concentration and time of exposure exceeds the lethality threshold. If the cloud is ignited, persons in or very near the flammable vapor cloud could be fatally injured by the heat energy released by the fire.

INTRODUCTION TO RISK AND RISK ASSESSMENT:

Before we start with what is actually risk we should know what is a **hazard**?

Hazard is the term used for *those substances or objects which have the potential of causing harm to people or the environment and other objects.*

Risk is an abstract notion, relating to the occurrence of undesired events in the immediate or distant future. The term combines two separate notions of likelihood of one or more undesired events and severity of consequence resulting from them.

HSE documentation defines **risk** as *the probability a specified undesirable event will occur in a specified period or as a result of specified situation.*

However none of these definitions are complete, for the purpose of safety analysis the word risk is defined as "*the mathematical expectation of the consequences arising from the failure of some engineering or other system in specified period of time*". This can be expressed more concisely as" Expected cost of failure".

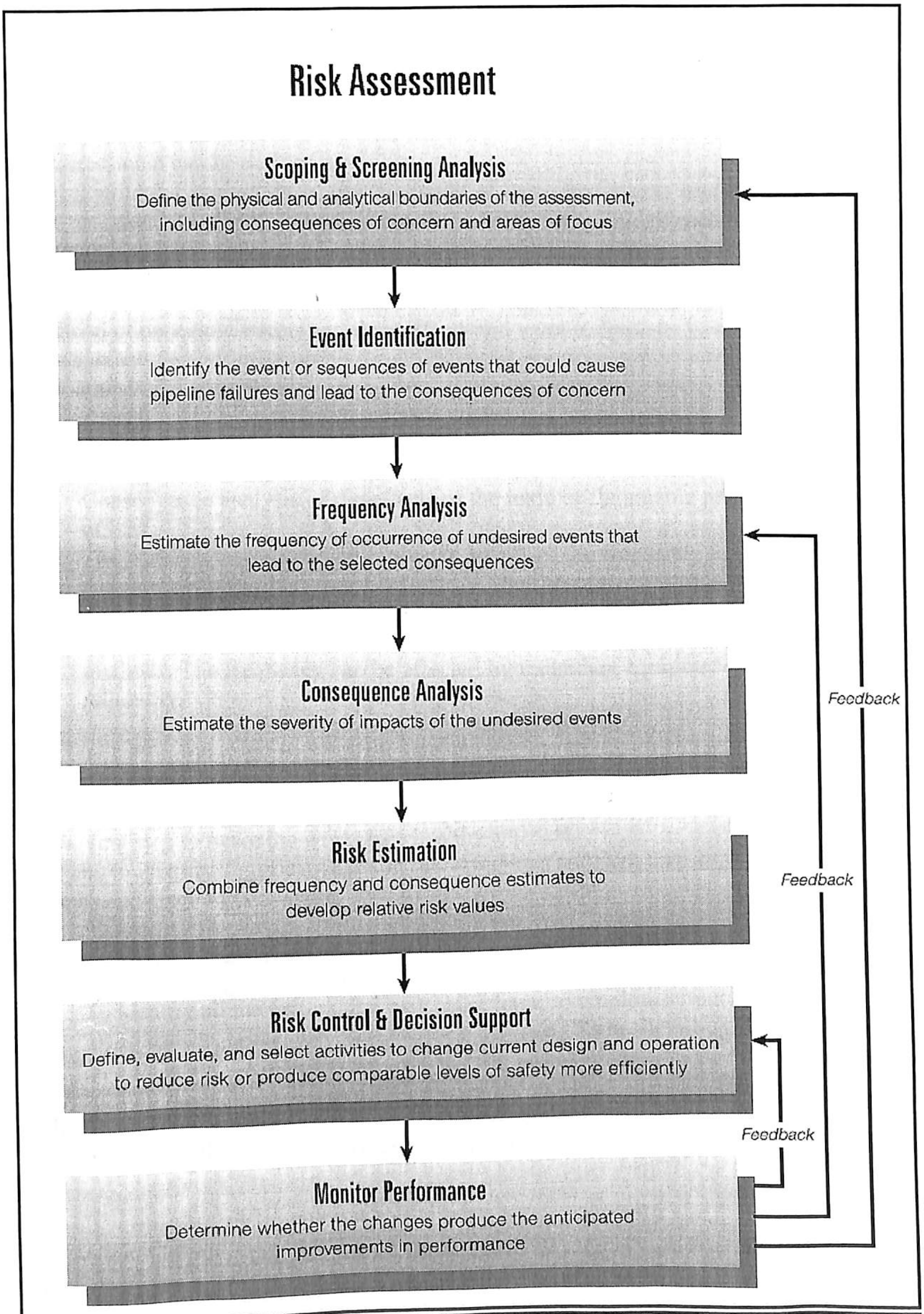
So

RISK =	EXPECTED NUMBER OF DEATHS+ EXPECTED NUMBER OF SERIOUS INJURIES+ EXPECTED LONG TERM HEALTH EFFECTS+ EXPECTED ENVIRONMENTAL EFFETS+ EXPECTED ADDITIONAL FINANCIAL LOSSES.

RISK can be mathematically defined as,

Risk = likelihood of occurrence x severity of consequence.

This means that in order to reduce risks from a particular event, one can either seek to reduce the frequency of occurrence of the undesired event or ameliorate the consequence of its occurrence by suitable siting policy (segregation distances) or other protective measures.


Risk Assessment
Scoping & Screening Analysis
Define the physical and analytical boundaries of the assessment, including consequences of concern and areas of focus
Event Identification
Identify the event or sequences of events that could cause pipeline failures and lead to the consequences of concern
Frequency Analysis
Estimate the frequency of occurrence of undesired events that lead to the selected consequences
Consequence Analysis
Estimate the severity of impacts of the undesired events
Risk Estimation
Combine frequency and consequence estimates to develop relative risk values
Risk Control & Decision Support
Define, evaluate, and select activities to change current design and operation to reduce risk or produce comparable levels of safety more efficiently
Monitor Performance
Determine whether the changes produce the anticipated improvements in performance
Feedback
Feedback
Feedback

RISK ASSESSMENT

A risk assessment should be conducted whenever a potential release can result in a toxic or flammable release that can affect the people around and the environment.

Risk assessment can be defined as:
"*The quantitative evaluation of the likelihood of undesired events and the likelihood of harm or damage being caused, together with value judgments concerning the significance of the results.*"

The key points are that it is quantitative; it requires estimates to be made of the likelihood of undesired events and their effects and value judgments have to be made.

A risk assessment consists of:

1. An estimate of the potential release quantity.
2. A quantitative evaluation of the frequency of the event.
3. A dispersion model of the release.
4. Consequence analysis of the effects of the toxic or flammable release both on and off site.
5. The consequence should be evaluated based on the frequency to determine if the risk is acceptable. If it is not acceptable, then recommendations must be made to decrease the frequency or the consequences. The consequences may be lowered by reducing the amount released, the resulting dispersion, or by mitigating methods. The frequency can be affected by redundant equipment or by increasing reliability.

Need of Risk Assessment:

It is the first step to make the workplace healthy and safe.
It's a way to identify significant risks in the workplace and then take steps to prevent accidents and ensure good health.

Purpose of Risk Assessment:

1. To identify all the factors that may cause harm to employees and others.
2. To consider what are the chances of that harm befalling anyone in the circumstances of a particular case and the possible consequence that could come from it.
3. To enable employers to plan, introduce and monitor preventive measures to ensure that the risks are adequately controlled at all the time.

Risk assessment considers a number of factors such as:

1. The likelihood or probability that an accident or incidents could occur.
2. The severity of the outcome in terms of injury, damage or loss.
3. The number of people affected.
4. Frequency of exposure to risk.
5. The maximum possible loss.

All risks assessments begin with the identification of hazards whose likelihood and consequence are then evaluated using a variety of techniques to assess the risk. Where the risk is in excess of previously defined performance standards additional risk control measures must be derived and implemented to manage the risk to an acceptable level.

The process comprises of seven basic elements:

1. Identify all hazards and their possible effects i.e., what could go wrong in connection with all activities, product or service.
2. Use screening criteria to rank and determine the significance of these hazards.
3. Assess the risk i.e. how likely is that it occur; how serious would it be to any combination of personnel the environment, property, image, etc; how could the risk be controlled.
4. Set performance standards to allow objective measurement and monitoring of the effectiveness of control measure.
5. Select risk control measures by comparing the risk assessment results to the performance standards.
6. Implement the controls.
7. Assess the effectiveness of the risk management controls through review, feedback, audit, etc and if necessary revisit or modify to ensure and maintain their effectiveness.

INDIVIDUAL STAGES OF RISK ASSESSMENT

1. HAZARD IDENTIFICATION

The first major stage in the risk assessment process is that of Hazard Identification. The methods broadly fall into two categories:

I. **Fundamental methods**: these are structured ways for stimulating a group of people to apply foresight in conjugation with their knowledge to the task of identifying hazards by raising a series of "What If"? type question. Examples of this methodology are:

HAZARDS AND OPEARBILITY STUDIES (HAZOP)

FAILURE MODEAND EFFECT ANALYSIS (FMEA)

Hazard and operability studies is a technique widely used in the process industries for systematically considering deviations from the design intent, by the application of guide words, to an operation or process flow sheet. It can be carried out at an early stage on a conceptual flow sheet, in which case only safety aspects are usually noted, or at the detailed design stage, line by line, on a piping and instrumentation diagram. In this case all deviations which are undesirable, either for safety or for operability are noted.

Failure Mode and Safety Analysis is a qualitative technique for systematically studying causes of failure and their possible effects. It was developed to identify critical components or elements in systems involved in space flight in order that the required reliability could be ensured. However, it is a general technique with wide potential and has become a standard method in reliability analysis.

II. Failure logic diagrams: these offer a pictorial for the presentation of formal logic. They encourage the analyst to speculate how a particular situation could arise or what may ensure from such a situation and hence identify the cause or outcomes of the undesired events. Their main purpose is to provide a structure to the failure logic which can be used in determination of the frequency and consequences of failure events.

Failure and Logic Diagrams are usually classified as being either top-down or bottom-up.
For example;
Fault Trees: employ a top down approach involving backwards or deductive reasoning to translate effect into causes whereas,
Event Trees: employ a bottom up approach involving forward or inductive reasoning to translate different initiating events into possible outcomes.

2. ***FREQUENCY ANALYSIS:***

The simple purpose of frequency analysis is to estimate the likelihood of each of the undesired events or accidents scenarios identified at the hazard identification stage. There are two basic approaches which are commonly employed in trying to estimate event frequencies. These are

I. To use relevant historical data.
II. To synthesis event frequencies using techniques such as fault tree analysis and event tress analysis.

The two approaches are in fact complementary, each having strengths where the other has weakness and hence, wherever possible, it is useful to pursue both. However, as with new or novel processes, there are situations where both approaches cannot be used.

3. CONSEQUENCE ANALYSIS:

This stage consists of assessing the likely impact on adjacent people and property should the undesired event occur. Normally for safety risk calculations it consists of estimating the probability that people located in different environments at different distances from the scene of the incident will be either killed or seriously injured. Sine the undesired events usually comprise either:

I. Release of toxic materials.
II. Fires and pool fires, flash fires, torches, fireballs etc.
III. Explosions (confined, unconfined, vapor cloud, condensed phase)
IV. Projection of debris.

One needs approximate consequence models for predicting casualty probabilities for these events. With release of flammable and toxic materials the appropriate models have to be able to reflect difference in release mode; for flammable release they also have to be able to reflect possible difference in the mode of combustion.

4. CALCULATION OF RISK LEVELS:

The output from a full 'safety' risk analysis would be expected to contain estimates of a number of parameters:

I. Individual Risk (IR) to members of the general public.
II. Societal Risk (SR) to the general public.
III. Occupational Risks (OR) amongst the workforce.

5. ASSESSMENT:

In order to make fullest use of any risk analysis, there is an eventual need to tackle the fundamental question of 'what is an acceptable level of risk'. Unless the question can be answered on some sort of basis it is difficult to assign rational limits to be expenditure of resources for safety improvement on a particular activity. It is nearly always possible to effect some reduction in risk levels by increased capital expenditure. However the problem is that one can soon enter a region of rapidly diminishing returns, where relatively large capital expenditure only secures a marginal reduction in risk and where really the money would be far better spent on reducing risks elsewhere. To avoid this problem one has to be able to determine when enough has been done, and when the risks are broadly acceptable. However it should also be immediately pointed out that there are a number of considerations to be taken into account when deciding whether a given risk is acceptable or not, of which the absolute size of the risk is but one.

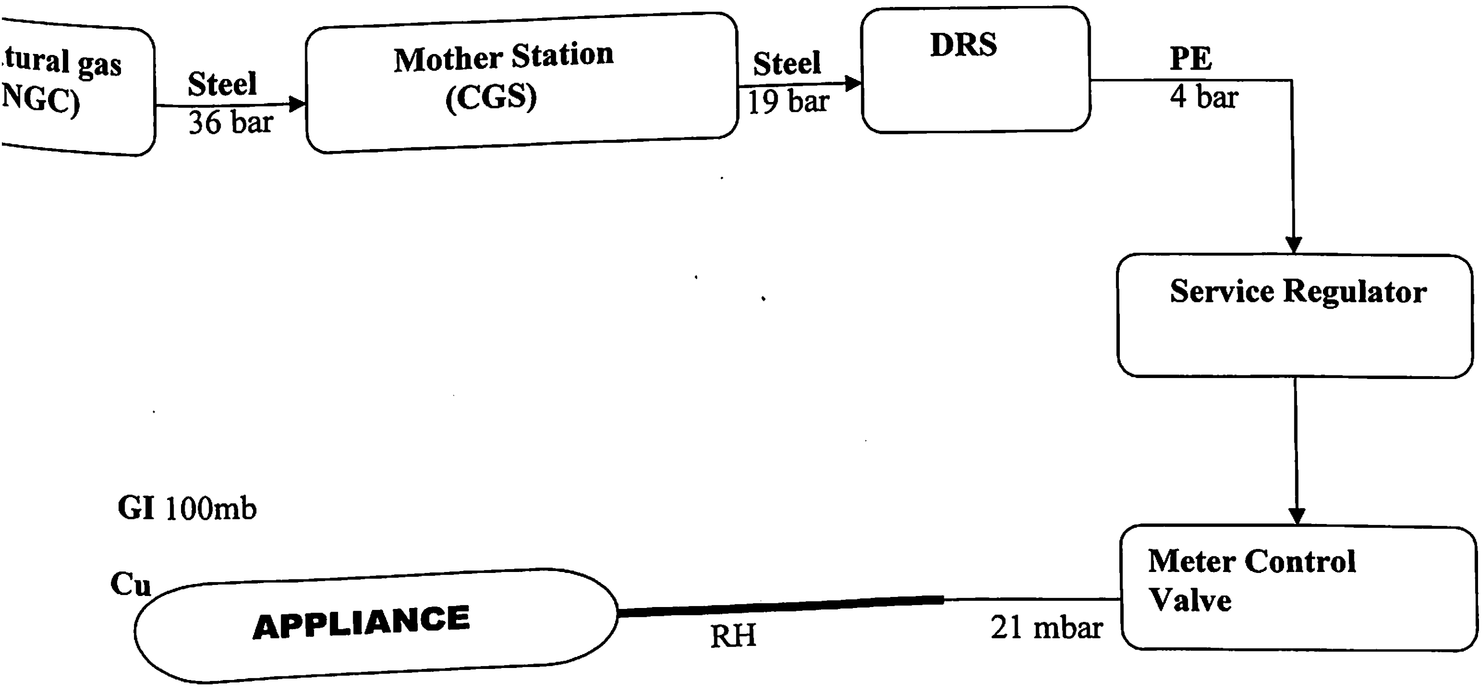
PIPED NATURAL GAS (PNG)

All the gas pipelines carrying gas above 4 bar are seamless pipes steel pipes which are internationally approved. These pipes are 100% radio graphed for welding joints and laid1.5 meters below ground level. These lines are also given cathodic protection inclusive of insulating joints to avoid corrosion. The gas pipelines for local area network are served by district regulating stations (DRS) and are laid underground as the gas pressure is above 4 bar. These pipes are yellow in color and are made of medium density polyethylene material (MDPE).

The pipe is laid at the centre of a trench of adequate depth with non-corrosive proper quality sand bed of at least 150mm. The MDPE line underground in the main streets has a working pressure of 4 bar the above pressure is further brought down to 100mbar and again to 21mbar finally at the customer site by installing a metering and regulating stations (MRS).

PNG NETWORK DETAILS

For an example sake lets take the network Mahnagar Gas Limited in Mumbai::



DRS: District Regulating Station.
MCV: Meter Control Valve
SR: Service Regulator.
RH: Rubber Hose.
Cu: Copper.
PE: Polyethylene.
GI: Galvanized Iron.

SAFETY FEATURES OF PNG NETWORK

INBUILT SAFETY FEATURES OF BASIC STEEL GRID:

- Basic steel grid conforms to the requirement of ASME b 31.8.
- Enhanced wall thickness over design, to take care of mechanical impact.
- Steel pipelines meets fracture toughness test requirement, which offers better impact resistance.
- More stringent weld joints acceptance criteria applied over API 1104 requirements.
- All welded joints are subjected to 100% X ray / Gamma ray examination against code requirement of 30%.
- World's best available corrosion protection technique applied in the form of 3 layer PE coating in addition to cathodic protection.
- All steel fittings are of forged seamless type and conforms to ASTM a 234.
- The steel pipeline is hydrotested at more than 150% of maximum allowable operating pressure.
- Steel pipelines are laid underground with 1 meter top cover against code requirement of 0.75 m.
- Warning tape with "danger gas main below" placed 300m above gas pipelines.
- Isolating valves installed at approximately 3 km intervals against code requirement of 8 km.
- QA/QC of all materials and construction activities carried out by reputed third party inspection agency.
- Regular patrolling by pipelines walker for ensuring safety and avoiding third party interference damage to the pipeline.

Inbuilt Safety Feature Of MDPE Gas Distribution Network

- MDPE pipe conforms to the requirement of British Gas Standard BG/PL2-PART1.
- Type testing of pipe is carried out at 17 bar pressure and at 20 deg centigrade temperatures for 5000 hrs, before start of commercial production.
- Pipeline is laid underground with 1 meter top cover.
- The PE main is pneumatically tested at 1.5 times the maximum working pressure of 4bar.
- MDPE pipe can be easily squeezed off for stopping gas supply in case of emergency.
- Best method of PE jointing is through use of electro fusion fitting
- Isolation valves are provided in PE network at strategic locations.
- Maximization of low pressure network (0.1 bar), to the extent of 75% of total PE network, in and around the domestic societies.

- Testing of low pressure network at 6 bar though the operating pressure is only 0.1 bar
- Use of tapping saddles help in taking tap offs from live gas mains without stoppage of gas supply and purging operations, thus ensures continuity of gas supply.

District Regulating Stations (DRS): Device Used To Reduce The Pressure From 19 Bar To 4 Bar

- Consisting of two streams, so that in case of failure of one stream, gas supply is still maintained through standby stream, thus ensures continuity of gas supply.
- 2 no's clam shut valves provided to shut off the gas supply when the pressure at downstream side increases beyond the desired limits. Hence downstream is protected from over pressurization.
- Relief valve provided to protect against downdtream over pressurization.

Service Regulators (SR): Device Used To Reduce The Pressure From 4 Bar To 0.1 Bar

- Consists of an inlet and outlet isolation valves.
- Over pressure shut off device in built in regulator to protect against downstream over pressurization.
- Incorporated with creep relief valve to protect against downstream over pressure.

Meter Regulators: Device Used To Reduce The Pressure From 0.1 Bar To 21mbar And Fitted In Kitchen:

- Inbuilt with low pressure cut off device, which shuts off the regulator when the inlet pressure falls to below 13mbar.
- Lock up pressure is 30mbar which helps in protecting the down stream piping and apparatus from over pressurization.
- Re pressurization safety devices fitted to prevent the regulator from re opening even when the inlet pressure is restored, unless there is downstream back pressure i.e. all connected appliances have been turned off.

Metering And Regulations Stations (MRS): Device Used To Reduce The Pressure From 19 Bar Or 4 Bar To Required Outlet Pressure:

- Consist of two streams, so that in case of failure of one stream gas supply is maintained through standby stream, thus ensuring continuity of gas supply.
- Slam shut valves provided to shut off the gas supply when the pressure at downstream side increases beyond the desired limits, hence downstream is protected from over pressurization.
- Relief valve provided to protect against downstream over pressurization.

COMPRESSED NATURAL GAS:

An alternative fuel for motor vehicles, considered one of the cleanest fuels because of low hydrocarbon emissions and its vapors are relatively non-ozone depleting. However, it does emit a significant quantity of nitrogen oxides. Compressed Natural Gas, is the best available environment friendly auto fuel in India, for Western India in particular (and hopefully in Eastern India in near future) with the availability of Natural Gas and the long coastline permitting the import of LNG.

CNG IN INDIA:

CNG movement was started by GAIL in Delhi, Mumbai and Baroda in 1992 as a pilot project. Gujarat Gas Co. Ltd. also established a few CNG stations in Surat and Ankleshwar. Delhi and Mumbai have now developed CNG distribution infrastructure on a fairly large scale. The largest players of CNG business in India today are IGL (Indraprastha Gas Limited) at Delhi and MGL (Mahanagar Gas Limited) at Mumbai.

ADVANTAGES OF CNG:

- The most economical and environmental friendly fuel available.
- Though the initial cost of conversion kit may seem to be high, the same can be recovered in less than 2 years because of low operating cost.
- CNG is environment friendly, no cancer causing particulates, less carbon monoxide and hydro carbon emission, less ground level ozone contamination and green house gases effects.
- CNG is much safer than gasoline, diesel fuels or LPG. If released, CNG does not liquefy or accumulate. It dissipates in the air because Natural Gas is lighter than air and thus less prone to ignite or explode.
- CNG reduces engine wear, more than doubling engine life because CNG burns clean and leaves no carbon deposits.
- CNG offers lower maintenance cost. It is dry gaseous fuel and does not dilute the lubricant oil, thus saving on oil filter and oil changing. Intervals between tune ups for CNG vehicles are stated to be more than 70,000 km.
- If CNG is used, there is complete freedom from adulteration by solvents, kerosene or any other harmful substance.
- Because CNG is already in a gaseous state, it offers superior drivability even under severe hot and cold weather conditions.
- CNG has high Octane Number when compared with petrol/ diesel which makes it superior in terms of combustion efficiency.
- Per unit of energy Natural Gas contains less carbon than any other fossil fuel and therefore produces lower CO_2 emission per vehicle kilometer traveled.

Safety in Compression Storage And Dispensing Of Natural Gas

1. SAFETY ASPECTS FOR CNG COMPRESSORS:

- Design of compressors conforms to API 618/ Other Relevant International Standards.
- Construction of piping/ tubing of compressors conform to ANSI B 31.3.
- All electrical devices, control panel, instrumentation and electric motors (flame proof type) are suitable for hazardous area classification class I, Division I, Group D as per NEC or Zone-I, Group II A/II B as per IS/IEC specification or equivalent specification.
- Pressure Relief Valves on inlet and all stages to prevent pressure built-up above predetermined set point.
- Protection against high gas discharge temperature.
- Protection against high cooling water temperature and low flow.
- Protection against high inlet pressure, inter stage and discharge.
- Protection against low lube oil pressure.
- Intrinsically safe control system.
- Gas detection system inside compressor enclosure.
- Noise level < 75DB at a distance of 1meter around the perimeter of compressor enclosure.
- ESD (emergency shut down) system is provided.

2. CNG CASCADES

- The cascade frame is fabricated using structural steel to house 20-40 cylinders fixed rigidly to avoid displacement, both lateral and rotational movement.
- The cylinders are made of seamless chrome-mol alloy steel as per IS: 7285, Gas Cylinder Rules 1981 and prior approval of Chief Controller of Explosives, GOI.
- Each cylinder is equipped with a shut off valve and safety relief device consisting of burst disc assembly and the cylinder valve conforms to requirements of IS: 3224.
- Pre piping/ inter connection tubing of cylinders and fittings meet the requirements of ANSI B31.3.
- Each cylinder is clearly marked:
  - ✓ For CNG only!
  - ✓ Manufacturer's marking and serial number.
  - ✓ Date of last Hydro Test with Test Pressure.
  - ✓ Working Pressure.
  - ✓ Tare Weight, Water Capacity.
- All cylinders are periodically examined and retested once every five years as per the requirements of Gas Cylinder Rules 1981.

3. SAFETY ASPECTS FOR DISPENSING UNITS:

- Design of dispenser conforms to NFPA- 52, NZS 5425/ relevant international standards.
- Dispensing units have overfilled protection through pressure limiter device.
- Construction of piping/ tubing of dispenser conforms to ANSI B31.3
- All electrical and electronic component is suitable for hazardous area classification class I, Div. I, Group D.
- Dispenser is provided with emergency shut of valve.
- All electrical solenoid valves close with removal of power from dispenser.
- Dispenser automatically shuts off CNG supply, in case of power failure, low flow and overfill.
- Refueling hose designed for a minimum burst pressure of four times maximum working pressure with electrical conductivity.

4. CNG INSTALLATION SAFETY:

- All CNG installation are done as per the layout plan approved by Chief Controller of Explosives (CCOE), Nagpur. Safety guidelines for locating CNG equipments as laid down by CCOE/ OISD179 is followed.
- All electrical fittings, lighting etc used in CNG installation area are suitable for hazardous area classification.
- All dispensers are installed on raised plinth to prevent hitting of vehicle that comes for refueling.

5. CNG VEHICLE SAFETY:

- Mobile cascades are mounted and secured on dedicated Light Commercial Vehicles/ Trailer.
- All carriers carry warning sign boards on all its 3 sides as per rules for transporting hazardous gases. Trailers are provided with hydraulic braking system for safe operation.
- All carriers are provided with spark arrestors on exhaust pipe.
- Fuel feed lines are made of high pressure stainless steel tubing.
- A non return valve in the vehicle refueling connection protects against back flow.
- CNG regulator provided with relief valve in the 1st stage to avoid excess pressure built-up.
- Quick action shut off valves, one at the storage cylinder and other at refueling valve.

Benefits Of Natural Gas A Transportation Fuel

Economics

- On a gallon-equivalent basis, natural gas costs an average of 15 to 60% less than gasoline and diesel.
- Natural gas is clean-burning fuel that reduces vehicle maintenance. Many CNG vehicles owners report that oil changes are needed only every 16,000-32,000km.Standard spark plugs last as long as 120,000km.
- Natural gas, unlike liquid fuels, cannot be siphoned from a vehicle. Fuel theft is an ongoing concern of fleet mangers.
- Vehicles can be 'fast filled" in five to six minutes using compressed gas stored in cascades of natural gas cylinders or fuelled overnight on a "timed fill" basis in about five to eight hours. Many private fleet fueling across stations use a combination of fast fill and timed fill.

Emissions

- Natural gas is the cleanest burning alternative fuel. Exhaust emissions from CNG vehicles are much lower than those from equivalent gasoline-powered vehicles. For instance, CNG vehicles emissions of carbon monoxide are approximately 70% lower, non-methane organic gas emission are 89% lower, and oxides of nitrogen emissions are 87% lower. In addition to these reductions in pollutants, CNG vehicles also emit significantly lower amounts of greenhouse gases and toxins than do gasoline vehicles.
- Dedicated CNG vehicles produce little or no evaporative emissions during fuelling and use. For gasoline vehicles, evaporative and fuelling emissions account for at least 50% of a vehicle's total hydrocarbon emissions. Dedicated CNG vehicles also can reduce carbon dioxide exhaust emissions by almost 20%.
- Exposure to the levels of suspended fine particles matter found in many U.S. cities has been shown to increase the risk of respiratory illness. Diesel exhaust is under review as a hazardous air pollutant. Natural gas engines produce only tiny amounts of matter.
- Green House Gases, natural gas contains less carbon than any other fossil fuel, and thus produces lower CO_2 emissions per vehicle mile traveled. While compressed natural gas vehicles do emit methane, another principle greenhouse gas, any slight increase in methane emissions would be more than offset by a substantial reduction in CO_2 emissions compared to other fuels. CNG vehicles also emit very low levels of carbon monoxide (approximately) 70%nlower than a comparable gasoline vehicles and volatile organic compounds. Although these two pollutants are not themselves greenhouse gases, they play an important role in helping to break down methane and some other greenhouse gases in the atmosphere, and thus increase the global rate of methane decomposition.

Vehicle emissions	By PETROL (gms/km)	By CNG (gms/km)	Daily reductions (Kgs/day)
Carbon dioxide	**272**	**212**	**465144**
Carbon monoxide	**3.80**	**0.90**	**22482**
Nox	**0.52**	**0.33**	**1473**
Sulphur dioxide	**0.21**	**0.01**	**1550**
Particulates	**0.0035**	**0.00**	**27**
Benzene	**0.01**	**0.00**	**78**
1,3 Butadiene	**0.001**	**0.00**	**8**
Total			**490762**

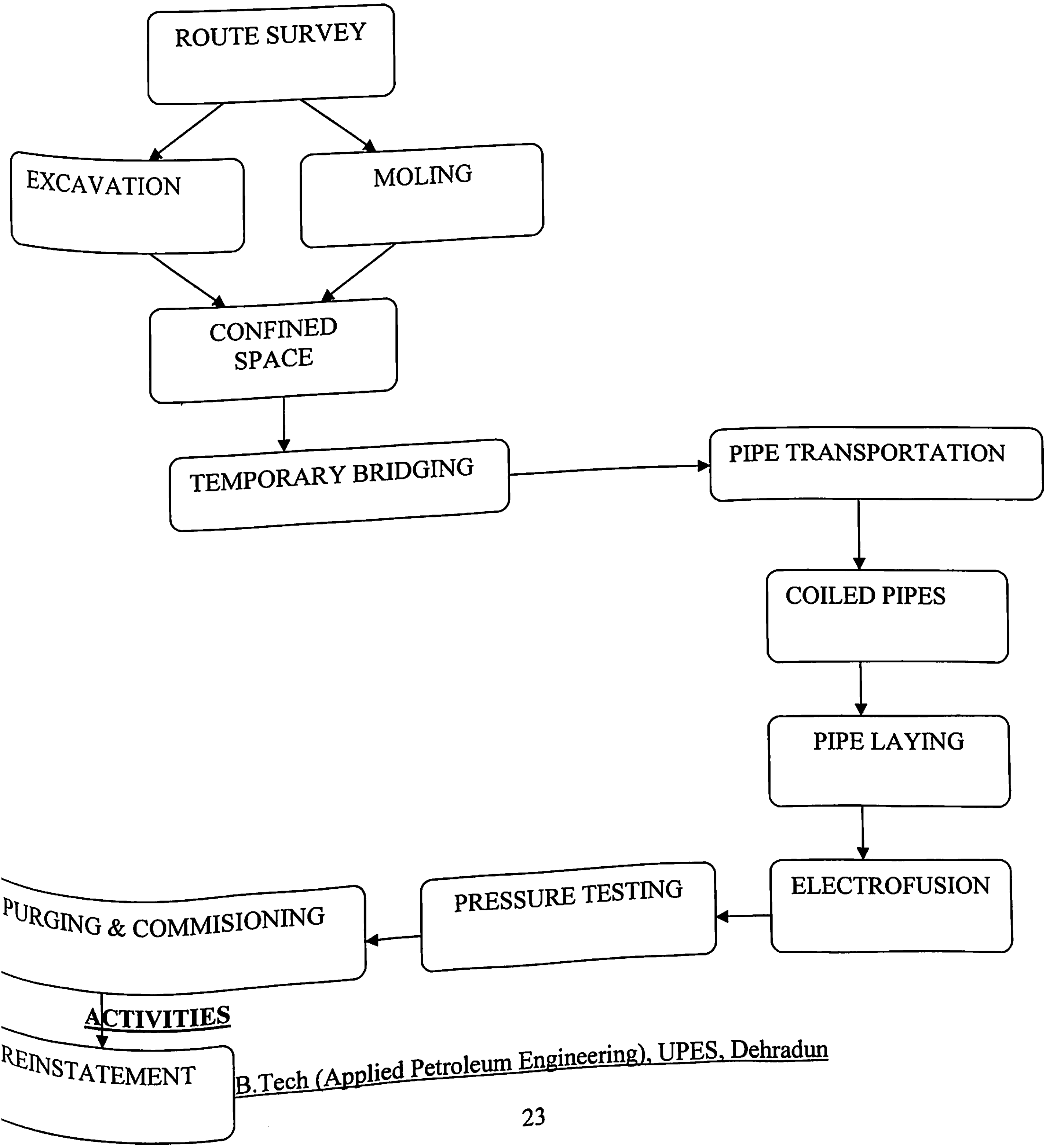
SAFETY:

- Vehicles that run on clean burning natural gas are as safe as vehicles operating on traditional fuels such as gasoline.
- There are two fundamental reasons for this excellent NGV safety record: the structural integrity of the NGV fuel system and the physical qualities of natural gas as a fuel.
- The fuel storage cylinders used in NGVs are much stronger than gasoline fuel tanks. The design of NGV cylinders are subjected to a number of federally required" severe abuse" tests, such as heat and pressure extremes, gunfire, collisions and fires.
- While fuel storage cylinders are stronger than gasoline fuel tanks, the composite material used to encase the tanks are fundamentally more susceptible to physical damage than metals under abusive conditions. For this reason, composite materials on NGV cylinders must always be properly handled and protected. Incidents involving natural gas cylinders ruptures revealed that some form of chemical attack or physical damage to the composite over wrap on the cylinders was involved.
- NGV fuel systems are "sealed", which prevents any spills or evaporative losses. Even if a leak were to occur in an NGV fuel system, the natural gas would dissipate into the atmosphere because it is lighter than air

PNG HAZARD IDENTIFICATION

Hazard identification plays a major role in preventing accidents. Pipe laying involves various activities which are highly dangerous for those who are involved in the activity and for the public. A proper identification of hazards in each and every activity helps to take preventive actions to avoid accidents and to train the workers about the safe working procedures. Here some of the major activities which are taken and its hazards are identified.

Main Activities Identified For Hazard Identification



ACTIVITIES

1. ROUTE SURVEY.
2. MOLING.
3. CONFINED SPACE.
4. TEMPORARY BRIDGING.
5. PIPE TRANSPORTATION.
6. PIPE LAYING.
7. WORK AT HEIGHT.
8. COILED PIPES.
9. ELECTROFUSION.
10. PRESSURE TESTING.
11. PURGING & COMMISSIONING.
12. REINSTATEMEN.

HAZARD IDENTIFICATION

ACTIVITY NO: 1 ROUTE SURVEY AND EXCAVATION

S.NO: 1	SAFE PROCEDURES FOR ROUTE SURVEY AND EXCAVATION	HAZARDS IF NOT FOLLOWED
1.1	Use a cable locator before and during excavation.	If not used, excavators may damage pipelines and other utilities including electricity which may lead to loss of the life and property.
1.2	Dig excavations by hand to expose underground plant prior to using mechanical excavators.	----------------DO---------------------
1.3	All excavations over 1.2m deep, or made in unstable ground conditions, shall be supported.	Chances of caving and persons may get trapped inside.
1.4	Sufficient space (minimum 300mm shall be left between the trench side and excavated material).	Danger of small work tools and debris failing in to the trench, and workers getting trapped underneath.
1.5	Use a ladder (or other aids), where it is not easy to get in and out of trenches.	Overstressing may cause cramps also person may tumble in to pit due to inappropriate access.
1.6	Check trench supports and road plates daily.	Collapse of these items will cause serious injuries or death.

1.7	Seek advice before you enter a trench deeper than 2m use a safety harness and lifeline.	Some trenches may contain poisonous gases or less oxygen which may lead to fainting/death. With out life line rescue will take more time
1.8	Provision of suitable protection like barricades caution tapes to show the existence of trenches.	Lack of these indicators result in persons failing in to excavations especially during night time.
1.9	Wear high visibility clothing when working in or near a main road.	Workers may be hit by vehicles.
1.10	If excavations is done in water logged area first the water should be pumped out use gum boots.	Water logged trenches may contain sharp objects snakes etc. which may not be visible also the chance of trench collapsing is there due to wet soil.
1.11	During excavation if any new lines are observed the matter should be immediately reported and work should be stopped.	Working near a newly unidentified exposed line may create problems of shock, gas leakage, fire.
1.12	Signs and barriers and/or road tape and pins shall be used around the excavations.	Persons/ vehicles will fall or get trapped.
1.13	The emergency telephone number should be displayed.	During an accident emergency services may be delayed which will worsen the situation.
1.14	Excavations shall be illuminated at night with appropriate waning lamps where necessary.	People will fall in to the trenches.
1.15	Do not go below bottom of foundation level, unless specifically instructed.	This may lead to the collapse of the structure which in turn results in huge fatalities.
1.16	Do not load edge of the pit.	The pit will collapse which will cause the workers inside the trench getting trapped.
1.17	If an excavated pit is covered, ensure that the cover is properly secured.	Falling of personnel.
1.18	Always keep an eye on excavating soil.	Dangerous reptiles will be present sometime.

Activity No: 2 Moling

S.NO: 2	SAFE PROCEDURES FOR SOIL DISPLACEMENT MOLING	HAZARDS IF NOT FOLLOWED
2.1	Detailed working instructions for the use of particular type of equipment should be obtained from the manufacturer and used.	Working with out knowing the proper operations will result in accidents.
2.2	Follow the cable avoidance procedure.	Shock, fire etc may result.
2.3	Avoid launching the mole towards cables or other plant.	This will damage those utilities which may led to gas escape fire etc.
2.4	Never leave the equipment unattended whilst in operation.	The equipments will lose direction some times and may damage other utilities structures etc. which may lead to emergency.
2.5	Make sure that the air supply valve is within easy reach of the operator.	If not then machine can not be stopped in the event of an emergency.
2.6	The operator shall not stand in the reception pit.	Because of the risk of being struck by the equipment.

Activity No: 3 Confined Space

S.NO: 3	SAFE PROCEDURES FOR CONFINED SPACE ENTRY	HAZARDS IF NOT FOLLOWED
3.1	Entry only if work permit is obtained	Lack of permit may lead to many problems which can put the life of workers into danger. Like abrupt energizing of electric lines, flow of gases.
3.2	Person entering confined space should be briefed about the hazards and the emergency procedures to be followed.	If not during emergency he may not know what to do which may cost his life.
3.3	All sources of energy affecting the space have been isolated.	Abrupt energizing will lead to accidents.
3.4	Testing of atmospheres is conducted, verified and repeated as often as defined by risk assessment.	If not done, the work space may catch fire due to flammable gas, lack of oxygen or presences of poisonous gas will danger the worker.
3.5	Standby person is stationed.	To assist the worker in case of emergency.

3.6	All necessary PPE's should be used (including oxygen cylinder in case of oxygen deficient atmosphere)	Lack of PPE's will cause injury suffocation etc.
3.7	Sufficient fire fighting equipment's should be in place.	To deal with any unexpected fire.

Activity No: 4 Temporary Bridging

S.NO: 4	SAFE PROCEDURES FOR CONFINED SPACE ENTRY	HAZARDS IF NOT FOLLOWED
4.1	Where temporary steel road plates are required, then they shall be minimum thickness: Heavy traffic load 20mm Light loading traffic 10mm Driveways and accesses 5mm	Collapse of plates will cause vehicles fall into trenches.
4.2	Do not work under a roadplate unless traffic is halted.	Working under traffic will result in serious injuries if vehicles fall in to trench.
4.3	Check the condition of all roads plated daily.	Deteriorated plates will collapse.
4.4	Support all road plates by overlapping each side of the trench by 600mm.	This practice will give adequate stable support.

Activity No: 5 Transportation

S.NO: 5	SAFE PROCEDURES FOR PE PIPE TRANSPORTATION	HAZARDS IF NOT FOLLOWED
5.1	Pipe should not be pushed or pulled over rough or sharp edges. Protection against contact with sharp objects is necessary and pipe should not be dropped.	Pipe strength deterioration leaks which will result in gas escape, fire etc.
5.2	No other materials should be placed on top of polyethylene pipe during transportation. Care must be taken when cutting the straps.	PE pipe will get damaged which will cause the gas to escape leading to emergency.
5.3	Crane hooks, chains and wire ropes should not be used in direct contact with pipe coils or bundled packs.	------------DO--------------
5.4	It is possible to receive a mild electric shock from the build-up of static electricity whilst handling polyethylene pipe. Persons handling pipes should be made aware of this.	Shock even if small, the person will lose his balance and fall down.

5.5	Where the pipes may be subjected to intense prolonged sunlight they should be protected from direct exposure during storage.	Quality of pipe will be lost which will affect the strength of the pipe
5.6	Polyethylene pipe and fittings should not at any time be situated where contact is possible with aggressive chemicals, such as lubricating and hydraulic oils, and chemical solvents.	Deterioration of pipe will take place which will affect the strength.
5.7	At no time should polyethylene pipe or fittings be in contact with hot surfaces.	High temperatures will affect the strength of the pipe which may lead to gas escape and fire.

Activity No: 6 Coiled Pipes

S.NO: 7	SAFE PROCEDURES FOR COILED PIPES	HAZARDS IF NOT FOLLOWED
6.1	Any personnel using a coil dispenser should be given training.	Lack of training will lead to unsafe acts and accidents.
6.2	When the pipe is manufactured, plastic tape is used to restrain the pipe.	Else it will lash and cause injuries
6.3	Great care should be taken when unwinding coiled pipe.	Careless unwinding will result in the abrupt release of coil which will cause injury.
6.4	The plastic banding should be cut progressively from the outer to the inner bands as the pipe is dispensed.	If not done this way the coil will whiplash.
6.5	Where a coil dispensing trailer is not being used and the coil is to be unwound then: Enough room should be cleared so that the coil does not obstruct traffic. One person should progressively cut the banding on the coil from the outer to inner bands.	Lack of space will create unsafe conditions also traffic will get affected, all these factors lead to accident.

Activity No: 7 PE Pipe Laying

S.NO: 7	SAFE PROCEDURES FOR PE PIPE LAYING	HAZARDS IF NOT FOLLOWED
7.1	PE pipes must not be laid 1. In positions where the pipe is exposed to day light. 2. Above ground unless encased in a suitable protective sleeve. 3. Where solvents, detergents and other harmful chemicals are present. 4. If it is damaged or scored deeper than of the wall thickness.	All these will affect pipe strength and will cause gas leak and fire.
7.2	PE pipe will be marked with the company name: the manufacturer's name and the word GAS at regular intervals along its length.	To make sure about the quality and make of pipe for safe use.
7.3	The standard color for PE pipe used is yellow. Care should be taken when working on buried mains as some cables are also colored yellow.	Work on similar colored lines ay lead to accident/ damage.
7.4	Where possible PE mains and services should be laid with a clearance of at least 300mm from other plant and obstacles.	This is to avoid the effects of other lines like electric cables other utility supplies.
7.5	A minimum cover of 1 meter should be maintained above the surface of the PE pipe.	If not load or impacts above the pipe which may lead to rupture.
7.6	All pipes shall have warning tape buried 100mm to 30mm above the pipe.	This helps to remind the excavators (workers) about the presence of the gas pipeline immediately below, there by avoiding the chances of striking the lines with the excavating tools.
7.7	PE pipes must be laid on a bed of sand or other soft materials free from sharp objects and covered over with the same material.	Presence o sharp materials will cause damage to pipe in case of loading above the pipeline.

Activity No: 8 Wok at Height

S.NO: 8	SAFE PROCEDURES FOR WORK AT HEIGHTS	HAZARDS IF NOT FOLLOWED
8.1	Follow safety work permit system	Existence of unsafe conditioned improper communications.
8.2	Tool box talks prior to start riser installation.	To educate workers about the hazards involved and to deal

		with it.
8.3	Select the best route for safe installation of riser.	Avoiding risky routes will make the work easy and safe.
8.4	Prefer mechanical winch type Jhoola rather than manual handling tool.	Manual handling will not be smooth and safe; moreover it becomes tiring for the operator.
8.5	Tie rope of Jhoola with column or strong secured support on terrace.	To avoid rope slipping and falling down while usage.
8.6	Install fall arrestor with rope from terrace support to the ground floor along with the Jhoola/Platform.	The fall arrestors will save the workers from falling.
8.7	Check required PPEs like Safety Belt, Hard Hat, Safety Goggles etc, and conditions of drilling machine with cables, before its use.	PPEs help to avoid injuries,.
8.8	Ensure safe keeping/handling of material, tools and tackles on Jhoola/ platform, to prevent its fall from height.	People standing below get injured.
8.9	Ensure smooth operations of lowering/lifting of Jhoola to avoid any jerk-imbalance.	Jerk will sway the lowering worker who may get injured by hitting walls or other structures.
8.10	Do not work at height during strong wind/ adverse weather.	Bad weather will cause slipping swaying etc, which will lead to injuries.
8.11	Utmost care shall be taken while walking on asbestos roof.	Fragile roof will break easily and the person will fall down.
8.12	Use crawling board to walk/ work on asbestos roof.	Without crawling board the roof will break due to person's weight.
8.13	Underside safety net may be used to arrest a falling person.	This final layer safety precaution is important to prevent a person falling and hitting the ground.
8.14	Place a ladder so that the horizontal distance from the base to the vertical plane of the support is approximately $1/4^{th}$ the ladder's length between supports.	Place ladder other than this will cause ladder to slip and injury to worker.
8.15	Do not place a ladder in front of a door that opens toward the ladder unless the door is locked.	Abrupt opening of door will result in person falling down.
8.16	Tie the ladder at the top and bottom.	Else ladder will slip.
8.17	Extend the ladders side rails at least 3ft above the top landing.	This will give stability and easy for the workers to use ladder.
8.18	No ladder shall be used which is coil, grease or other slippery material on the steps or rungs.	This will result in person slipping and falling down.

Activity No: 9 Electrofusion

S.NO: 9	SAFE PROCEDURES FOR ELECTROFUSION	HAZARDS IF NOT FOLLOWED
9.1	The Electrofusion technique shall not be used if there is gas in the atmosphere greater than 20% LEL.	Chance of fire.
9.2	If work is carried out in the dark or poor light, then adequate lighting arrangements need to be made available.	Inadequate lighting arrangements will lead to accidents like falling down, tripping etc.
9.3	Do not take an Electrofusion box into the trench or use in a gaseous atmosphere.	Electrofusion box is not intrinsically safe so it may cause fire.
9.4	Stand clear whilst fusion is in progress.	If not chance of burns and shock.

Activity No: 10 Pressure Testing

S.NO: 10	SAFE PROCEDURES FOR PRESSURE TESTING	HAZARDS IF NOT FOLLOWED
10.1	Testing may not be carried out against closed valves, squeeze offs or other temporary flow stopping device.	Pressure build up results in rupture which will injure the workers.
10.2	Any anchorage points in open trenches must be checked at regular intervals whilst the system is being pressurized at intervals during the test.	This is to check the stability of pipe else over pressure will cause pipe movement.
10.3	Do not enter any excavations during the test.	This will cause serious injuries or death in case of pipe rupture.
10.4	All excavations should be back filled prior to testing except test points.	This will help to reduce the impact of rupture if any.
10.5	Open excavations must be securely guarded and warning notices advising the public and other employees that a main is being tested shall be displayed.	Without the warning symbols people may fall in to the pits.
10.6	No person enter or remain in an excavation from the time pressurization begins and until the test is completed and the main fully de-pressurized.	Danger of pipe rupture and getting injured.
10.7	Al test ends must be examined prior to pressurization.	This will help to find any weak points if any and take counter measures to avoid rupture.

10.8	Any connections or other joints not included in the pressure test must be tested with a leak detection fluid at operating pressure immediately after commissioning.	Else pressure buildup will cause these items to break and injuring people also this will allow gas to escape and catch fire.
10.9	The test pressure must be raised slowly	Else sudden rise in pressure may cause violent pipe burst.
10.10	Care should be taken not to over-pressurize.	Over pressure will lead to pipe rupture and there by injuring those in the vicinity.

Activity No: 11 Purging

S.NO: 11	SAFE PROCEDURES FOR PURGING	HAZARDS IF NOT FOLLOWED
11.1	Exclude all ignition sources within 5m of any gas purging operation.	Fire hazard.
11.2	Prevent the build-up of static electricity in PE pipes by using wet rags in contact with both the pipes and the ground.	Static electricity will cause shock to workers. Even if it is small reaction due to shock will result in indirect accidents.
11.3	Make fire extinguishers available and position them for immediate use.	Lack of extinguishers will lead to big fires.
11.4	Provide warning signs to alert the public.	Warning signs help to remind public about the hazards and the adequate measures to be taken.
1.15	Exercise care when venting/purging large volumes of gas in built-up areas.	Chance of fire.
1.16	All vent points must be installed before the purging operation commences and must terminate with a flame trap at least 2m above.	Flame trap prevents the ingress of sparks.
1.17	All personnel involved in the commissioning exercise must be briefed on the sequence of operation and their rules immediately prior to the operation. Method of communication and roles of individuals to be given in the approved written procedure.	Proper communication and clarity of duties will make work easier as it will avoid omissions and helps in immediate response in case of emergency.

Activity No: 12 Reinstatements

S.NO: 12	SAFE PROCEDURES FOR PURGING	HAZARDS IF NOT FOLLOWED
12.1	Where the excavated material is to be reused, the surface material shall be kept separate from the sub-soil, so that the suitable layers may be replaced in the correct order.	This will affect the environment especially in agricultural areas.
12.2	Avoid standing near to the trench while doing the back filling.	Persons may fall in to the trench.
12.3	Use all necessary PPE	Lack of PPE's helps to prevent injuries.

Therefore we can say that identification, evaluation and control of hazards in processes are essential to loss prevention and require a comprehensive knowledge of the chemical and physical aspects of the unit being studied. Unrecognized hazards have been created in existing processes by change in process condition, operating practices, or equipment; inadequate knowledge of reactions; or behavior of materials of construction.

An accurate assessment of the potential of each identified hazard will assure that release of hazardous materials and the resulting injuries and the property loss will be minimized. Sound engineering knowledge must be applied to formulate corrective measures.

CONSEQUENCE ANALYSIS

Consequence analysis involves estimating how severe the impacts of the identified event or sequence of events will be on human health and safety, the environment, availability of service, or other factors included in the operator's risk management program.

Consequence analysis must consider not only the events that lead up to loss of pipeline containment, but also other events (e.g., success/failure of isolation valves) and considerations (e.g., population distribution) that could affect the severity of these consequences.

Consequence analysis usually considers the following:

- The amount of hazardous substance released;
- The physical pathways and dispersal mechanisms by which the substance can reach and affect workers, the public, environmental resources, etc.;
- The amount of substance that would actually be expected to reach the workers, public, and environmental resources through these pathways;
  &
- The expected effect of the released substance on the person, environmental resource, etc

Consequences of events can be estimated qualitatively, quantitatively, or both.

Qualitative processes often use relative categories such as severe, significant, moderate, or insignificant to depict the severity of these consequences. Often the qualitative categories are calibrated to ranges of quantitative consequences (e.g., "significant" might be assigned to events with an expected consequence of between one and five serious injuries per year).

Quantitative processes calculate the expected severity level in number of fatalities, serious injuries, and so forth.

Semi-quantitative processes often use a numeric index to estimate the relative consequences of events.
For example, an event that is expected to lead to a fatality may be assigned an index score of 100; an event that leads to a serious injury may be assigned a smaller index score; and an event that leads to moderate property damage may be assigned a still smaller index score to indicate the relative importance, or value, placed on these impacts.

A gas release can have many consequences and the idea should be to try to consider them all. This is a complex task and needs a structured approach. Here is this done on the basis of a failure case definition tree. These figures are called trees because they have a branching structure which describes alternatives sequences of events. At each node, or branching point, a question is asked about the release; the answer determines which path we should then follow. For all these trees if it's likely that both answers are possible, then both paths should be followed.

Failure case, definition trees is simple. It helps to choose the appropriate event tree by asking questions about properties of release.

Flammable gas event tree

Since flammable gases are usually only a danger if they ignite, identifying the sources and probabilities of ignition is very important part of the analysis.
According to the timing of ignition, it is convenient to divide the ignition into two categories:

1. **Immediate Ignition:**
In this case the gas is ignited while it is still escaping from containment. Immediate ignition prevents a large cloud of vapor developing, but can result in a jet flame or a fire ball, depending on the nature of release. These can cause damage in the immediate vicinity of the release but rarely affect anything outside the plant boundary.

2. **Delayed Ignition:**
This occurs after the material has escaped from containment and has formed a cloud which is drifting downwind. Delayed ignition can result in an explosion or a flash fire, which can cause widespread damage. Heat and pressure effects calculated for fires and explosions are used to assess fatalities and material damage, and also to determine whether there are likely to be any "knock on" effects, such as damage to another piece of equipment which contains hazardous materials.

Another important part is the calculation of density of the cloud since density is a major factor in determining how far the cloud travels and spreads before it is diluted own to a safe concentration. The choice of the appropriate model for dispersion is made according to the density of the cloud relative to ambient air.

SCENARIO:

Leakage Of Piped Natural Gas (PNG) At 19 Bar Through A 6cm Hole Which May Be Due To Any Excavation Activity:

PNG steel network is running through all parts of the city. So here in this consequence analysis we assume that there will be a leakage in the steel pipe due to excavation or any other reason.

Aim: To find the area affected by release of the gas, Fire, Explosion if any.

Through this modeling we shall be able to find the radius of exposure, the intensity of heat and its effect on people and the property.

As consequence modeling is a complex process many assumptions are made to compensate the lack of data's and calculations have been done on the simplest level.

INPUTS:

CHEMICAL NAME: NATURAL GAS

Molecular Weight	16 kg/kmol
Density at 1 atm and 30° C	0.6 kg/m^3
Boiling point	-161.49 °C
Specific volume at 30° C and 1 atm	1.55m^3 /kg
Heat of combustion	50 MJ/kg
Diameter of pipe hole (rupture)	6cm
Area of pipe hole (rupture)	2.826x10^{-3} m^2
Pressure inside the pipe	19 bar

STEP 1: TO FIND THE GAS DISCHARGE RATE

METHOD: use of gas flow equation for calculating discharge rates for gases from sources under pressure.

OUTPUT: gas discharge rate.

CONSTRAINTS: the simple equation assumes ideal gas behavior which is probably reasonable for all but very high (near critical) pressure.

The method discharges from vessels and pipes containing gas under pressure are normally readily calculated using standard equation for gas flow. The first step in the calculation is to determine whether the flow is critical i.e. sonic, or choked, or sub critical. The distinction is made as follows, assuming reversible adiabatic expansion and ideal gas behavior.

- ***Flow is critical if***
  $Pa<P1*[2/(\gamma+1)]$ ^ $\{\gamma/\gamma-1\}$
- *Flow is sub-critical if*
  $Pa<P1*[2/(\gamma+1)]$ ^ $\{\gamma/\gamma-1\}$

Pa=1.013*10^5 Pascal
P1=19*10^5 Pascal
$\gamma=1.3$

So on calculating the above values we find that
1.013*10^5<19*10^5*[2/ (1.3+1)] ^ {1.3/1.3-1}

So here the flow comes out to be critical.

For critical flow Y=1

Now we shall calculate the discharge rate using the formula taken from Crane (1981)

$$Q=YC_dA_rP_1\left[(M\gamma/RT_1)(2/\gamma+1)^{\wedge(\gamma+1)/(\gamma-1)}\right]^{\wedge}(1/2)$$

Where,
Q= rate of release (Kg/s)
M=molecular weight
T_1=temperature of the gas (Kelvin)
A_r=area of the hole in the pipe.
P_a=ambient pressure (Pascal)
P_1=process reservoir pressure (Pascal)

R=universal gas constant
$\gamma = (C_p/C_v)$ specific heat ratio
Y=1

Here,
M=16
$T_l=300^0K$
$A_r=2.826*10^{-3}$
$P_l=19*10^5$ Pascal
$P_a=1.013*10^5$ Pascal
R=8310 joules/Kelvin/mol
$\gamma = 1.3$
$Q= 1*1*2.826*10^{-3}*19*10^5 \, [(16*1.3/8310*300)\,(2/\,1.3+1)^{\wedge (1.3+1)/(1.3-1)}]^{\wedge}(1/2)$
Q= 9.082 Kg/s

STEP 2: <u>TO FIND THE DISPERSION PATTERN OF THE JET</u>

<u>METHOD</u>: SIMPLE JET MODELS

<u>OUTPUT</u>: for a given distance from the release point the concentration and velocity on the jet axis and the concentration profiles at right angles to the axis.

<u>CONSTRAINTS</u>: plume characteristics can be calculated where jet momentum is dominating the mixing process.

The TNO model that is used here is relatively simple model which is applied to a jet of vapor at ambient conditions. In most cases the material will not be at ambient conditions immediately after the release. The temperature will be lower than ambient temperature and if the lower than ambient temperature and if the flow was choked, the pressure will be above ambient conditions. The jet is modeled as equivalent jet with the same release rate as the real out flow but with ambient out flow conditions.

The equivalent jet emerges from an orifice with an equivalent diameter (D_{eq})

$$D_{eq}= D_o \sqrt{(O'_{go,\,a} / O'_{g,\,a})}$$

D_o= diameter of the real orifice used in the outflow conditions.
$O'_{go,\,a}$= density of the gas immediately after release.
$O'_{g,\,a}$=density of the gas at ambient conditions.

The density of the gas inside the pipe is obtained as 10.26 kg/m^3.The density becomes almost 0.6 immediately after the release so in this case we can assume that $D_o = D_{eq}$

$O'_{g,a} = 0.6\ kg/m^3$
$O'_{go,a} = 0.6\ kg/m^3$
$D_o = D_{eq} = 0.06m$

The Concentration Profile of the Jet:
The concentration on the axis of the jet at a distance x from the orifice is given by,
$Cm = ((b_1+b_2)/b_2)/ [(0.32*x*1/D_{eq})*(O'_{g,a}/(O'_{go,a})^{1/2})+(1-O'_{go,a})]$

Where b_1 and b_2 the distribution constants given by:
So $b_1 = 50.5+48.2\ O'_{g,a} - 5O'^2_{g,a}$
$b_2 = 23+41\ O'_{g,a}$

$O'_{g,a} = 0.6\ kg/m^3$ $O'_{go,a} = 0.6\ kg/m^3$ $D_{eq} = 0.06m$

$b_1 = 75.47$ $b_2 = 47.5$

The concentration on the axis of the jet at a distance "x" from the orifice

$Cm = ((b_1+b_2)/b_2)/ [(0.32*x*1/D_{eq})*(O'_{g,a}/(O'_{go,a})^{1/2})+(1-O'_{go,a})]$

The concentration on the axis of the jet at a distance 1m from the orifice,

$Cm = ((75.47+47.5)/47.5)/ [(0.32*1*1/.06)*(0.6/(0.6)^{1/2}) + (1-0.6)]$
$= (1.63/4.50) = 0.362\ Kg/m^3$

1 K of natural gas at 300^0C and at 1 atmosphere occupies $1.55m^3$ so the volume % of gas in atmosphere = 0.362*1.55=0.561=56%

By similar calculations we can find the volume % of gas at different distances along the axis. This helps us to find the flammable distances range.

- Concentration at a distance 4m from the point of discharge along the axis i.e. C_4
  $C_4 = 0.097\ Kg/m^3$
  Volume %=0.097*1.55=0.1503
  =15.03% (Upper Flammability Limit)
- Concentration at a distance 7m from the point of discharge along the axis i.e. C_7
  $C_7 = 0.057\ Kg/m^3$
  Volume %=0.057*1.55=0.88
  =8.8%

- Concentration at a distance 10m from the point of discharge along the axis i.e. C_{10}
  $C_{10} = 0.0390\ Kg/m^3$
  Volume %=0.0390*1.55=0.0604
  =6.04%

- Concentration at a distance 11m from the point of discharge along the axis i.e. C_{11}
  C_{11}=0.0357 Kg/ m^3
  Volume %=0.0357*1.55=0.0553
  =5.53% (Near To Lower Flammability Limit)

So from the above calculations we can roughly say that along the axis the flammability range is from 4 to 11m.Even though many other factors like the wind direction and other atmospheric factors will have considerable effect in the limit range.

The concentration profile in a plane at right angles to the axis of the jet is given by:

$$C_{xy}/C_m=e^{\{-b_2 (y/x) 2\}}$$

C_{xy} =concentration at a point a distance x from the orifice and a distance y from the axis.
This is the concentration at a point which is 1m from the point of discharge and 0.223 from the axis.

- $C_{1,0.223}=C_1* e^{\{-b_2 (y/x) 2\}}$
  $=0.362* e^{\{-47.6(0.223/1) 2\}}$
  =0.0339 Kg/ m^3
  =1.55*0.0339=0.525
  =5.25% (near to LFL)

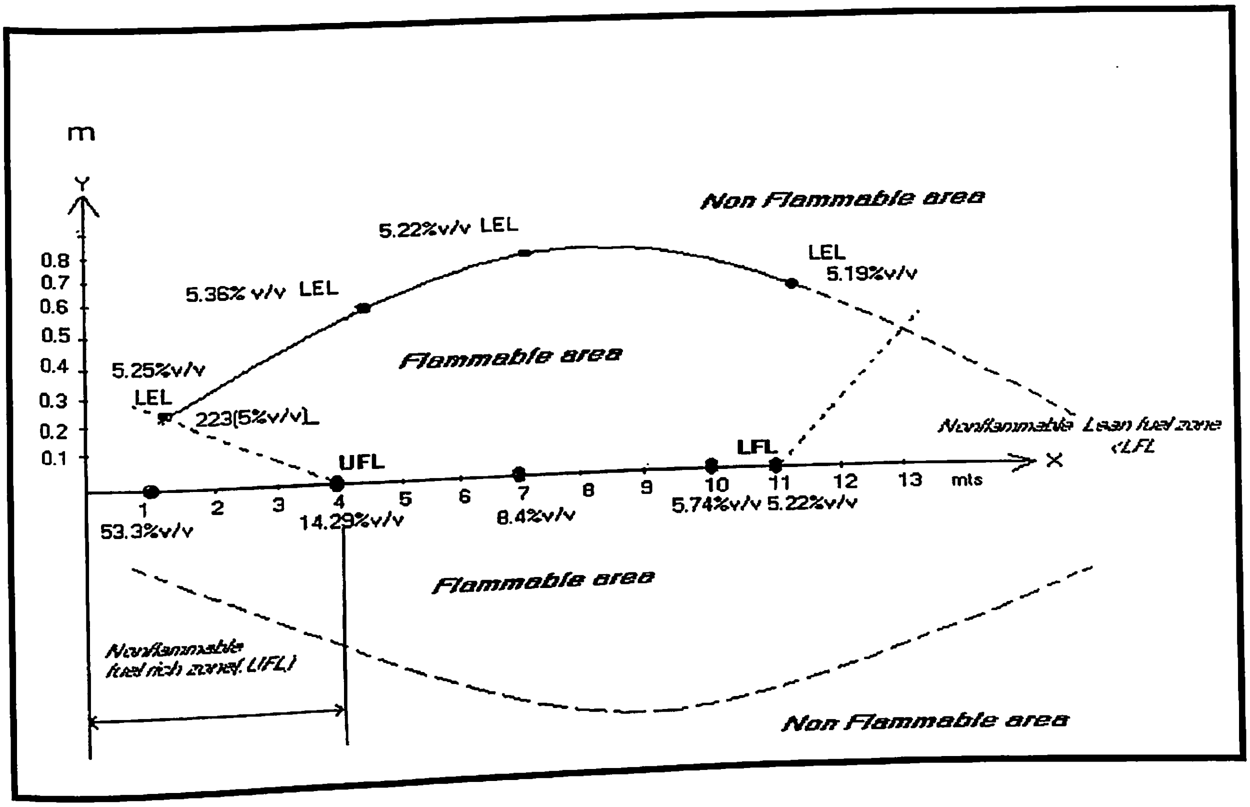
- $C_{4,0.588}=C_4* e^{\{-b_2 (y/x) 2\}}$
  $=0.097* e^{\{-47.6(0.588/4) 2\}}$
  =0.0346 Kg/ m^3
  =1.55*0.0346=0.536
  =5.36% (near to LFL)

- $C_{7,0.735}=C_7* e^{\{-b_2 (y/x) 2\}}$
  $=0.057* e^{\{-47.6(0.0.735/7) 2\}}$
  =0.0337 Kg/ m^3
  =1.55*0.0337=0.522
  =5.22% (near to LFL)

- $C_{10,0.560}=C_1* e^{\{-b_2 (y/x) 2\}}$
  $=0.0390* e^{\{-47.6(0.56/10) 2\}}$
  =0.0335 Kg/ m^3
  =1.55*0.0335=0.519

=5.19% (near to LFL)

By incorporating the above values of jet concentration we can find out the flammable range of the dispersed gas.



Concentration profile of the jet

The End of the Turbulent Mixing Phase:

The speed of the jet will drop with distance along the axis, until at a certain point on the axis; the jet speed will equal the wind speed. At this point the released has ceased tube a momentum jet and must be modeled differently. The velocity distribution along the axis of the jet is given by:

$$U_m/U_o = (O'_{go,a} / O'_{g,a})*b_1/4[(0.32*x/ D_{eq})*(O'_{go,a} / O'_{g,a}) + (1- O'_{go,a})]$$

U_m= velocity on the axis at a distance x from the orifice.

U_o= real out flow velocity of the release calculated as follows.

U_o= Mo/ [C_d* $O'_{go,a}$ *Π*(D_o/2)^2]

D_o = diameter of orifice in meters=0.06m

C_d = coefficient of discharge=1

$O'_{go,a}$ = 10.26 Kg/m^3

$O'_{g,a}$ =0.6 Kg/ m^3

Mo=mass flow rate (Kg/s) =9Kg/s

$U_o = 9/[1 * 10.26 * 3.14 * (0.06/2)^2]$
$= 310.4$ m/sec

The analyst should calculate the X_w, the value of x at which Um equals the speed of the wind, and the centre line portion corresponding to X_w. This will help to fix a boundary for the dispersion or as we can eliminate concentration below the flammability limit.

$U_m/U_o = (O'_{go,a} / O'_{g,a}) * b_l / 4[(0.32 * x * 1/D_{eq}) * (O'_{go,a} / O'_{g,a}) + (1 - O'_{go,a})]$

- Velocity of gas at x=10m= U_{10}

$U_m = U_o (O'_{go,a} / O'_{g,a}) * b_l / 4[(0.32 * x * 1/D_{eq}) * (O'_{go,a} / O'_{g,a}) + (1 - O'_{go,a})]$
$= 310.4 (0.6 / 0.6) * 75.57 / 4[(0.32 * 10 * 1/.06) * (0.6 / 0.6) + (1 - 0.6)]$
$= 11.32$m/s

Similarly,
U_{12}=9.43 m/s
U_{20}=5.64m/s
U_{30}=3.75m/s

So roughly we can say at about 35m from the point of discharge the velocity of the gas equals to velocity of gas equals to velocity of wind or the jet will end at 35 m.

- So here we get the flammable range of jet as 4 to 11 m.
- The velocity of jet at the point of discharge as 310.4m/s.
- The entire length of the jet with out considering the flammable range as 35m.

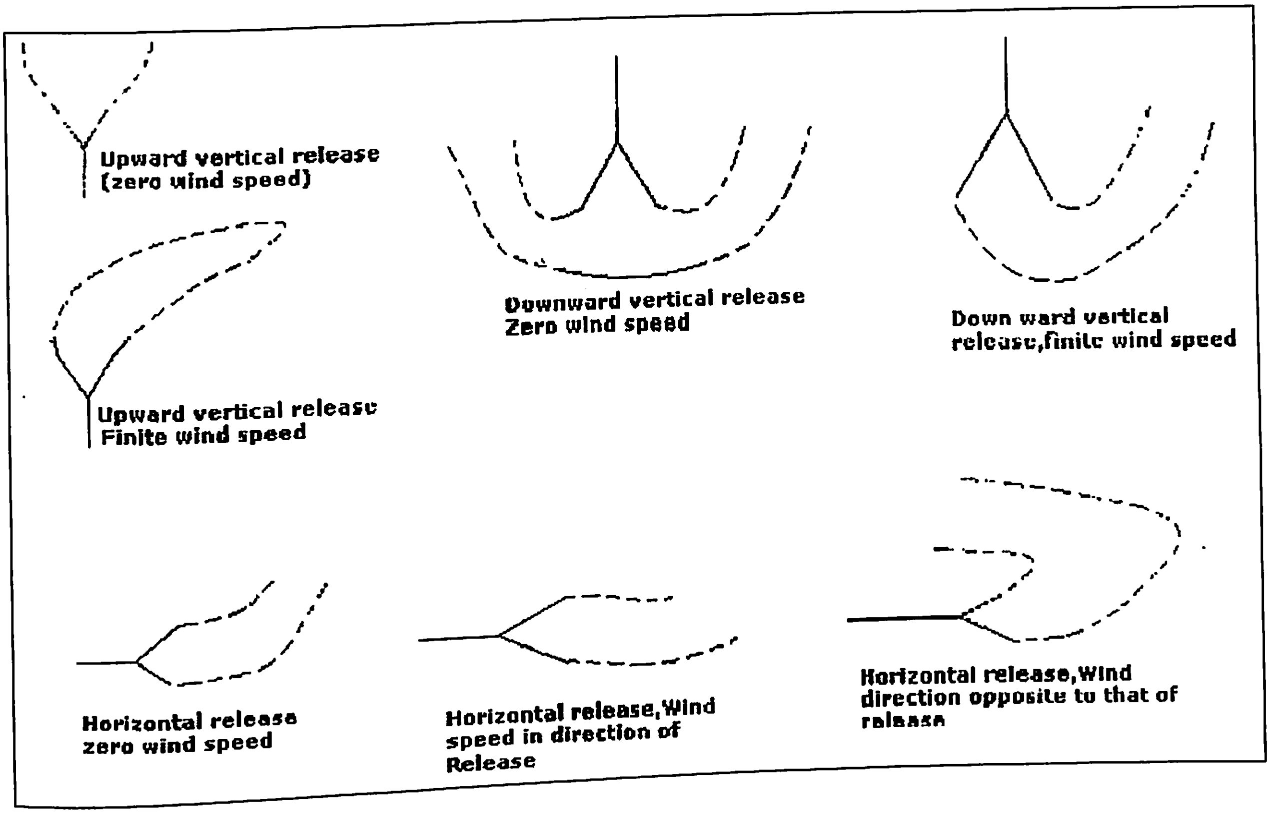
STEP 3: <u>TO FIND THE DISPERSION OF BUOYANT PLUME</u>

<u>Dispersion of a buoyant plume:</u>

METHOD: Brigg's Buoyant Surface release model to determine whether a plume on the ground will become air-borne, followed by Brigg's Plume Rise Model to calculate the trajectory of the release and Gaussian Dispersion to calculate the ground level concentration.

OUTPUT: Plume trajectory and concentrations.

CONSTRAINTS: Based upon empirical observations.



DISPERSION PATTERNS

There are several stages in modeling a plume of material with a density less than that of the surrounding air. Normally in the case of less dense case like natural gas it will lift off. There is no need of calculations in this case but for gases where density is close to that of air lift off, calculations are required to find whether the gas will move up. If the plume does lift off, the next stage in the modeling is to calculate the rise of the plume as a function of a distance downwind. Using the Gaussian dispersion model with the appropriate value, for plume elevation.

Rise of the Plume:
The rise of the plume as a function of distance down wind depends on such factors as the relative density of the plume, the wind speed and the atmospheric stability. The stability in particular has a very important effect on the final height reached by the plume, and the concentrations experienced at the ground level. In stable conditions the plume rises until it encounters warm air. It then no longer experiences a buoyancy force so no longer rises. The models used here are applicable to neutral and stable conditions and this model is called Brigg's Model.

For all the stability conditions the initial rise of the plume is as follows:

$\Delta h = 1.6\ (X^{2/3} / u)*F^{1/3}$

F= buoyancy flux parameter.

$F = (1 - O'_{go,\,a})*g*u^2*r^2$

Where
U= speed of the wind (m/s)=3m/s
g= acceleration due to gravity=10 m/s
r= radius of the orifice=0.03 m/s

$F = (1 - O'_{go,\,a})*g*u^2*r^2$
$= (1 - 0.6)*10*3^2*0.03^2$
$= 0.0324$

$\Delta h = 1.6\,(X^{2/3} / u)*F^{1/3}$

For stable conditions the plume rise equation given above holds approximately to a down wind distance of
$X = 2.4u/\sqrt{s}$
$= 2.4*3/(6.67*10^{-3})^{1/2}$
$= 87.80m$
$\Delta h = 1.6\,(87.80^{2/3} / 3)*0.0324^{1/3}$
$= 3.29$ m
The initial rise of plume is about 3.29 m

For neutral conditions the plume will continue to rise indefinitely although the above equation is valid only apart of the rise. Briggs suggests the conservative approximation that the plume rises according to the equation above until it reaches a ceiling height at a distance downward given by:

$X = 6.49*F^{2/5}*h_s^{3/5}$ for $h_s < 300m$

$X = 6.49*F^{2/5}$ for $h_s > 300m$

h_s = height of the stack (for a release from the ground a nominal stack height such as 1m should be used)
$S = (g/T)*(\partial E/\partial z)$ where S is the stability parameter and T is temperature in °C
$= (10/300)*0.02$
$= 6.67*10^{-3}$
$\partial E/\partial z$ is a measure of the atmospheric temperature gradient. For stable conditions $\partial E/\partial z$ is in the range of 0.01-0.03 °C /m. beyond this down wind distance the plume levels off about.

Beyond 87m downwind distances the plume levels off at about:
$\Delta h = 2.9(F/us)^{1/3}$
$= 2.9(0.0324/ (3*6.67*10^{-3}))^{1/3}$
$= 3.4m$

STEP4: MODELLING OF JET FIRE

METHOD: Use of radiation formula to determine intensity of radiated heat.

OUTPUT: Heat intensities

CONSTRAINTS: Estimated radiations levels close to the base of the flame may be subject to error due to flame lift-off at the source.

The model is taken from API RP 521, "FLARE RADIATION". The flame is modeled as a series of point sources spaced along the centre line of the jet with all sources radiating equal quantities of heat Q_P.
The heat radiated Q_p, for a release rate Q and n_p point sources given by:

$Q_p = \hat{A} * Q * H_c$

$\hat{A}$= efficiency factor (taken as 0.35)
Q= Release Rate 9Kg/s
H_c= Heat of Combustion= 50 Megajoules/Kg

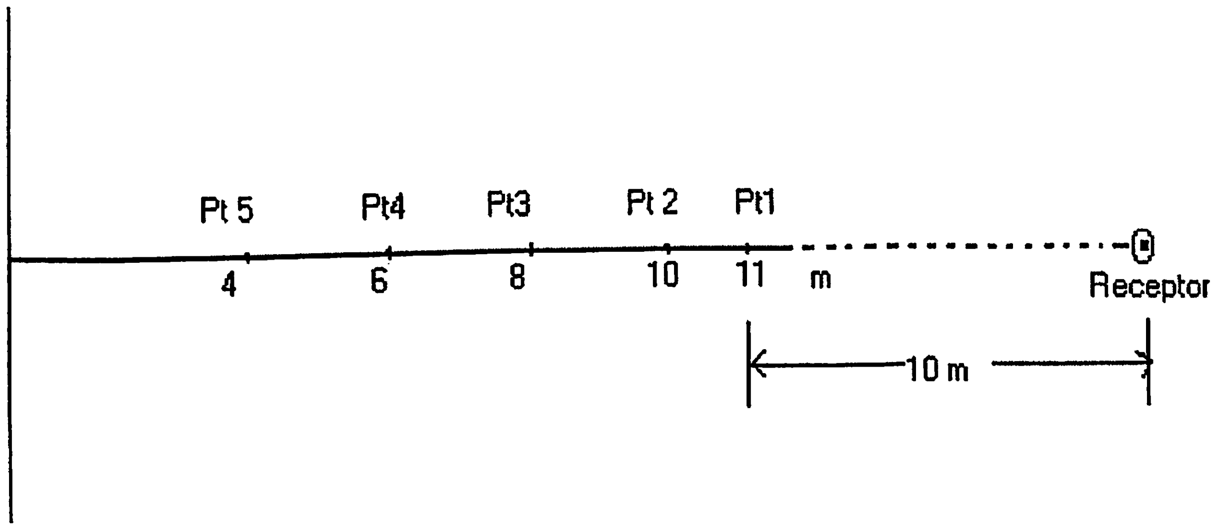
$Q_p = \hat{A} * Q * H_c$
$= 0.35*9*50*10^6$
$= 157.5*10^6$

The size of the jet is obtained from the jet dispersion model by taking the length from the orifice to the LFL. But in the case of heat flux its better to take length upto LFL/1.5. The choice of np is arbitary. Five points are usually adequate for hazard analysis.

The radiation I from a particular point in the flame to a receptor at distance r is given by
$\mathbf{I = (X_g * Q_P)/(4\Pi r^2)}$

X_g = Emissivity factor (for jet fires it can be taken as 0.2)

The length of the flame is obtained about 11m from the initial calculations so while calculating the radiations received from a particular point we are taking points as r=4,6,8,10,11 m from the discharge point. Now we should find the sum of heat radiated from each point.



Radiation received by a receptor at a distance r=10m(ie the distance from point 1) from the flame end is given by

$I_{11} = (X_g * Q_p)/ (4 \Pi r^2)$
$= (0.2*157.5*10^6)/ (4*3.14*10^2)$
$= 25.9$ KW/m^2

Radiation received by a receptor from point 2 (10m from orifice) from the flame ie r=11m is

$I_{10} = (X_g * Q_p)/ (4 \Pi r^2)$
$= (0.2*157.5*10^6) / (4*3.14*11^2)$
$= 20.72$ KW/m^2

Radiation received by a receptor from point 3 (8m from orifice) from the flame ie r=13m is

$I_{08} = (X_g * Q_p)/ (4 \Pi r^2)$
$= (0.2*157.5*10^6)/ ((4*3.14*13^2)$
$= 14.84$ KW/m^2

Radiation received by a receptor from point 4 (6m from orifice) from the flame ie r=15m is

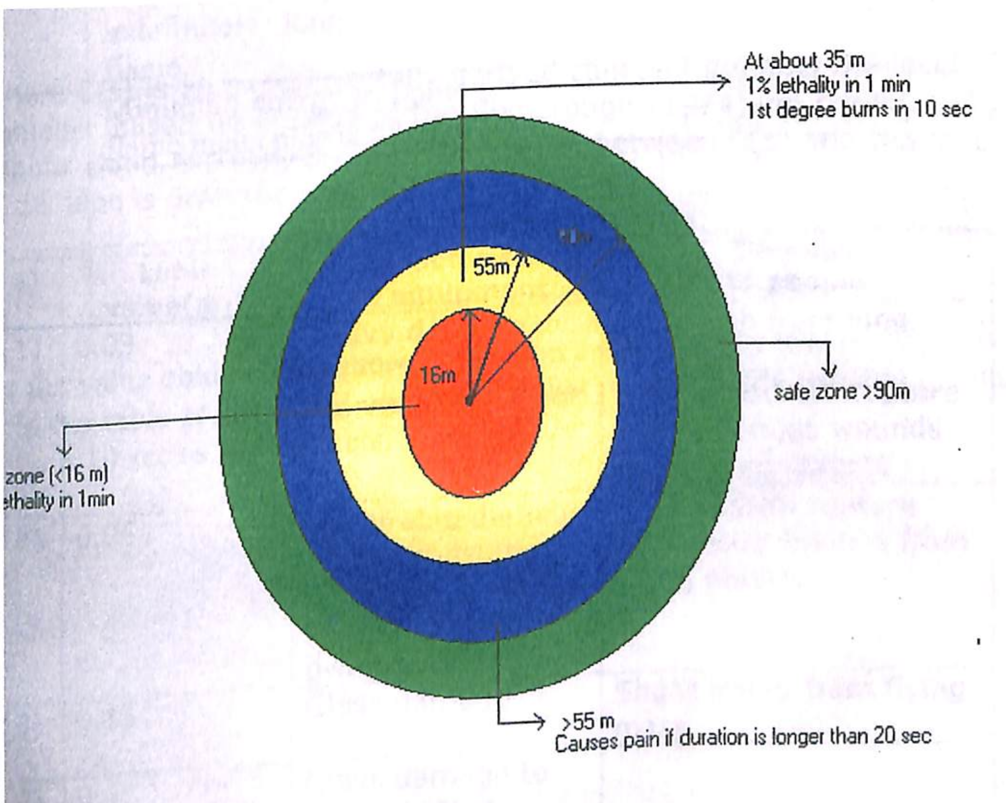
$I_{06} = (X_g * Q_p) / (4\,\Pi r^2)$
$= (0.2*157.5*10^6) / ((4*3.14*15^2)$
$= 11.15\ KW/m^2$

Radiation received by a receptor from point 5 (4m from orifice) from the flame ie r=15m is

$I_{04} = (X_g * Q_p) / (4\,\Pi r^2)$
$= (0.2*157.5*10^6) / ((4*3.14*17^2)$
$= 8.67\ KW/m^2$

The total heat flux at 10m distance from the flame is the summation of the radiation from each point, from the flame:
$I = I_{04} + I_{06} + I_{08} + I_{10} + I_{11}$
$= 8.67+11.15+14.84+20.72+25.9$
$= 81.29\ KW/\ m^2$

Here we get the heat intensity of the jet. Based on this we can calculate the fire damage.



FIRE DAMAGE

STEP5: CALCULATE FIRE DAMAGE

METHOD: fire damage estimates are based upon correlations with recorded incident radiation flux and damage levels.

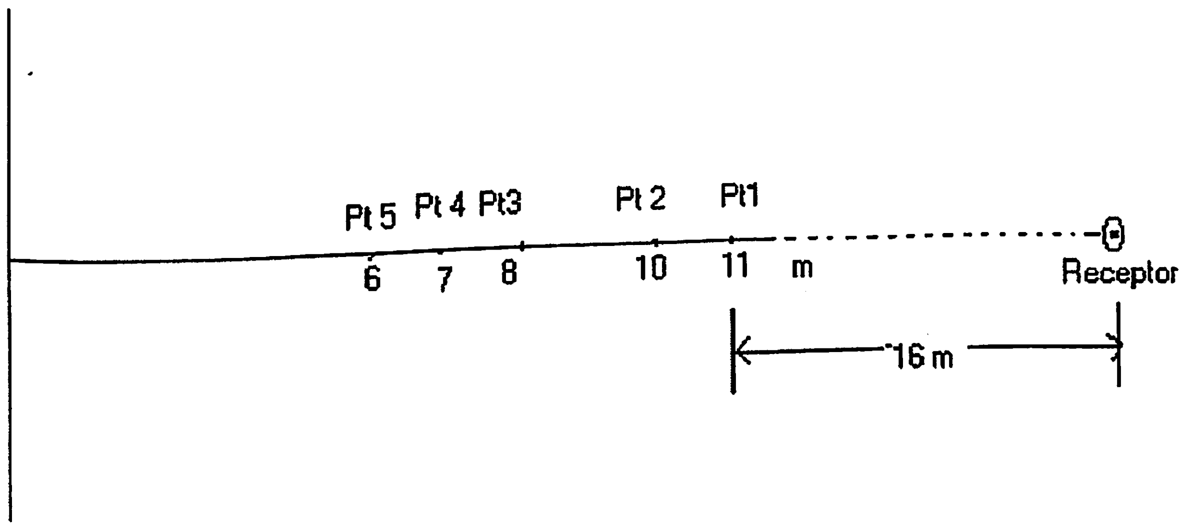
OUTPUT: indication of damage as function of incident radiations.

The table below gives the criteria for damage to people and property from fire. The effect on people is expressed in terms of the probability of death and different degrees of injury for different levels of radiations. The effect on buildings, natural surroundings and equipment is measured in terms of probability of ignition; this is particularly important for wooden structures.

Incident flux (KW/m^2)	Type of damage	Damage caused to human life
37.5	Damage to process equipment	100% lethality in 1min. 1% lethality in 10 sec
25.0	Minimum energy to ignite wood at indefinitely long exposure without a flame.	100% lethality in 1 min and significant injury in 10 sec.
12.5	Minimum energy to ignite wood with a flame melts plastic tubing.	1% lethality in 1 min. 1st degree burns in 10 sec.
4.0		Causes pain if tomorrow is longer than 20 sec but blistering is unlikely.
1.6		Causes no discomfort for long exposure.

As per the value obtained for a receptor at 10m away its 81.29 KW/m^2 which is above the value in the table so the effect on people at that point is 100% lethality in 1min and 1% lethality in 10 sec as per the table.

If we consider another point at about 16m away from the flame and do the similar calculations



And if we find $I = I_{11} + I_{10} + I_{08} + I_{07} + I_{06}$

$= 9.79+8.67+6.94+6.26+5.68$

$= 37.35\ KW/m^2$

So as per the details in the table we can assume that if the receptor is beyond 16m the consequence of fire or the fire damage will come down to second level i.e. 100% lethality in 1min significantly injury in 10 sec.

If we calculate the radiations received by a receptor at a distance of about 55m from the flame end we will get a value less than, $4KW/m^2$ i.e. a person at a distance of 55m causes pain if duration is longer than 20 sec but blistering is unlikely.

In the same way if we consider the receptor at 90m we can see that the total incident flux received by the receptor will come below 1.6 KW/m^2 which is declared as the comfort zone. This means that those who are at a distance of 90m or more will not have any effect of this even on long exposure.

STEP 6: FINDING EXPLOSION CORRELATION

METHOD: correlation of damage produced with energy of explosion.

OUTPUT: distances to various levels of damage caused by a vapor cloud detonations.

CONSTRAINTS: should not be extrapolated for very small clouds.

Here we estimate the damage levels directly. The correlation method given here is taken from TNO (1979). This method predicts the damage radii R(s), given by

$$R(s) = C(s)\,[N.Ee]^{1/3}$$

Where C(s) is an experimentally derived constant defining the level of damage based on studies of the Flexborough (1974), and Breek (1975) vapor cloud explosions. The relationship between C(s) and the level of damage is given below.

C(s)	Limit value (m-j)	Characteristic to equipments	Damage to people
C(1)	0.03	Heavy damages to buildings and to process equipment.	1% death from lung damage. >50% eardrum rupture >50% serious wounds from flying objects.
C(2)	0.06	Repairable damage to buildings and damage to the facades of dwellings.	1% eardrum rupture 1% serious wounds from flying objects.
C(3)	0.15	Glass damage.	Slight injury from flying glass.
C(4)	0.4	Glass damage to about 10% of panes.	

In this case the value of C(s) is taken as equal to 0.15

E_e is the total energy of the explosion, obtained by multiplying the heat of combustion by the mass of vapor within the flammable limits.

$E_e = H_c$* quantity of gas released.

Assume that it will take 10 minutes to close the valve (considering the time to reach the spot and close the valve manually)

So gas releasing at the rate of 9 Kg/s will release a total amount equal to 9*10*60 i.e. 5400 Kg.

Considering 10% gas will be dispersed so we can take 5000 Kg as gas released.

$\mathbf{E_e=50*10^6*5000}$

$\mathbf{=2.5*10^{11}\ joules}$

$R_s=0.15*(0.054*2.5*10^{11})^{1/3}$

N is the yield factor, i.e. the proportion of Ee which is available for pressure wave propagation.

N is given by:

$N=N_e*N_m$

Where,

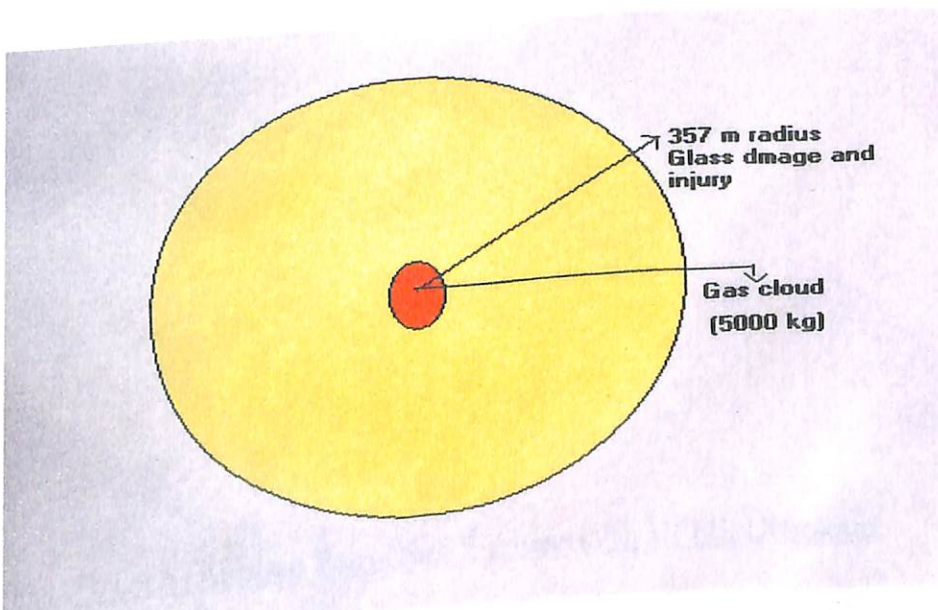
Nc is the proportion of yield loss due to the continuous development of fuel concentration. Typically Nc is taken as 30%.

Nm is the mechanical yield of combustion, which is usually taken as 33% for constant volume or isochoric combustion (i.e. confined explosion) and as 18% for constant pressure combustion (i.e. unconfined explosion). Most explosions are confined in some way so it is best to take Nm as 30%, giving a total yield of 10%.

$R_s=0.15*(0.054*2.5*10^{11})^{1/3}$

$= 357.16m$

So if the gas escaping from the pipe is not catching fire (jet fire). It will form a cloud in atmosphere. For this the atmosphere conditions should not be turbulent. Assuming that the atmospheric conditions is stable, in this case the detonations caused by 5000Kg of natural gas will effect about 357 m from the point of explosion at 357m the explosion wave will damage the window glasses and people may get injured due to flying objects.



Results

Final results of the consequences analysis for 19 bar natural gas carrying steel pipe with a rupture hole of 6cm diameter.

1. Gas Discharge ....9 Kg/s
2. Gas Velocity At The Point Of Discharge..................................310m/s
3. Flammable Distance Along The Jet Axis....................................4-11m
4. Length Of Jet Without Considering The Flammable Limits...............35m
5. Initial Rise Of The Cloud..3.29m
6. Plume Levels At A Distance...87m
7. Plume Thickness When It Levels At 87m..................................3.4m
8. Safe Zone For Heat Reduction...>90m
9. Explosion Radii(For Glass Damage And Minor Injuries)...................357m

REFERENCES:

1. MHIDAS (MAJOR HAZARD INCIDENT DATA SERVICE) operated by the Health & Safety Executive and UKAEA'S Safety & Reliability Directorate.
2. A review of hazard identification techniques and their applications to major accident hazards- S T PARRY, SRD REPORT T 379.
3. Hartley F and Moreton P A, Towards the definition of a threshold level of risk, Technical Report D/R/4 Royal Military College of Science.
4. Safety & Loss Prevention in The Chemical & Oil Processing Industries, by members of The Institution of Chemical Engineers.
5. Risk Based Inspection And Integrity Management of Pipeline System, By John Willocks.