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ACTING ON BEHALF OF PETROMOC

RISK ASSESSMENT OF THE TRANSPORTATION OF NATURAL GAS CONDENSATE FROM TEMANE CENTRAL PROCESSING FACILITY (CPF) TO PETROMOC TANK FARM IN MAPUTO

Report No.: IR/2005/I_P-01 Rev 0

DATE: APRIL 2005

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ACKNOWLEDGEMENTS

The authors would like to express their sincere appreciation for the invaluable discussions and technical input from Mario Jorge Rassul, John Hutton and Mia Couto from Impacto. Furthermore, Herberto Nhampanze, also from Impacto is thanked for his prompt effort in supplying all the necessary detailed information required to complete the study.

EXECUTIVE SUMMARY

Background

The Mozambique petroleum company, Petromoc, has been awarded the contract to transport the natural gas condensate generated at the Central Processing Facility (Temane) by road tankers, and subsequently store it at Petromoc's Matola Harbour tank farm in Maputo. The transport route covers approximately 800 km. At the time of the investigation, Petromoc subcontracted four additional companies to transport the condensate, namely TCO, MOCARGO, LALGY and SUPERSTEEL. Ilitha-Riscom (Pty) Ltd was appointed by Impacto Lda to complete a quantitative risk assessment of the transportation.

The condensate is currently scheduled for transport using 8 trucks per day, on a 3-day cycle. Transportation of loaded tankers is only allowed between 4h00 to 20h00 – this does not apply to unloaded tankers. The average tanker load is 35 000 litres. The tankers can be one of two configuration types, namely a single compartmentalised tank, or two non-compartmentalised tanks.

Terms of Reference

In terms of agreements between Sasol Petroleum Temane Limitada, Sasol Oil (Pty) Ltd and Petromoc, safety, health and environmental compliance obligations are imposed on the transportation contract. The obligations entail, amongst others, that the transporter of the condensate, must conduct an Environmental Impact Assessment ("EIA") in accordance with the provisions of the Mozambican Regulations for the Procedure for Environmental Impact Assessment contained in Decree 76/98 of 29 December 1998. Part of the EIA is to include a formal analysis of individual and social risk. Ilitha-Riscom (Pty) Ltd was specifically appointed to undertake an investigation to illustrate and predict the probability of accidental spills of condensate and the consequential health effects (including lethal probability). The results of the investigation would be used in the completion of an Environmental Impact Assessment.

The specific terms of reference are summarised as follows:

- Describe the state of the existing road infrastructure. Distinguish areas of road safety hazard in detail;
- Distinguish between areas of potentially increased risk in the event of an accident (areas of greater population density, any particularly sensitive activities such as schools, gathering places, areas of increased pedestrian traffic across the road)
- Describe and map areas of ecological sensitivity in respect of hazardous spill risk (mainly wetlands and river systems). Characterize any areas which have official or recognized conservation status.
- Accident Risks and Hazards, including
    - Failure mode and effects analysis
    - Frequency of accident scenarios using international failure rate data, modified by knowledge of local conditions
    - Maximum individual risk caused by the project;
    - Societal risk caused by the project (i.e. the consequences of an accident, taking specific land use along the route into consideration);
    - Evaluate the acceptability of the risk using internationally accepted risk criteria (ALARP)

The assessment is therefore required to include the risks of an explosion, fire and, in the event of an un-ignited cloud, that of a toxic cloud.

The likelihood of incidents must take cognisance of its physical state (liquid or vapour), the likelihood of a tank failure and the probability of a tanker collision. Although the analysis needed to consider the reduction of risks by, for instance, recommending management plans and programmes, the assessment did not require a comparison of risks between different modes of transportation (e.g. pipeline and rail) or alternative routes.

Methodology

The main sequential stages of the quantitative risk assessment used in the study included:

1. *Hazard and failure identification* - to identify all of the failure cases;
2. *Frequency estimation* – to establish the failure or initiating event frequencies from historical failure rate data for road collisions and subsequent events (fires, explosions and toxic cloud releases);
3. *Consequence analysis* - using theoretical models of chains of events (discharge of hazardous materials, dispersion in the air, ignition, explosion, fire and so on), predict the extent of their effect in terms of thermal radiation or toxic concentration, and the probability of fatalities at a particular location along the route;
4. *Risk summation and evaluation* - involves summing the likelihood and consequence information derived in steps 2 and 3 above and expressing the total risk in a form, which suits the decision-making process.

Results

Chemical Hazard Identification

Natural gas condensate is a clear, bright liquid, which is characterised as having a pungent, hydrocarbon odour. The liquid consists mainly of paraffins (63.5 mass %) and naphthalenes (34.7 mass %), with a low aromatic content of 1.8 mass%. The total sulphur contents is less than 0.004 mass% and the total metal content is 1 ppm. When released into the environment in relatively large quantities, natural gas condensate could form a flammable vapour cloud (Reid Vapour Pressure 49 kPa) and the liquid may be toxic to aquatic life – similar impacts as gasoline. Although no emissions would result under normal conditions during the transportation, there is a likelihood of an accidental spill of the material following a collision. The hazards of condensate spillage are therefore:

- The formation of a possible toxic cloud when not ignited;
- A possible vapour cloud explosion, if confined and after the cloud has had some time to develop. A flash fire would precede such an event.
- Thermal radiation from a pool fire following immediate ignition; and,
- Possible intoxication due to the combustion products formed during a fire.

Reference was made to the South African Bureau of Standards' Code of Practice, SABS 0228:1995, in the classification of condensate. The code deals with the identification and classification of dangerous substances and goods that are capable of posing significant risk to health and safety or to property and the environment. Substances are classified into nine classes and four danger groups in accordance with internationally recognised classifications. Accordingly, the SABS regards condensate as a FLAMMABLE LIQUID, i.e. Class 3, with a Danger Group rating of II, i.e. SEVERE RISK. The UN number is 3295, and is classified according to the DOT, TDG, IMDG and IATA-DGR Classifications as Class 3 (flammable liquid) and Packing Group II.

Route Hazard Identification

Most of the transportation route is currently considered to be in a poor condition. Nearly 30% of the route shows significant deterioration (e.g. large pot holes and flaking of top tar layer). About 40% is considered to be less deteriorated, but still requires careful negotiating around bad road patches. The balance (~30%) may be considered good to very good road surfaces. The road surface condition is only one part of the hazard in transportation – bad behaviour of other vehicles (including motor vehicles, bicycles and other forms of transportation) and pedestrians has a major potential to cause collisions along the route.

Using accidents with casualties, a collision rate per vehicle in Mozambique was estimated to be 0.055. For comparison, the South African statistics for 1991 (SAStats) are 0.081 collisions per vehicle including all accidents, 0.002 collisions per vehicle including only fatalities, and 0.025 collisions per vehicle for accidents with casualties, respectively. This gives an indication that serious accident rates for Mozambique is more than double that in South Africa.

During the one year period 2004/2003, 12 incidents were reported by the transportation subcontractors to Petromoc. Of these, 67% involved vehicle collisions and the balance equipment failures (e.g. faulty valves and connectors). Two accidents resulted in loss in human lives. These occurred at 3 de Fevereiro and between Hunguane and Massinga, respectively. The latter accident also resulted in a large spillage of 16 000 litres. The cause of the first accident was driver fatigue, whilst the latter was due to an attempt to avoid a collision with other vehicles. In another accident at Bobole (Marracuene) a spill of 2 300 litres resulted after a front wheel tyre burst. Although the tanker rolled over, there were no human losses. Other, less severe accidents also occurred. Only one of these was due to a mechanical failure – a break defect. The other three were driver or third party errors.

A semi-quantitative hazard rating was calculated using an estimate of the vehicle density, the number of bends in the road, blind rises and maximum vehicle speed along the route. The index represents a product of these factors, with vehicle speed weighed to the power “2”. Blind rises were considered to be twice as dangerous as bends in the road. Travelling from Temane, the first increased hazardous zone was calculated to be at Maxixi. This is mainly due to the increased number of vehicles and the speed achievable on the road. Road conditions (bends and blind rises), and increased traffic and aggressive driver behaviour along the road from Zandamela, Chidenquele Turn Off to Xai-Xai result in a significantly more hazardous section. A similar hazard rating is only again equalled when approaching Marracuene.

Collision Rates

For those countries with a history of hazardous goods accidents, consulting historical records is an acceptable method for defining incident sizes and providing failure rate data. In Mozambique, however, the number of such incidents is much less and not as well documented. The approach in this assessment adopted general historical information on vehicle accidents in Mozambique, South Africa and Petromoc’s recent incident records. Furthermore, spillage sizes were adopted from the scenarios used by the Dutch authorities in their recommended transport risk methodology. Perforation and ignition probabilities where derived from Petromoc's records and from literature.

Road collision statistics were obtained from the South African Statistical Services (StatsSA), and included detailed information up to 1998. Collision rates have decreased steadily from $4.51x10^{-6}$ per vehicle-km (1990) to $3.931x10^{-6}$ per vehicle-km (1998). The derived collision rate for urban conditions was estimated to be $3.54x10^{-6}$ per km, and $3.9\ x10^{-7}$ per km for rural conditions, respectively. The estimates for heavy commercial and articulated vehicles only, excluding injury incidents, were $4.0x10^{-7}$ accidents per km (urban) and $2.6x10^{-7}$ accidents per km (rural) roads, respectively. These are similar to statistics for the USA, i.e. $2.03x10^{-7}$ per km for rural and $3.58x10^{-7}$ per km for urban roads, respectively. Canada reported $4.97x10^{-7}$ per km for all roads.

Very limited accident statistics for Mozambique could be obtained. Furthermore, the available information did not distinguish between heavy, light and passenger vehicles. Assuming the same average annual distance travelled by a vehicle in South Africa (i.e. 20 000 km/yr), the collision rate for Mozambique was estimated to be $2.74x10^{-6}$ per km. It is expected that only collisions resulting in casualties were reported. The corresponding South African rate for collisions resulting in casualties is this is $1.24x10^{-6}$ per km. This is more than twice less than the Mozambican collision rate.

Using the reported Petromoc tanker collisions for the annual period since the operations started in March 2004 to March 2005, an accident rate of $1.38x10^{-5}$ per vehicle-km is calculated. It must be emphasised that it includes all incidents. This is 3.26 times the South African collision rates for heavy and articulated vehicles.

Spillage Probability

An analysis of road incidents involving tankers containing hazardous materials showed that releases could occur from two sources:

- *Puncture* or *rupture* following tanker collision or roll-over; and,
- *Failure* or *maloperation* of tanker equipment.

Based on the Petromoc transportation records for transporting condensate from Temane to Maputo, 40% of the incidents were due to failure or maloperation of tanker equipment and not due to collisions and 60% resulted in spillage due to vehicle accidents. According to an analysis of UK collisions statistics, less than 10% resulted in significant spillages.

Using the Petromoc records, the spillage rate was estimated to be:

- $6.62x10^{-6}$ per vehicle-km, in urban areas; and
- $1.66x10^{-6}$ per vehicle-km, in rural areas.

The spillage rates for both cases are significantly higher than derived frequencies for South Africa (i.e. $1.24x10^{-7}$ per vehicle-km, in urban areas, and $8.66x10^{-8}$ per vehicle-km, in rural areas). The Dutch authority reference spill frequencies of $8.38\ x10^{-9}$ per loaded tanker-km for motorways, $2.77\ x10^{-8}$ per loaded tanker-km for suburban and $1.24\ x10^{-8}$ per loaded tanker-km for urban zones, respectively. An analysis of the UK road transport incident data for a four-year period yielded a spill frequency of $1.4\ x10^{-8}$ per loaded tanker-km for large spills (greater than 1.5 tonnes) resulting from collisions. These rates are almost an order of magnitude less than the South African statistics for heavy commercial and articulated vehicles. If the UK perforation probability is used, the spillage rate was estimated to be

- 4.04×10^{-7} per vehicle-km, in urban areas; and
- 2.82×10^{-7} per vehicle-km, in rural areas.

Loss of Containment Scenarios

Based on typical inventories of 23 tons for atmospheric tankers, the accepted loss of containment scenarios used by the Dutch authorities is given below:

1. Release of the complete inventory (“Large Spill”);
2. Release of 5 m^3 of the inventory (“Medium Spill”); and
3. Release of 0.5 m^3 of the inventory (“Small Spill”).

Although a release of 0.5 m^3 from an atmospheric tanker would result in a small pool, and hence, especially in open road (rural) situations, this scenario may in most cases be omitted, all three scenarios were nonetheless included in the calculations.

The probability of occurrence for each of the scenarios was based on a detailed analysed of a total of 123 road tanker accidents with hazardous material releases occurring during the period 1978-1997 in the Netherlands. The probability of an entire tank spillage was calculated to be 15%. A release of 5 000 litres was calculated to have a probability of 60%, and 500 litres, 25%, respectively.

Likelihood of Ignition

None of the Petromoc incidents resulted in a fire or explosion. The probability of ignition of a flammable liquid was derived from international literature. In urban areas, the probability was assumed to be 34.4% and in rural areas, 6.5%.

Summary of Impact Results

Toxic Inhalation

The condensate has a similar evaporation rate as gasoline. The evaporation rate increases with increased ambient temperature and wind speed. However, the increasing wind speed results in increasing dilution of the vapour at a rate faster than the dilution. Therefore the highest downwind concentration occurs with lower wind speeds in spite of the higher evaporation rate.

The maximum concentration near a large spillage was predicted to be 45 000 mg/m^3. This concentration is slightly higher than the IDLH[1] value of 40 000 mg/m^3 for methylcyclohaxane. The concentration drops below the IDLH value within 10 m from the spillage. Therefore, although the vapour cloud would not result in a very toxic hazard, prolonged exposure near the pool must be avoided.

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[1] This value was developed by the National Institute of Occupational Safety and Health (NIOSH), and refers to a maximum concentration to which a healthy person may be exposed for 30-minutes and escape without suffering irreversible health effects or symptoms that impair escape (ranging from runny eyes that temporarily impair eyesight to a coma). IDLHs are intended to ensure that workers can escape from a given contaminated environment in the event of failure of the respiratory protection equipment.

In the case of open fires, plume rise due to the high temperature of the cloud is significant enough to result in low ground level concentrations and therefore little no lethal effects are expected from the combustion products, mainly nitrogen dioxide.

Explosion Overpressure

Following a delayed ignition of a vapour cloud, depending on obstruction, either a flash fire or blast overpressure (explosion) would result. The maximum distance to the lower explosion limit of the evaporated cloud resulting from a complete tanker spill is 25.4 m under calm, night time atmospheric conditions. The amount of explosive material within the explosive limits under these conditions is 42.7 kg. The minimum distance was calculated to occur under convective (very unstable) daytime conditions, viz. 4 m with only about 5 to 6 kg in the flammable region.

In open road situations, the vapour cloud is unconfined, and this amount would rather result in a flash fire than an explosion. However, in densely populated or confined areas, the occurrence of an explosion cannot totally be excluded.

For unconfined conditions, the 'safe distance' (i.e. 95% probability that no serious damage would occur beyond this distance) is calculated to be between 112 m and 144 m. Some damage to house ceilings and 10% window glass broken could also be broken at this distance. In confined conditions, this distance was calculated to be 320 m. The distance to the 50% expected lethality, i.e. an over-pressure of 145 kPa, was calculated to be between 8 and 10 m. For confined conditions, this distance could be up to 17 m. The probability of death beyond the 69 kPa is very low. The distance calculated for unconfined conditions is between 11 m and 14 m. For confined conditions, the distance is between 21 m and 23 m. Significant building damage (0.2% probability) can still occur up to 7 kPa, i.e. 50 m unconfined to 108 m confined.

However, the likelihood of explosion conditions occurring after an accidental spill is low due to the relatively small amount in the explosive limits, i.e. less than 100 kg. Nonetheless, since the lethal distance to explosion overpressure is within the same order as the impact from thermal radiation (11 m to 23 m), the probability of death following an explosion of a spillage was incorporated as part of the pool fire consequences.

Thermal Radiation from Pool and Flash Fires

Thermal radiation is considered to be the main consequences following a spillage and ignition of the condensate. The results are summarised in the table below.

Table A: Predicted distances to various consequences due to heat radiation.

Incident Size	Thermal Radiation (kW/ m^2)			
	4.7[(a)]	*12.6*[(b)]	*35*[(c)]	*60*[(d)]
0.5 m^3	15 m	7 m	4 m	3 m
5 m^3	49 m	29 m	13 m	10 m
full contents	95 m	59 m	28 m	20 m

[(a)] - Cause pain in 15 - 30 seconds and second degree burns after 30 seconds

[(b)] - 10% chance of fatality for instantaneous exposure or 30% chance of fatality for continuous exposure and a high chance of injury

[(c)] - 25% chance of fatality if people were exposed instantaneously

[(d)] -100% chance of fatality if people were exposed instantaneously

Maximum Individual Risk

The maximum individual risk is calculated for an individual who is presumed to be present at some specified location. The parameter is not dependent on the knowledge of the population at risk. The risk calculations, however, included the effect of wind speed and atmospheric turbulence. Differences between land-use, i.e. urban and rural locations, were also considered.

In all societies, virtually all decisions involve some implicit or explicit assessment of risks. The acceptable level is often dependent on the individual's priorities in life. A starving person is more likely to eat unsafe food than otherwise. Therefore the specification of an "acceptable" risk criterion is not necessarily the same in for all societies. As guidance, the acceptable risk criteria used by the UK Health & Safety Executive were adopted. A risk value above $1x10^{-4}$ per year to the general public is regarded "intolerable" and should be reduced before operation starts. A risk below $1x10^{-6}$ per year is regarded "tolerable" and therefore broadly acceptable. Between the levels of $1x10^{-6}$ per year and $1x10^{-4}$ per year, the risk needs to be reduced to "As Low As Reasonably Practicable", or ALARP.

Base on this ALARP triangle, the risk of transportation of condensate falls within the ALARP region. The calculated maximum risks, including the lower estimates, do not exceed the upper level for ALARP (i.e. $1x10^{-4}$ per year), however, the upper estimate in urban conditions closely approach this limit. It is therefore strongly recommended that additional mitigation measures be applied to reduce the maximum risk. A risk value for vulnerable societies (e.g. schools, hospitals, etc.) is $3x10^{-7}$ per year.

Due to the limited historical data available for spillage of the condensate, a lower and upper risk was calculated. This range is primarily due to the considerably higher probability of perforation actually witnessed when compared to international norms. The table summarises the calculated maximum distances to the broadly acceptable risk ($1x10^{-6}$ per year) and risk level for vulnerable societies ($3x10^{-7}$ per year). The calculated maximum risk is $4.9x10^{-5}$ per year in urban conditions. The results are summarised in Table B.

Table B: Calculate maximum individual risks for different locations along the transportation route and the distances to acceptable levels.

Location	Distance To		`Maximum Risk (per year)
	$1X10^{-6}$ Risk Isoline (m)	$3X10^{-7}$ Risk Isoline (m)	
Urban			
Lower Estimate	18	30	$3.0x10^{-6}$
Upper Estimate	24	36	$4.9x10^{-5}$
Rural			
Lower Estimate	Not reached	17	$9.0x10^{-7}$
Upper Estimate	22	36	$5.0x10^{-6}$

The calculated maximum risks, including the lower estimates, do not exceed the upper level for ALARP (i.e. $1x10^{-4}$ per year), however, the upper estimate in urban conditions closely approach this limit. It is therefore strongly recommended that additional mitigation measures be applied to reduce the maximum risk.

Societal Risk

The maximum individual risk takes no cognisance of the population density. The societal risk is presented as the frequency and severity (lethality) corresponding to each of the spill cases considered in the investigation. The approach adopted is to arrange the accidents in the order of decreasing fatalities (per year). The cumulative frequencies are then calculated in the same order, i.e. the lowest frequency corresponds to the highest fatality. Plots of the cumulative frequency (**F**), vs. severity (**N**) were prepared for different sections along route, different population densities and incident definitions.

The societal risk criteria adopted in this investigation is that recommended in the Netherlands for dangerous goods transport (i.e. road, rail and pipelines), i.e. a risk of 10^{-4} per year per km for ten fatalities, a risk of 10^{-6} per year per km for 100 fatalities, and so on. Above the recommended societal risk criterion line the risk has to be reduced and below the line, the risk needs to be reduced to "*As Low As Reasonably Achievable*", i.e. ALARA. Both spillage assumptions (lower & upper estimates) result in a risk which is above the ALARA criterion and into the zone requiring risk reduction.

Conclusions

Considering the calculated maximum individual risk, the transportation of condensate could be regarded "tolerable", but above the risk criteria normally adopted as broadly acceptable by the general public. When the population density is included, the societal risk clearly indicates that the risk is above the norm accepted in countries such as the Netherlands, and would therefore require the current transportation operation to stop. However, due to the practical implications, this may not be possible. Accordingly, immediate risk reduction measures must be implemented to reduce risk to As Low As Reasonably Achievable (ALARA).

11Recommendations

Although a large part of the risk can be attributed to external, uncontrollable hazardous sources, e.g. poor road conditions, pedestrians, other bad driver behaviour, etc., Petromoc has to immediately address all those aspects under their control which would reduce the risk. Therefore, the primary focus of risk reduction must initially be on improving driver alertness, behaviour and habits (e.g. alcohol intake).

Spillage occurs as a result of mechanical failure of the tank or the vehicle, driver misjudgements or third party involvement. Causes of accidents are usually attributable to one or more of the following factors:

- Ignorance of traffic regulations or approved practice. Excessive speed for the prevailing road and traffic conditions is responsible for the majority of highway accidents.
- A poor attitude by the driver towards other road users.
- Lack of driving skill.
- Other parties, including vehicles, other forms of transport (e.g. bicycles) and pedestrians.

Since third party activities are not easily controlled, the emphasis on risk reduction must be on ensuring minimal mechanical failure and driver errors.

The current accident record of the vehicles transporting condensate from Temane is considerably higher than the statistics in South Africa (more than 3-fold) and generally found internationally. Accident prevention should therefore receive considerable attention. Since the circumstances surrounding accidents vary widely, only general recommendations can be provided.

1. Employing the right vehicle for the job is an important aspect in any transportation operation.
    a. Rigid vehicles are inherently more stable than articulated vehicles and are therefore better suited for use in very hilly country and on poor roads. This is because articulated vehicles (tractor semi-trailer) are prone to 'jack-knife' in steep or slippery conditions, especially when severely braked.
    b. Irrespective of the type of vehicle and axle configuration that are chosen it is essential to ensure that it is a stable unit. Vehicle stability depends upon the effects of the centre of gravity of the payload/tank (or body), its height and position relative to the axles and the stiffness or deflection of the suspension.
    c. The design of the driver’s cab must be aimed at making him comfortable and facilitating control, thereby reducing fatigue.
    d. The underperformance of a vehicle may hamper safe manoeuvrability of the vehicle. It is obviously quite possible that the current vehicles are appropriate, but it is recommended that the most appropriate vehicle and load be chosen for the current road conditions.
2. A badly maintained vehicle can be both dangerous and illegal. Management should therefore ensure roadworthiness of all vehicles by implementation of an effective maintenance programme.
3. Since human behaviour is the dominant element in road safety, influencing driver attitudes and performance must be a prime objective of managers and supervisors. With enforcement of Petromoc company standards, local norms could transcend to produce improved safety performance.
4. Managers and supervisors must have appropriate experience, and thorough initial training, motivation, regular assessment and retraining advocate careful driver selection as the means of achieving safe driving.
5. First line supervisors are the vital link between management and driver and their role is crucial to road safety programmes. They are responsible for turning the objectives and policies of management into action and results. To be effective they must not only have a strong commitment to safety but must be familiar with all aspects of road safety and have sound supervisory and motivational skills. Although drivers must be encouraged to take personal responsibility for their own performance, supervisors still need to know and understand each driver and be sensitive to change of circumstances or personal behaviour which may indicate potential adverse influences on safety performance.
6. The following qualities should be sought when appointing a driver:
    a. A proven safe driving record of heavy duty vehicle driving.
    b. A positive attitude to road safety.
    c. Physical fitness for the task.
    d. Integrity.
7. It is recommendation that Petromoc conduct its own driving tests.
8. Training is a continuous process comprised of three elements:
    a. Induction Training
    b. Job Training
    c. Defensive Driver Training
9. Detailed inspection of motor vehicles at regular intervals generally results in a reduction of

accidents due to defective equipment.

10. A road safety programme must be based on known facts about the causes of accidents so that the best means of preventing them can be developed. This information can be obtained only by an adequate and accurate system of reports and records. Accidents should therefore be reported in writing on a special report form as soon as possible after they occur. Even the most minor accident should be reported, particularly where another vehicle or third party property may have suffered damage. The report should include all relevant information about
11. Incentive schemes for paying monetary awards to drivers for safe driving are not always effective in reducing accidents.
12. Consequences of road accidents can often be minimised by effective emergency action at the scene. Action may be required to:
    a. Prevent any worsening of the situation created by the original accident, e.g. by deployment of warning devices or control of hazardous areas.
    b. Apply life saving first aid to injured persons.
    c. Contact the emergency services, i.e. ambulance, fire brigade or police.
13. Every tanker should be equipped with:
    a. Fire-fighting appliances;
    b. Tool kit for emergency repairs to vehicle;
    c. Mechanical brake of a size suitable for the mass of the vehicle and tank contents, and the wheel size;
    d. Two amber lights independent of the electrical system of the tanker;
    e. Placards for warning of spill (toxic cloud and fire warning); and,
    f. Protective equipment.

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1 INTRODUCTION

Natural gas condensate is a by-product formed during the conditioning of natural gas prior to exportation. Compared to solid fuels such as coal, natural gas is considered to be a more environmentally friendly and cost effective energy source for a variety of industrial and domestic applications. It is within this context that Sasol installed an 850 km pipeline to convey natural gas from the Temane/Pande gas fields in Mozambique to their Synthetic Fuels Plant at Secunda in Mpumalanga, South Africa. Natural gas consists of a high percentage of methane and varying amounts of heavier hydrocarbons such as ethane, propane, butane and inert elements (e.g. nitrogen, carbon dioxide and helium). The composition can vary from field to field. Table 1-1 is a summary of the average raw gas composition analyses taken at the Temane wells (Sasol 2000).

Table 1-1: Natural gas hydrocarbon composition derived from an average of recombined wellstreams (Sasol 2000).

Wellstream Composition	Volume %
Nitrogen	2.20
Methane	91.50
Ethane	2.90
Propane	1.50
i-Butane	0.30
n-Butane	0.60
i-Pentane	0.20
n-Pentane	0.20
n-Hexane	0.20
n-Heptane	0.50
n-Octane	0.00

When the gas arrives at the Central Processing Facility (CPF) from the wells, it first passes into the Inlet Separator, where any free liquids are knocked out. Before the gas is compressed (HP compressor) and finally exported through the overland pipeline, a number of cleaning and phase separation steps are completed in the CPF. These units include the Glycol Dehydration System, the Low Temperature Separator and Compressor Knockout drums. The liquid collected from these units are flashed in a three-phase separator. The resulting gases pass to the fuel gas system, the hydrocarbon liquids to the condensate stabiliser, and produced water to the produced water tank. The stabilised condensate has temporarily been stored onsite in two tanks for export, whilst produced water is re-injected into the wells.

The Mozambique petroleum company, Petromoc, has been awarded the contract to transport the condensate generated at the CPF by road tankers, and subsequently store it at the Matola Harbour tank farm in Maputo. The transport route covers approximately 800 km. PETROMOC subcontracted four additional companies to transport the condensate: TCO, MOCARGO, LALGY and SUPERSTEEL.

1.1 Main Hazards

Although the Temane natural gas condensate can be used as a combustion fuel (e.g. boilers and industrial furnaces for steam generation and air heating for drying), it is possibly more beneficial when blended in gasoline to increase the octane number. The condensate a clear, bright liquid, which is characterised as having a pungent, hydrocarbon odour.

When released into the environment in relatively large quantities, natural gas condensate could form a flammable vapour cloud and the liquid may be toxic to aquatic life, similar to gasoline. Although no emissions would result under normal conditions during the transportation, there is a likelihood of an accidental spill of the material following a collision. The hazards of condensate spillage are

- The formation of a possible toxic cloud when not ignited;
- A possible vapour cloud explosion, if confined and after the cloud has had some time to develop. A flash fire would precede such an event.
- Thermal radiation from a pool fire following immediate ignition; and,
- Possible intoxication due to the combustion products formed during a fire.

The condensate is a liquid mainly consisting of paraffins (63.5 mass %) and naphthalenes (34.7 mass %), with a low aromatic content of 1.8 mass%. The total sulphur contents is less than 0.004 mass% and the total metal content is 1 ppm. With its initial and final boiling points at 35^{o}C and 250 ^{o}C, respectively, condensate is a relatively volatile liquid (Reid vapour pressure 49 kPa), which is similar but less volatile than gasoline (Reid vapour pressure 60 - 75 kPa). So, significant evaporation of the condensate could occur following a spillage. The rate of evaporation would obviously depend on the size (area), the ambient and substrate temperature, the wind speed and the nature of the material onto which the spill took place. Evaporation would increase with increased ambient temperature and wind speed. If the spillage is on soil, the evaporation would be greatly minimised due to the absorption capacity (depending on the characteristics of the soil).

Reference was made to the South African Bureau of Standards' Code of Practice, SABS 0228:1995, in the classification of condensate. The code deals with the identification and classification of dangerous substances and goods that are capable of posing significant risk to health and safety or to property and the environment. Substances are classified into nine classes and four danger groups in accordance with internationally recognised classifications. Accordingly, the SABS regards condensate as a FLAMMABLE LIQUID, i.e. Class 3, with a Danger Group rating of II, i.e. SEVERE RISK.

The UN number is 3295, and is classified according to the DOT, TDG, IMDG and IATA-DGR Classifications as Class 3 (flammable liquid) and Packing Group II.

The main road (EN1) between Maputo and Temane is illustrated in (Figure 1-1). It is proposed that the same route be used for the transportation of condensate. Due to sections of the road currently experiencing dense traffic patterns (particularly in Maputo) and its close proximity to numerous residential areas along the route, it is important to establish the probability of a condensate spill and the consequences (toxic and/or explosion) following such an incident.

Figure 1-1: Main road between the Central Processing Facility at Temane and the storage tanks in Maputo.

Although a leak (or even a large spillage) of condensate would not immediately flash off (less than 5% condensate have boiling point of <50 ºC), the resulting liquid pool would gradually evaporate to form a flammable cloud. Due to its relatively low vapour pressure it is therefore expected that the pool would not evaporate fast. The vapour is heavier than air and can travel a considerable distance to a source of ignition and flash back.

1.2 Terms Of Reference

In terms of interim letter agreements between Sasol Petroleum Temane Limitada, Sasol Oil (Pty) Ltd and Petromoc (as the transporter of the condensate), safety, health and environmental compliance obligations are imposed. These obligations would also be incorporated in the final agreements between the parties referred to above. The obligations entail, amongst others, that the transporter of the condensate, must conduct an Environmental Impact Assessment ("EIA") in accordance with the provisions of the Mozambican Regulations for the Procedure for Environmental Impact Assessment contained in Decree 76/98 of 29 December 1998. The EIA is to include a formal analysis of individual and social risk, prepared by a specialist in the field of environmental risk engineering.

Ilitha-Riscom (Pty) Ltd was specifically appointed to undertake an investigation to illustrate and predict the probability of accidental spills of condensate and the consequential health effects (including lethal probability). The results of the investigation would be used in the completion of an Environmental Impact Assessment.

The specific terms of reference are summarised as follows:

- Describe the state of the existing road infrastructure. Distinguish areas of road safety hazard in detail (e.g. poor road surface, fog belts, potholes, road shoulder drop off, narrow road sections, areas of poor visibility, absence of road signs and road markings, narrow bridges, blind corners, poor horizontal and vertical geometry, pedestrian traffic, animal traffic);
- Map immediately surrounding land use along the route. Distinguish between areas of potentially increased risk in the event of an accident (areas of greater population density, any particularly sensitive activities such as schools, gathering places, areas of increased pedestrian traffic across the road,)
- Describe and map areas of ecological sensitivity in respect of hazardous spill risk (mainly wetlands and river systems). Characterize any areas which have official or recognized conservation status.
- Accident Risks and Hazards, including
    - Failure mode and effects analysis
    - Frequency of accident scenarios using international failure rate data, modified by knowledge of local conditions
    - Maximum individual risk caused by the project;
    - Societal risk caused by the project (i.e. the consequences of an accident, taking specific land use along the route into consideration);
    - Evaluate the acceptability of the risk using internationally accepted risk criteria (ALARP)

The risk assessment needs to investigate both the risks of an explosion (fire) and, in the event of an un-ignited cloud, that of a toxic cloud. The likelihood of these incidents needs to take cognisance of its physical state (liquid or vapour), the likelihood of a tank failure and the probability of a tanker collision. Although the analysis needs to consider the reduction of risks by, for instance, recommending management plans and programmes, the assessment does not require a comparison of risks between different modes of transportation (e.g. pipeline and rail) or alternative routes.

1.3 The Report Structure

Section 2 provides an overview of the proposed transportation route (including local meteorology), general aspects of the tanker design and some technical background on the condensate (chemical properties and toxicological data). The subsequent section (Section 3) includes a detailed description of the hazards associated with the transportation of condensate. Section 4 contains a quantification of tanker spillage likelihood using collision statistics from Mozambique, South Africa and international resources. Consequence and risk calculations, i.e. toxic clouds, thermal radiation and explosion overpressures, are contained in Section 5. Section 6 provides some recommendations for the reduction of tanker accidents. The conclusions and recommendations are summarised in Section 7.

The Material Safety Data Sheet (MSDS) is provided in Appendix A. More detail regarding the calculation methodologies are given in Appendix B.

2 BACKGROUND INFORMATION

2.1 General Tanker Description

The condensate is currently scheduled to be transported using 8 trucks per day, on a 3-day cycle. Transportation of loaded tankers is only allowed between 4h00 to 20h00 – this does not apply to unloaded tankers. An example of the condensate tanker is provided in Figure 2-1. As shown, the steel vessel is supported by a reinforced frame. The average tanker load (Table 2-1) is 35 000 litres – the maximum vehicle mass allowed on the roads in Mozambique is 48 ton.

The tankers can be one of two configuration types, namely a single compartmentalised tank, or two non-compartmentalised tanks.

Figure 2-1: An example of condensate tanker.

Figure 2-2: Rear of tanker.

Table 2-1: Summary of condensate tanker capacities.

Tanker	Gross Vehicle Weight (ton)	Empty Mass (ton)	Condensate Load	
			ton	litre
1	43.050	18.300	24.750	35.328
2	48.900	23.150	24.750	36.168
3	40.350	18.100	22.250	32.006
4	47.100	23.850	23.250	33.511
5	48.600	24.650	23.950	34.043
6	46.350	22.650	23.700	33.617
7	48.750	23.300	24.450	35.883
8	47.600	24.300	23.300	32.984
9	49.650	24.100	25.550	35.703
10	43.200	16.600	26.600	38.328

Connections to the tanks are DN80. Compartmentalised tanks have discharge valves on the side; whereas the non-compartmentalised tanks have a single discharge valve situated at the rear (see Figure 2-2). Duplicate (emergency) valves are supplied in the event that the primary valves do not function properly. Although some of the valves are pneumatically driven, the majority are mechanical valves.

Each tank is fitted with a vacuum break and pressure valve at the top to accommodate internal pressure increases and potential vacuum formation during loading and discharging, respectively.

2.2 Transportation Route

Condensate is transported by road from the Central Processing Facility in Temane to the Petromoc storage tank farm in Matola harbour, Maputo. This comprises a total distance of approximately 740 km. The route from the CPF follows the EN1 road up to Maputo, from where it follows the EN4. The turnoff to the Matola harbour is along the EN4. The EN1 is a single lane road, whereas the EN4 has double lanes.

The EN1 is the only tarred road and the only feasible route of transport. Unfortunately, a large section of the current road surface is in a bad condition. Some road sections have partially lost the top tar layer of previously resurfaced roads (see Figure 2-3) whilst other sections contain extensive potholes. Erosion has also caused partial destruction of road edges (Figure 2-4), thereby greatly reducing the road width in some parts of the EN1.

Figure 2-3: Some sections of the EN1 lost the top tar layer and contain significant potholes.

Figure 2-4: The road edge has in places significantly eroded away along the EN1.

The road leaving the CPF to the T-junction with the EN1 is newly constructed, and therefore in very good condition. The section from the T-junction to the Vilanculos is straight and in relatively good condition. The maximum vehicle speed is about 110 km/h.

The approximately 150 km stretch of road from Pambarra to Massinga is, apart from a few sections, also in a relatively reasonable state. Bad parts (potholes, surface erosion) include sections at Mavanza, Unguana and the entrance to Massinga. The road is relatively straight with some minor bends (~47) and blind rises (~13). The maximum vehicle speed is about 100 km/h along the good sections and 60 km/hr along the bad surfaces. The road is currently being upgraded, and it is expected that due to the relatively straight and level road, speeding could occur once completed. The road crosses a small river after Unguana. Areas of increased hazard include the market place along the main road in Massinga and a major road crossing.

The road from Malova to Morrumbene (~40 km) is narrow and in a bad condition. The maximum speed is about 50 km/hr, and often requires traffic to travel along the opposite lane. In spite of the slow speed possible, the forced driving behaviour may still cause increased accident rates. It was also evident that whilst the bad road conditions slowed down passenger cars and small delivery vans, large haul trucks appear to maintain a faster speed. The road crosses seven rivers of varying significance along this stretch.

The approximately 27 km to Maxixe, which may be judged by a maximum speed of ~100 km/hr, is of medium to good condition. This is a straight road with very few blind rises (~3). Parts of the road are being upgraded. The road crosses a river and wet land about 6 km before Maxixe. The extended influence of activities in and around the town of Maxixe affects up 10 km of the route.

The approximately 25 km from Maxixe to Ashtimo Neto is of medium to bad condition (maximum speed 90 km/hr). The 13 km section between Ashtimo Neto and Cumbana is of better quality (maximum speed 100 - 110 km/hr).

Figure 2-5: Many towns are characterised with bad water drainage due to the lack of storm water drainage systems. Potholes are not visible during intensive rain storms and are often filled with muddy water following the episode, making it difficult to identify.

Heavy rains occurred during the route inspection and it was quite evident that, whilst the open road coped well with the rain, serious drainage problems existed in the towns (Figure 2-5). This was particularly obvious in Cumbana.

The 50km stretch or road between Cumbana and Inharrime is relatively straight and level with very few blind rises. A section of the road after Cumbana is of medium to good quality (maximum speed of 100 km/hr), whereas the 10 km before reaching Inharrime has significant potholes, forcing vehicles to drive on the wrong side of the road. Inharrime is a busy town and provides the opportunity for many busses and haul trucks to stop at vendors next to the road (Figure 2-6). The road through Inharrime is narrow and filled with pedestrians (Figure 2-7).

Figure 2-6: Buses and haul trucks parked at vendors along EN1 in town of Inharrime.

Figure 2-7: Busy and narrow road through Inharrime.

The road crosses a relatively large river south of Inharrime. An extensive wet land and lake stretches along the road. The conditions along this stretch are bad and had to travel on both sides of road.

The 44 km road between Inharrime and Quissico is in relatively good condition (maximum speed 120 km/hr) with some minor stretches with potholes. However, the intermittent potholed sections can lead to hazardous situations when trying to avoid potholes whilst approaching at high speed.

The road from Quissico to Chissibuca (32 km) is in a relatively bad condition (maximum speed 80 km/hr). This stretch is also characterised with the highest density of blind rises compared to the rest of the route (0.8 per km, compared to 0.2 per km for the entire route). As a result, this section of the route is also expected to have increased accident rates. This appeared to be evident from the accidents witnessed during the route assessment. Figure 2-8 shows an accident which occurred along a road works section outside Quissico. It is expected that with the future new road, increased speeding may even worsen the current accident rate.

Figure 2-8: Accident along the Quissico and Chissibuca road during route assessment.

The 91-km road between Chissibuca and Xai-Xai is similarly characterised by bind rises ((0.7 per km) and bends. Increased vehicle and pedestrian volumes were also evident. Figure 2-9 depicts an accident which occurred minutes before our arrival outside Chuzavane. This accident may have been caused by avoiding an oncoming car following the blind rise. (Our own vehicle was almost involved in an accident along this stretch at Zandamela.)

The road from the Chidenquele Turn Off to Xai-Xai is in a good condition. The numerous villages along this route give rise to in increased number of cyclists, pedestrians, bus stops, vendors and schools. Although speed restrictions are enforced, these are not always obeyed. Crops are grown along some sections of the road.

Figure 2-9: Minibus accident outside Chuzavane (between Quissico and Chissibuca).

The roads are often also very narrow, and hence haul trucks, tankers and buses often need to ride in the middle of the road, e.g. near Chongoene (Figure 2-10).

Xai-Xai is very congested, forcing vehicles to generally drive slower. The road sections before and after Xai-Xai is good. A new, raised road has also been completed over the Limpopo flood plain.

Whilst the 15 km stretch from Xai-Xai is in a good condition, the 50 km section between Chicumbane and Macia is has a bad surface (maximum speed 90 to 100 km/hr). The road within the immediate vicinity of Macia is in a very bad condition.

The road from Macia to Manhiça, a stretch of about 70 km, passes through extensive wetlands, most notably near Palmeira (~24 km before reaching Manhiça).   Farming activities include sugar cane. The Esperança College is located near Manhiça.

Figure 2-10 Narrow roads often forces large vehicles to veer over into on-coming traffic.

The best road condition along the EN1 is between Maluana and Marracuene (~27km). Unfortunately, this section also sees frequent speeding well in excess of 120 km/hr. In addition, with potentially tired tanker drivers, this situation could result in increased collisions. So, in spite of the generally good condition of the road, the increased speed (and hence the resulting higher momentum of impact) could result in severe collisions of large vehicles. In the event of a tanker collision, the higher momentum would also increase the likelihood for a spillage, as experienced by a Petromoc tanker on 8 October 2004 (Impacto 2004). During this accident, approximately 3000 litres were spilled onto the road surface and soil, fortunately without ignition. The road crosses two rivers along this section.

Human and vehicle activity increases significantly from Marracuene on approach to Maputo. The busiest section is through the market section of Benfica (Figure 2-11). Road barriers have been erected in places to limit pedestrians from crossing the road (Figure 2-12).

Certain sections of the road through Benfica suffer from bad drainage during rainy spells (Figure 2-13).

Figure 2-11: Traffic congestion in Benfica.

Figure 2-12: Attempts to limit pedestrians crossing the EN1 randomly in Benfica.

Figure 2-13: Lack of water drainage in Benfica causes traffic problems during rains.

From Befica, the EN1 road crosses a river and a train bridge before linking up to the EN4, a distance of approximately ~6 km. The route then follows the EN4, double-lane toll road, to the Matola Harbour intersection (CMC traffic lights, Figure 2-14). The tanker first turns right to be weighed at the weighing facility (Figure 2-15), after which it returns to the traffic lights. From here the tanker crosses the intersection towards Matola harbour (Figure 2-16).

Figure 2-14: CMC traffic lights.

Figure 2-15: Turning right, view towards weighbridge.

Figure 2-16: View towards Matola Harbour from CMC traffic light.

The road surface to the Petromoc tank farm is tarred for the entire route, and is considered to be in a generally good condition. However, certain sections of the road have been identified to have inadequate stormwater drainage. Furthermore, the road section from the harbour entrance to the intersection with the EN4 (CMC traffic lights) has virtually no road markings, with only minimal signages. Although pedestrian activity along this section is not as significant, the road is often congested with other heavy vehicles (cement, flour, gas cylinders, Mozal raw material and product transportation, etc.). Vehicles are often parked along the roadsides, with the highest density at the CIM entrance (Figure 2-17).

Figure 2-17: Parked vehicles at CIM entrance on route to the Petromoc tankfarm.

A sharp corner after the CIM entrance, next to the police station, is of particular concern due to the lack of adequate markings and signage (Figure 2-18).

The T-junction at Eperas is also of particular concern for vehicles travelling away from the harbour due to the restricted visibility caused by the advertising boards at the junction. The substation floodlighting at the Eparas T-junction has a blinding effect on motorists at night when travelling towards the harbour.

2.3 Accident Statistics

Detailed accident statistics for Mozambique could not readily be obtained, only total collision numbers, as given in Figure 2-19.

Figure 2-18: Sharp corner after CIM entrance, towards Petromoc.

It is interesting to observe the rapidly increasing accident rates after 1988 and again after 1990. The lower accident numbers during the early ‘80s may be due to more restricted vehicle movements brought about by the politically unstable conditions prevalent during that period. Increased vehicle numbers most likely contributed to the increased collisions reported during the ‘90s.

Unfortunately no split between heavy, light and passenger vehicles was given, nor is it certain whether these numbers reflect only fatal accidents, or whether major and minor accidents are also included.

In order to express these as a rate per vehicle-kilometres travelled, knowledge of the number of vehicles and the average kilometres per vehicle travelled are required. The African Development Bank conducted a survey to establish the number of vehicles being driven in each of the SADC countries, including Mozambique. Although the data for Mozambique was for 1986, collision rates could still be estimated using additional information on the number of reported collisions for that year from Figure 2-19.

The number of vehicles in Mozambique was estimated to be 42 800 with the number of cars, 32 900. The number of collisions for that year was 2348. The collision rate per vehicle is therefore 0.055. For comparison, the South African statistics for 1991 (SAStats) are 0.081 collisions per vehicle including all accidents, 0.002 collisions per vehicle including only fatalities, and 0.025 collisions per vehicle for accidents with casualties, respectively. Judging from these ratios, it is speculated that the Mozambican accident numbers quoted in Figure 2-19 are for accidents with casualties.

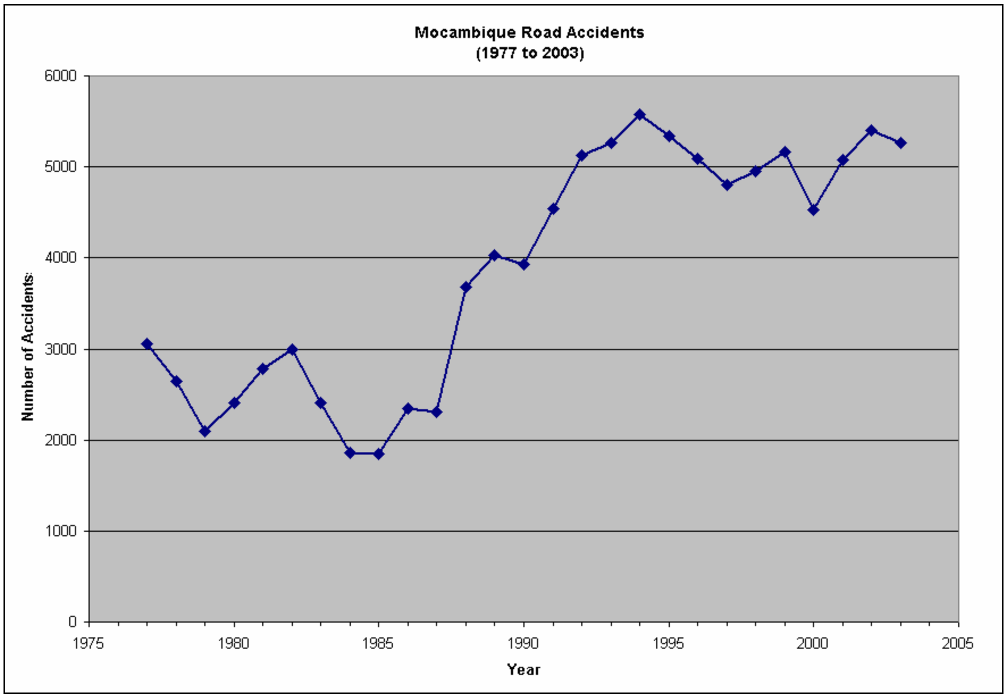


Figure 2-19: Recorded road accidents for Mozambique (1977 to 2003).

Of particular interest, however, are the accidents reported by Petromoc tanker for the since operations started in March 2004 up to March 2005 (Table 2-2). Of all reported incidents 60% resulted in a spillage of condensate. Most of these 40% resulted in small spills, whereas only two large spills of 2 300 l and 16 000 l occurred.

The distance travelled by these tankers during the period is 722 213 vehicle-kilometres (8 tankers per day, during a 3-day cycle of a one way distance of 742 km).

2.4 Meteorology

Meteorological mechanisms govern the dispersion, transformation and eventual removal of pollutants from the atmosphere. The extent to which pollution will accumulate or disperse in the atmosphere is dependent on the degree of thermal and mechanical turbulence within the earth's boundary layer. Dispersion comprises vertical and horizontal components of motion. The stability of the atmosphere and the depth of the surface-mixing layer define the vertical component. The horizontal dispersion of pollution in the boundary layer is primarily a function of the wind field. The wind speed determines both the distance of downwind transport and the rate of dilution as a result of plume 'stretching'. The generation of mechanical turbulence is similarly a function of the wind speed, in combination with the surface roughness.

The wind direction, and the variability in wind direction, determines the general path pollutants will follow, and the extent of crosswind spreading. Pollution concentration levels therefore fluctuate in response to changes in atmospheric stability, to concurrent variations in the mixing depth, and to shifts in the wind field.

Table 2-2: Historical accident and spillage record of current condensate transportation from Temane to Maputo.

Date	Operator	Kind Of Accident	Local	Severity (Brief Description)	Spill (Amount Of Product)	Possible Causes
2004/05/18	TCO	Loss of product	SPT – Temane	None. Contained and evaporated leak	Less than 1 litre	Tank valves faulty
2004/05/19	Super Steel	Piece from the hub of the tire came off	SPT – Temane	None	No spills	Defects on the breaking system
2004/06/13	TCO	Breaks	SPT - Temane	None	No spills	Defects on the breaking system
2004/06/26	MOCARGO	Spill of product	SPT - Temane	None (the product was retained and collected)	65 litre of Natural Gas Condensate	Differences in connector sizes at loading bay
2004/06/27	Lalgy	Slip of the tank	SPT – Temane	None (the tank was empty)	No spills	Lack of visibility when executing manoeuvres
2004/06/29	Lalgy	Engine oil leak in the Loading Bay	SPT – Temane	None (contained leak and the cab was substituted)	No spills	Depreciation of the block joint in the engine.
2004/08/09	Lalgy	The truck rollover	Crossing EN1 x EN4:	Severe, but without human losses.	Spill of 10 litre Natural Gas Condensate	Trying to avoid an accident with a minibus, the truck lost control and rolled over causing the spill.
2004/08/14	MOCARGO	Spill of product (Natural Gas Condensate)	SPT - Temane	None. Contained and allowed to evaporated	Spill of 8 litre Natural Gas Condensate	Differences in connector sizes at loading bay
2004/08/20	TCO	Road accident involving another vehicle	Massinga EN1 – about 191 km south from Temane	None Material damage: *- Lateral right side blinkers;* *-Frontal blinkers, right side;* *- Presence light; -bumper –right side.*	No spills	Bad take over

Date	Operator	Kind Of Accident	Local	Severity (Brief Description)	Spill (Amount Of Product)	Possible Causes
2004/09/06	LALGY	Slip of the stair from the "Loading Bay"	SPT – Temane	Not very severe	No spills	Slip of the stair from the filing system, due to anomalies in the fixation mechanism
2004/09/14	LALGY	Road accident	3 deFevereiro (Chicumbane Xai-Xai about 523km south from Temane)	Very severe, with loss of human lives and damage of the vehicle.	No spills	Apparently due to fatigue – caused by night driving (about 22h10)
2004/10/08	MOCARGO	Truck rollover	Bobole (Marracuene –about 755 km south rom Temane)	Very severe, with spill, but without human losses	Spill of 2 300 litres of product (Natural Gas Condensate)	Explosion of the front right tyre
2004/11/25	MOCARGO	Road accident: running over a car/bike	Between Hunguana and Massinga (173 km south from Temane)	Very severe, with loss of human lives and spill of product.	Spill of 16 000 litres of product (Natural Gas Condensate)	Trying to avoid a road accident by running over a bike, the truck left the road, lost equilibrium and rolled over

Surface meteorological data, in form of hourly average wind speed, wind direction and ambient temperature, are normally analysed for use in the various calculations, including evaporation from liquid spills, atmospheric dispersion, flame length and tilt calculations. Apart from Maputo, meteorological data along the rest of the route were not available. As a result all calculations were based in the observations at Maputo. The wind field over the region generally reflects the synoptic scale circulation, but clearly also illustrate the local land-sea breeze circulation patterns. Figure 2-20 represents the prevailing wind patterns observed in Maputo. Wind roses comprise 16 spokes, which represent the directions from which winds blew during the period. The colours reflected the different categories of wind speeds; the dark blue area, for example, representing winds of 1 m/s to 3 m/s. The circles provide information regarding the frequency of occurrence of wind speed and direction categories. For the current wind roses, each dotted circle represents a 4% frequency of occurrence.

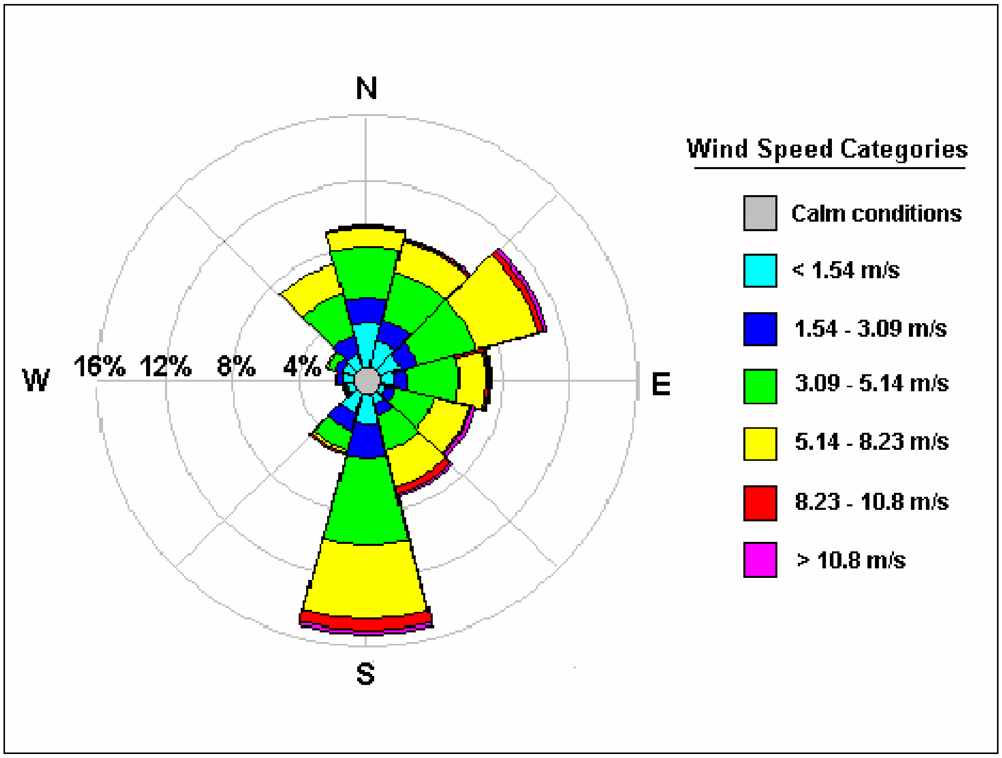


Figure 2-20: Wind rose for Maputo.

The 30-year average wind speed is 2.5 m/s (National Institute of Meteorology). The wind direction is predominantly from the south (~15%) and northeast (~10%). It is also clear from the wind rose, that most of the wind appears to originate from the eastern sector with only weak winds (< 3 m/s) occurring from the west. The months from March to June generally experience the lowest wind conditions. The average wind speed during the winter months is 2 m/s and during the summer months, 4 m/s. The most frequent occurrences of strong winds are from the northeastern and southern directions. Most of the very strong winds (22 - 31 m/s) occur from the south and the south east (23 – 24 m/s).

In the context of this investigation, air temperature is most important in estimating the amount of flammable vapour formed from an evaporating condensate pool. The highest temperatures are reached during the months of January, February and March (Table 2-3). The general nighttime temperatures during winter and summer are 13ºC and 21ºC, respectively. The daytime temperatures during winter and summer are 24ºC and 31ºC, respectively. Additional temperature statistics include:

Annual average temperature	:	22.9ºC
Maximum monthly average temperature	:	30.9ºC (January 1969)
Minimum monthly average temperature	:	13.3ºC (July 1980)
Absolute maximum temperature observation	:	44.1ºC (January 1980)
Absolute minimum temperature observation	:	– 8.6ºC (June 1984)

Table 2-3: Historical monthly temperature, rainfall and evaporation for Maputo over a 30-year period (1979 to 1998) - National Institute of Meteorology.

Month	Temperature (ºC)	Precipitation (mm)	Evaporation (mm)
January	26.1	171.1	106.9
February	26.0	130.5	93.7
March	25.4	105.6	96.1
April	23.7	56.5	88.0
May	21.8	31.9	91.3
June	19.5	17.6	86.1
July	19.3	19.6	91.9
August	20.3	15.0	104.1
September	21.6	44.4	99.0
October	22.4	54.7	100.9
November	23.6	81.6	95.4
December	25.3	85.0	108.0

The atmospheric boundary layer constitutes the first few hundred metres of the atmosphere. This layer is directly affected by the earth's surface, either through the retardation of flow due to the frictional drag of the earth's surface, or as result of the heat and moisture exchanges that take place at the surface. During the daytime, the atmospheric boundary layer is characterised by thermal turbulence due to the heating of the earth's surface and the extension of the mixing layer to the lowest elevated inversion. Radiative flux divergence during the night usually results in the establishment of ground-based inversions and the erosion of the mixing layer. Nighttimes are characterised by weak vertical mixing and the predominance of a stable layer (Table 2-4). These conditions are normally associated with low wind speeds, hence less dilution potential.

The atmospheric boundary layer is normally unstable during the day as a result of the turbulence due to the sun's heating effect on the earth's surface. The thickness of this mixing layer depends predominantly on the extent of solar radiation, growing gradually from sunrise to reach a maximum at about 5-6 hours after sunrise. This situation is more pronounced during the winter months due to strong nighttime inversions and a slower developing mixing layer. During the night a stable layer, with limited vertical mixing, exists. During windy and/or cloudy conditions, the atmosphere is normally neutral.

For elevated releases, the highest ground level concentrations would occur during unstable, daytime conditions. The wind speed resulting in the highest ground level concentration depends on the plume buoyancy. If the plume is considerably buoyant together with a low wind speed, the plume will reach the ground relatively far downwind. With stronger wind speeds, on the other hand, the plume may reach the ground closer, but due to the increased ventilation, it would be more diluted. A wind speed between these extremes would therefore be responsible for the highest ground level concentrations. In contrast, the highest concentrations for ground level, or near-ground level releases would occur during weak wind speeds and stable (nighttime) atmospheric conditions.

Table 2-4: Atmospheric stability classes.

Designation	Stability Class	Atmospheric Condition
A	very unstable	calm wind, clear skies, hot daytime conditions
B	moderately unstable	clear skies, daytime conditions
C	Unstable	moderate wind, slightly overcast daytime conditions
D	Neutral	high winds or cloudy days and nights
E	Stable	moderate wind, slightly overcast night-time conditions
F	very stable	low winds, clear skies, cold night-time conditions

2.5 Natural Gas Condensate Information

2.5.1 Physical and Chemical Properties

The natural gas condensate is a volatile liquid mainly consisting of paraffins (63.5 mass %) and naphthalenes (34.7 mass %), with a low aromatic content of 1.8 mass %. As shown in Figure 2-21, the main single compound is methylcyclohexane (14%). A complete list of the compounds contained in the condensate is summarised in Table 2-5.

Table 2-5: Chemical analysis of natural gas condensate.

Compounds >1%	Compounds <1%		
methylcyclohexane	benzene	dimethylundecane	methylheptane
n-hexane	butane	dodecane	methylnonane
n-heptane	butene	ethylbenzene	methyloctane
n-octane	butylcyclohexane	ethylcyclohexane	methylpropylcyclohexane
n-pentane	cyclohexane	ethylcyclopentane	methyltridecane
dimethylcyclohexane	cyclopentane	ethyldodecane	methylundecane
iso-pentane	decahydronapthalene	ethylheptane	pentadecane
methyl-cyclopentane	dimethylbutane	ethylmethylcyclopentane	propane
2-methylpentane	dimethylcyclopentane	ethylnonane	propylcyclohexane
n-butane	dimethyldecane	ethyloctane	tetradecane
n-nonane	dimethyldodecane	ethylpentane	toluene
2-methyl-hexane	dimethylhexane	ethylundecane	tridecane
3-methyl-hexane	dimethylnonane	heptadecane	trimethylbutane
3-methylpentane	dimethyloctane	hexadecane	trimethylcyclohexane
2-methylheptane	dimethylpentane	methyldecane	trimethylcyclopentanes
n-decane	dimethylpentane	methyldodecane	xylenes
1,3-dimethylpentane			
ethylmethylcyclohexane			
3-methylheptane			
2,2-dimethylbutane			
n-undecane			

Contaminants include sulphur, water and metals. The total sulphur contents is less than 0.004 mass % (typically 0.0017%) and the total metal content is 1 ppm. The main metals are aluminium and silicon (Table 2-6).

The distillation curve is provided in Figure 2-22. The initial boiling point is at 35^{o}C, and the final boiling point at 250 ^{o}C. The condensate has a Reid vapour pressure of about 49 kPa, which is similar but less volatile than gasoline (Reid vapour pressure 60 - 75 kPa).

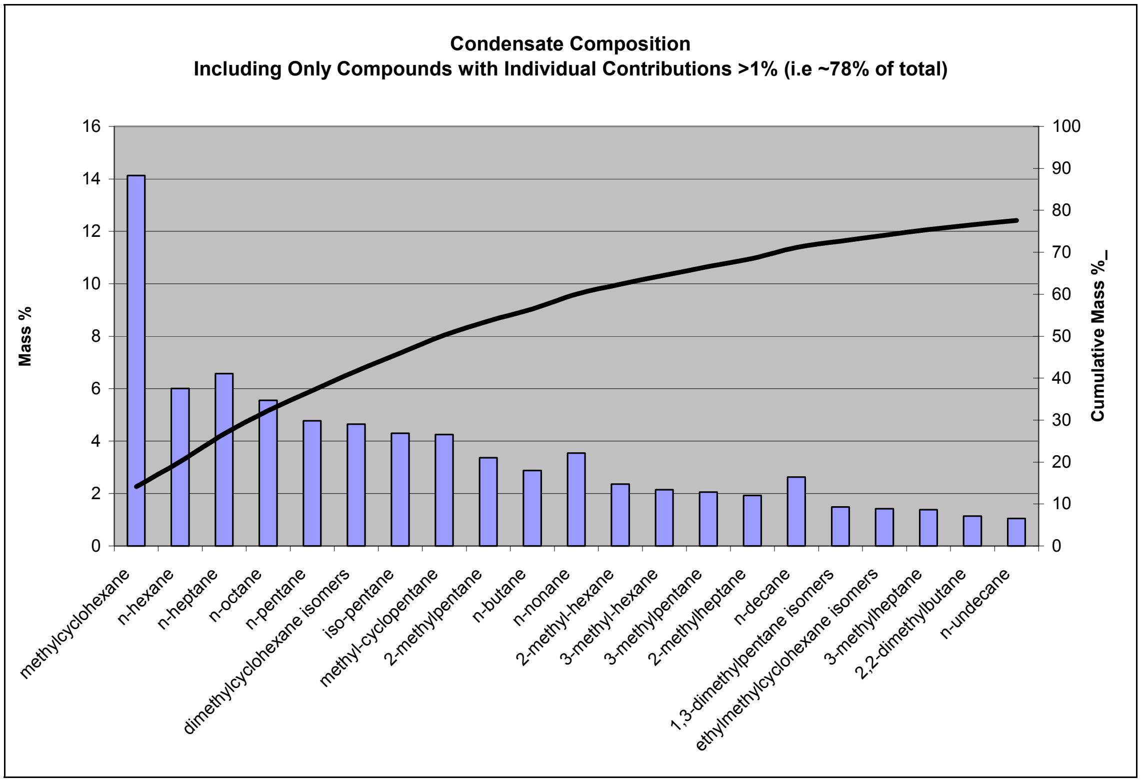


Figure 2-21: Chemical analysis of the condensate from Temane. Only those compounds with individual contributions of 1% or more are shown.

Calculating burning rates, evaporation rates and explosion cloud amounts require knowledge of heat capacity, vapour pressure, heat of vaporisation, heat of combustion and explosive limits. These and some other properties are summarised in Table 2-8.

Condensate is a clear and bright liquid, characterised as having a pungent, hydrocarbon odour. It is a flammable and the primary combustion products would be carbon dioxide (CO_2) and water (H_2O). However, other species may also be formed such as oxides of nitrogen (NO and NO_2), carbon monoxide (CO) and particulate matter (PM) – the latter two due to incomplete combustion. The amount of NO, NO_2, CO and PM formation is not easily established. In the absence or insignificant amounts of hetero-atoms (e.g. sulphur, chlorine, etc.) there is therefore no or very little opportunity for the formation of toxic vapours such as sulphur dioxide, hydrogen chloride etc.

Table 2-6: Metal composition of condensate

Element	Chemical Analysis (ppb)
Aluminium	45
Calcium	5
Chromium	4
Copper	7
Iron	6
Potassium	7
Magnesium	6
Manganese	4
Sodium	6
Nickel	5
Lead	4
Silicon	65
Vanadium	5
Zinc	14

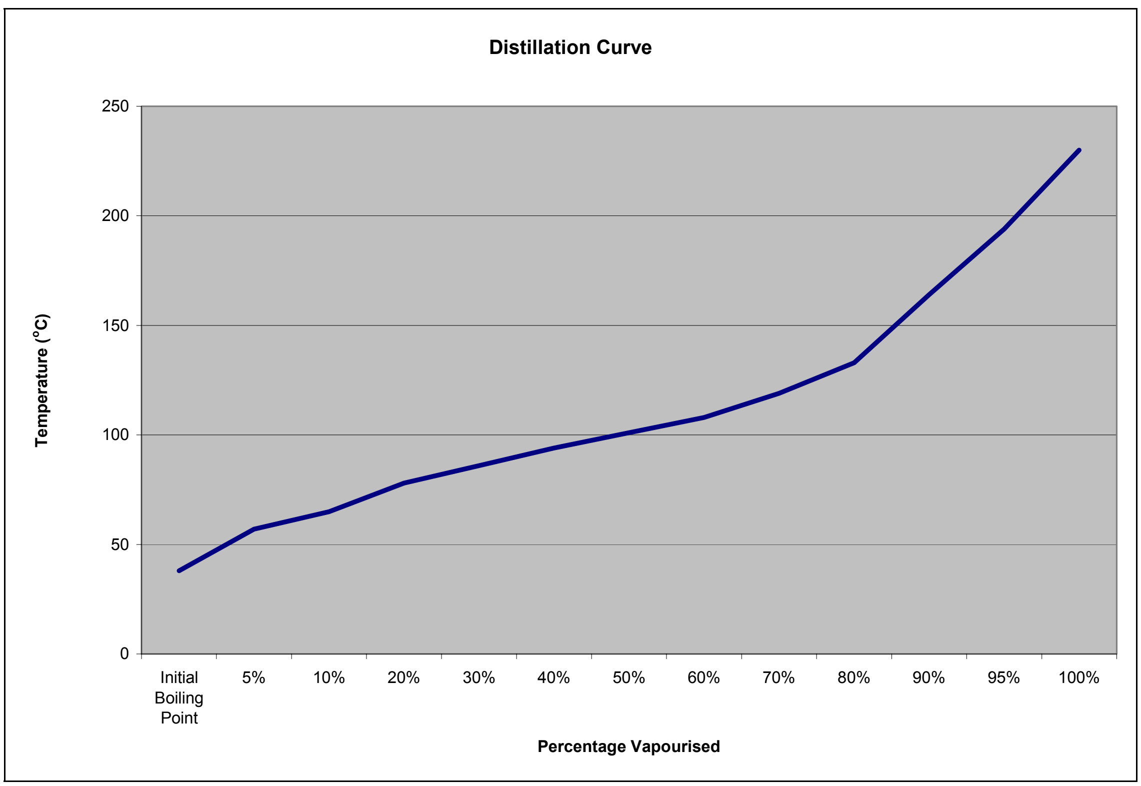


Figure 2-22: Experimental distillation results.

Table 2-7: Experimental results of some physical properties.

Analysis	Units	Parameter
Density @15 °C	kg/l	0.7228
Density @20 °C	kg/l	0.7186
Initial Boiling Point	°C	38
Final Boiling Point	°C	230
Reid Vapour Pressure	kPa	49

Table 2-8: Estimated thermodynamic properties.

Parameter	Value
Molecular Weight	65 to 192 (methylcyclohexane: 98)
Normal Boiling Point (K)	308 to 523 (use 374 K at 50%)
Heat Capacity : Vapour (J/kg.K)	1 306 (estimate using C_p/C_v = 1.41)
: Liquid (J/kg.K)	1 841 (methylcyclohexane)
Density : Vapour (kg/m^3)	3.4
: Liquid (kg/m^3)	720
Liquid Thermal Conductivity (W/m.K)	0.1 (estimate)
Vapour Pressure (kPa)	49 at 312 K (RVP)
Heat of Vaporisation (kJ/kg)	356 (methylcyclohexane)
Heat of Combustion (MJ/kg)	46.865 (methylcyclohexane)
Flash Point (K)	267(-6^{o}C)
Ignition Temperature in Air (K)	523.15 (methylcyclohexane)
Explosion Limits in Air (%v/v) – Lower	1.1 (estimated using paraffins)
– Upper	7.1 (estimated using paraffins)

2.5.2 Toxicological Data

No air quality criteria or lethal concentration limits (LC50) are available. However, due to the high percentage of paraffins, acute exposure to the condensate is expected to be mildly toxic.

The Immediately Dangerous to Life or Health (IDLH) value for methylcyclohexane is 10 000 ppm (40 000 mg/m^3). This value was developed by the National Institute of Occupational Safety and Health (NIOSH), and refers to a maximum concentration to which a healthy person may be exposed for 30-minutes and escape without suffering irreversible health effects or symptoms that impair escape (ranging from runny eyes that temporarily impair eyesight to a coma). The IDLHs are intended to ensure that workers can escape from a given contaminated environment in the event of failure of the respiratory protection equipment. The IDLH generally assumed for gasoline is also 10 000 ppm.

No odour threshold data are available.

3 HAZARD IDENTIFICATION

There is an important distinction between *risk* and *hazard*. Risk refers to the likelihood (probability) of a harmful event, such as injury or death from a particular hazard; hazard refers to a situation with a potential to cause harm (regardless of the likelihood of it actually occurring). During a general hazard identification process, the following considerations are normally taken into account:

- Chemical identities;
- Location of facilities that use, produce, process, transport or store hazardous materials;
- The type and design of containers, vessels or pipelines;
- The quantity of material that could be involved in a spillage and airborne release; and,
- The nature of the hazard (e.g., airborne toxic vapours or mists, fire, explosion, large quantities stored or processed, handling conditions) most likely to accompany hazardous materials spills or releases.

The hazard identification and risk assessment focused only on the transportation of the condensate. The assessment excludes risks associated with the loading at Temane and the offloading at the Petromoc tankfarm.

A predictive hazard evaluation assumes the plant, or in this case, the road tanker, will perform as designed, according to *Good Engineering Practices*. Although, by considering historical data, unintended events such as human errors (e.g. collision data), external events and process unknowns are allowed for, the prediction of these events is often not easily performed. This is mainly due to the difficulty in accurately assigning probabilities to the actual process under investigation using historical records, and/or the lack of historical data to develop adequate statistical parameters. As a result, the precautionary principles normally followed in risk assessments dictate a pessimistic direction; hence more conservative frequencies are generally used.

A detailed illustration of all the steps and actions to be taken within the predictive hazard evaluation process is depicted in Figure 3-1. In this assessment, the hazards are primarily associated with the condensate itself and the activity of transportation. Although the consequences of each of the potential outcomes of an incident need to be illustrated (i.e. toxic cloud, explosion and fire), a screening assessment may rule out the necessity show all, due to the very unlikely nature of occurrence.

Furthermore, the general hazard evaluation calls for the identification of opportunities in the analyses to reduce the consequences and probabilities of the initiating events. However, since the risk of transportation is often dominated by the actions of other, non-controllable factors (e.g. road conditions, pedestrian behaviour, other vehicle behaviour, etc.) only limited opportunities exist to reduce the risk. Furthermore, since a detailed tanker design risk assessment is excluded from the investigation, no design recommendations would be attempted to reduce failure rates. The assessment would merely quantify the risk using existing information, and recommend whether the risk is acceptable or not. General areas of potential risk reduction would be identified.

3.1 Industrial Accidents

Industrial accidents of vessels often occur as a result of improperly operated or maintained conditions. Vessels can fail catastrophically, kill and injure workers and others, and cause extensive damage even if the contents are benign. For example, in 1996, an accident in the USA resulted in three workers being killed and a number of others were injured when a high-pressure vessel containing air and water ruptured.

The results of a relatively recent investigation of chemical incidents in the USA for a ten-year period (1987-1996) are given in Figure 3-2. The study identified approximately 605 000 unique chemical incidents, with 42% occurring at fixed locations occupied by industrial and commercial businesses, and 43% related to transportation (CSB 1999). About 29% of these incidents resulted in at least one fatality (1.6%), evacuation of workers and/or the public (0.7%), or property damage (27%). The balance of the incidents held the potential for undesired consequences.

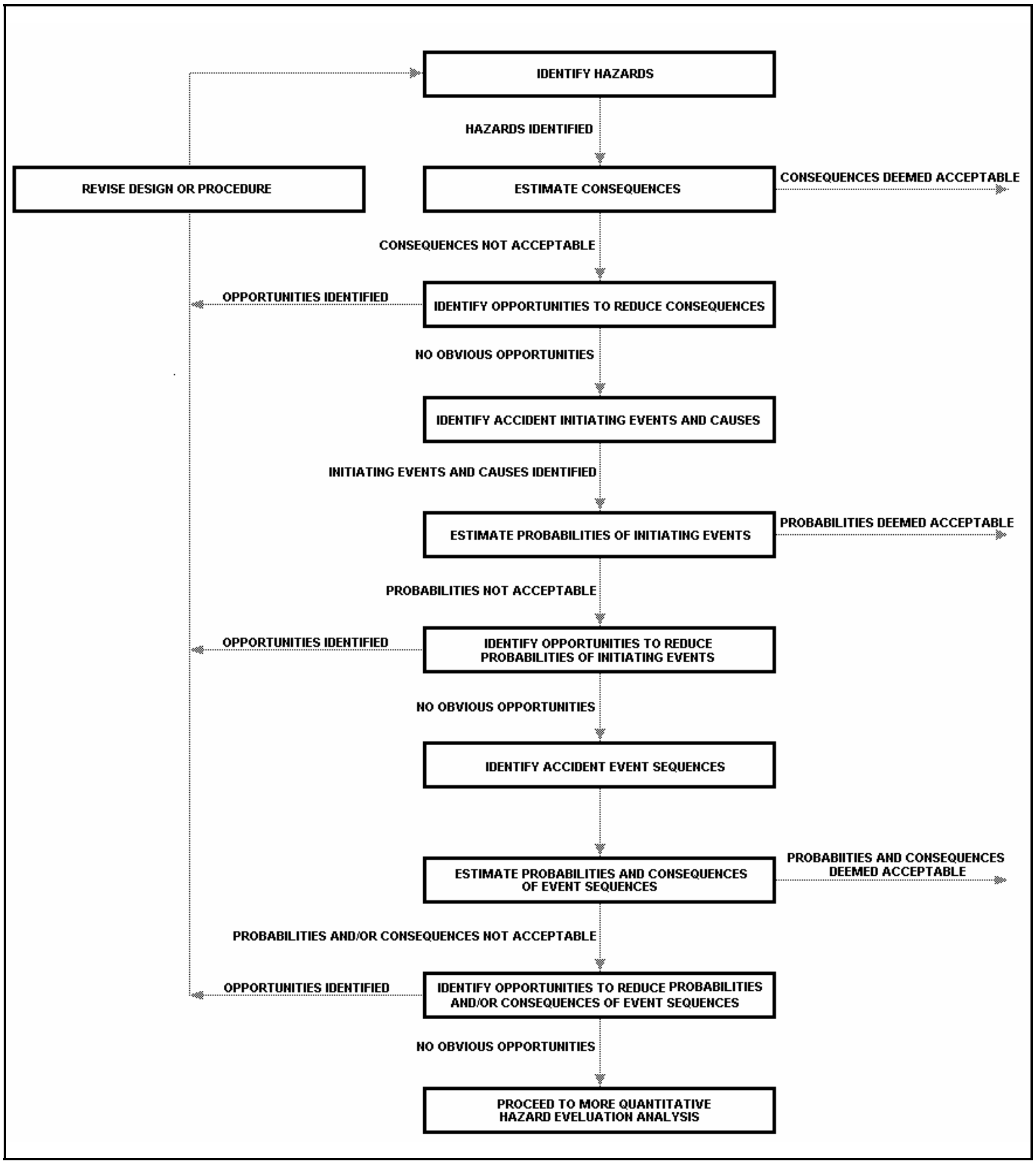


Figure 3-1: The steps in predictive hazard evaluation (Source: AIChE 1985).

These incidents were most frequently reported for the chemical manufacturing and fuel companies, with gasoline, being the substance most often involved in incidents (21.2%). Unfortunately, the actual cause of an incident was never recorded in the databases used in the analyses; only the presumed initiating event was identified. The incidents were grouped into "*Mechanical Failure*", "*Human Factor*", "*Natural Phenomenon*", "*Other*" and a large group constituting those for which no data were available ("*Unknown*"). Mechanical failures were cited as leading to 40% of the incidents. Human factors, including both unintentional and intentional acts, were cited in 27% of the reports, while the effects of natural phenomena accounted for only 1% of the incidents. Approximately 29% of the reports had no indication of an initiating event.

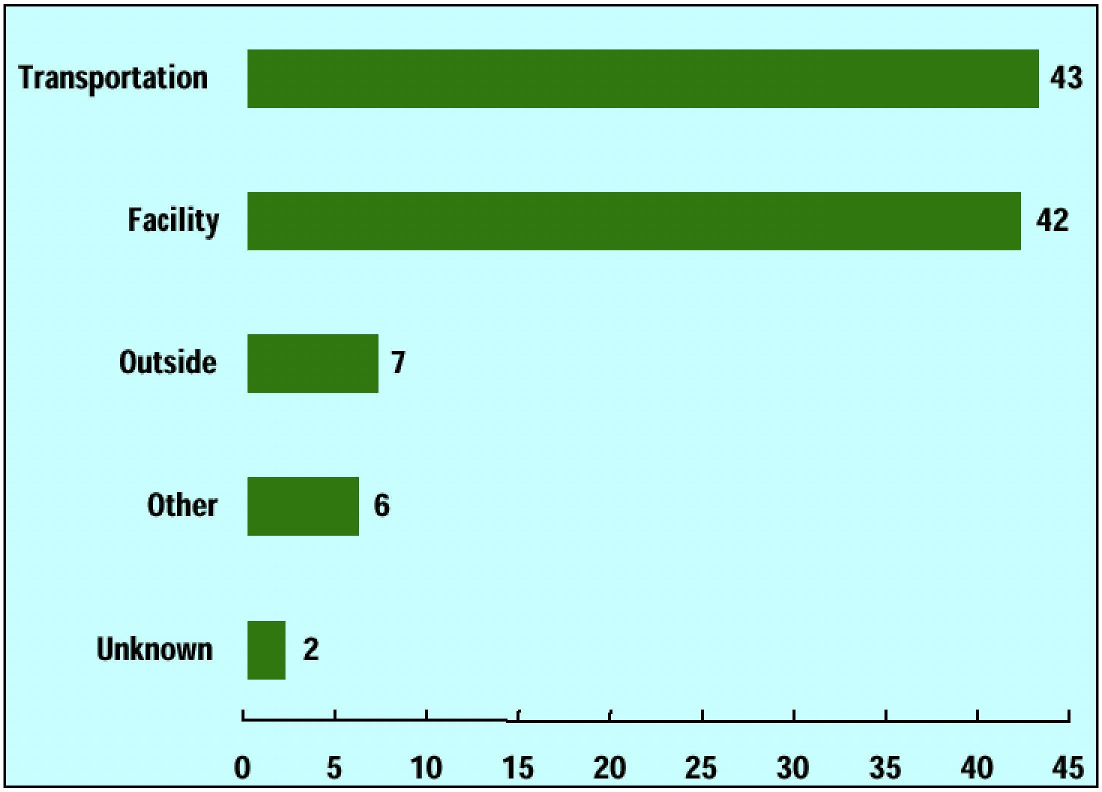


Figure 3-2: Summary of a ten-year (1987-1996) chemical incident history in the USA, analysing nearly 605 000 unique incidents (CSB 1999)

Transport related incidents are clearly very significant and include all modes: road, railroad, aviation, marine and overland pipeline. Although not necessarily related directly to chemical incidents, the United States Department of Transport (National Transportation Safety Board and Office of Pipeline Safety) summarised fatality statistics for the different modes of transport. As depicted in Figure 3-3, highway transportation is the largest contributor to the fatalities, contribution 94% of all transportation incidents reported in the USA. Cross-country transportation gas pipelines have created the safest mode of transportation, surpassing road, rail, air and water. This record has been achieved and maintained with the use of redundant safety systems, round-the-clock monitoring and extensive inspection and maintenance to keep the pipelines operating in top condition. However, unlike pipeline risks, which have been reduced significantly over the past decade through better design and safety precautions, road accidents cannot easily be engineered to reduce the risk.

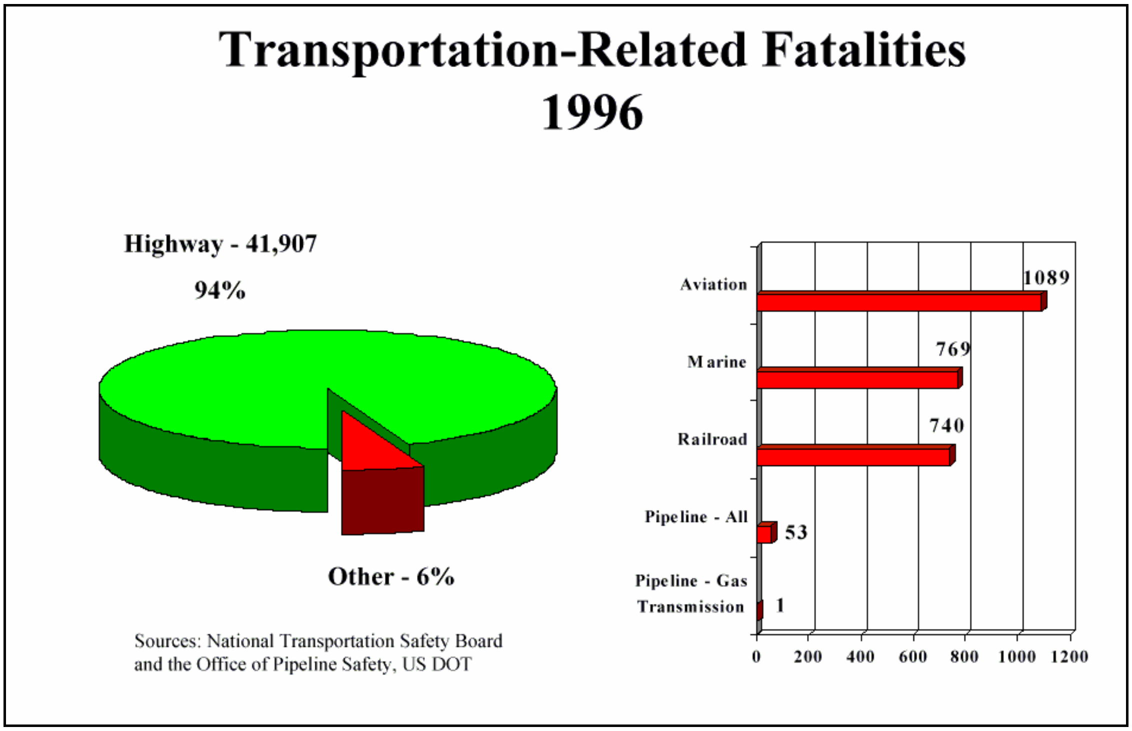


Figure 3-3: Statistical comparison of transportation fatalities in the USA (Sources: *National Transportation Safety Board and Office of Pipeline Safety, United States Department of Transport*).

3.2 Hazard Identification

The initial part of assessing the risks associated with an industrial installation or transportation is to identify and evaluate the particular hazards and the corresponding events that could cause an accident. The first step is therefore to identify potential hazards based on the type of chemical and quantities of hazardous materials. A number of hazard identification schemes may be used, such as the well-known Dow Chemical Company's Fire and Explosive Index. Hazardous substances and controlled quantities have also been listed as part of many regulations such as the USA EPA and the UK HSE. The Dutch authority (IPO 1994), on the other hand, adopted a generic methodology applicable to any substance and quantity, and is therefore not restricted to a list of substances. However, these methods are mainly applicable to fixed installations with multiple substances and processes – transport hazards depend on the chemical nature and amount of the substance, the design of the transport vehicle and the characteristics of the route (i.e. traffic volumes, condition of the roads and the proximity to residential areas).

As discussed in Section 2.1, condensate has been scheduled for transportation on eight trucks per day, on a 3-day cycle, with an average tanker load of 35 000 litres. The regularity of the trips and the size of the condensate load clearly indicate a significant hazard and the potential to cause damage along the route.

3.2.1 Condensate Hazards

According to the MSDS (Appendix A), the UN number for the condensate is 3295, and is classified according to the DOT, TDG, IMDG and IATA-DGR Classifications as "Class 3 (flammable liquid) Packing Group II". Reference was also made to the South African Bureau of Standards' Code of Practice, SABS 0228:1995, in the classification of hazardous substances.

The code deals with the identification and classification of dangerous substances and goods that are capable of posing significant risk to health and safety or to property and the environment. Substances are classified into nine classes and four danger groups in accordance with internationally recognised classifications. The nine classes relate to the type of hazard posed by the substance, whereas the four danger groups relate to the degree of danger posed within the class.

EXHIBIT 3.1
SOUTH AFRICAN BUREAU OF STANDARDS (SABS)
HAZARD CLASSIFICATION SCHEME

SABS Class	Class Description	
1	Explosives	
2.1	Flammable Gases (e.g. LPG)	
2.2	Non-flammable, Non-toxic Gases	
2.3	Toxic Gases	
3	Flammable Liquids	
4.1	Flammable Solids	
4.2	Substances liable to Spontaneous Combustion	
4.3	Substances that, on contact with water, emit flammable gases	
5.1	Oxidising Substances	
5.2	Organic Peroxides	
6.1	Toxic Substances	
6.2	Infectious Substances	
7	Corrosives	
8	Miscellaneous Dangerous Substances and Goods	
SABS Danger Level	**Description**	**Closed-Cup Flash Point**
I	Very Severe Risk	-
II	Serious Risk	< 23°C
III	Relatively Low Risk	≥ 23°C ≤ 60.5°C
IV	Very Low Risk	>60.5°C to 100°C

Exhibit 3.1 summarises the SABS classification scheme. Accordingly, the SABS regards condensate as a FLAMMABLE LIQUID, i.e. Class 3, with a Danger Group rating of II, i.e. SEVERE RISK.

3.2.1.1 Toxicity

The potential acute inhalation health effects include headache and slight dizziness. There is no known effect from long-term exposure to the product, but repeated or prolonged exposure is not known to aggravate medical condition. Overexposure signs and symptoms include central nervous system (CNS) depression, headache, nausea, vomiting, cramping and anaesthesia (see Appendix A for material safety data sheet [MSDS]).

As a reference, the Immediately Dangerous to Life or Health (IDLH) value for methylcyclohexane of 10 000 ppm (40 000 mg/m^3), may be used for comparison.

3.2.1.2 Flammability

Condensate is flammable and the primary combustion products would be carbon dioxide (CO_2) and water (H_2O). However, other species may also be formed such as oxides of nitrogen (NO and NO_2), carbon monoxide (CO) and particulate matter (PM) – the latter two due to incomplete combustion. In the absence or insignificant amounts of hetero-atoms, such as sulphur and chlorine, there is little opportunity for the formation of toxic vapours such as sulphur dioxide, hydrogen chloride etc.

Condensate poses similar dangers as gasoline - it is has a flashpoint of -6°C and an estimated autoignition temperature of ~250°C. The autoignition temperatures for some of the more significant compounds in the condensate typically range from 204°C for heptane, to 460°C, for iso-butane (Table 3-1).

Table 3-1: Flammability properties of some of the more significant compounds contained in the Temane natural gas condensate.

Compound	Flash Point (°C)	Flammability Limits		Autoignition Temperature (°C)
		Lower	*Upper*	
heptane	-4	1.05%	6.70%	204
Nonane	31	0.80%	2.90%	205
Octane	13	1%	6.50%	206
Decane	44	0.80%	5.40%	209
n-hexane	-22	1.1%	7.5%	225
methylcyclohexane	-3.9	1.20%	6.70%	250
n-pentane	-40	1.40%	7.80%	260
n-butane	-60	1.90%	8.50%	287
iso-pentane	-51	1.40%	7.60%	420
iso-butane	-88	1.80%	8.40%	460

The estimated (using Le Chatelier's method) Lower Flammability Limit (LFL) of condensate is 1.1% v/v (meaning 1.1 % gas to 98.9 % air, measured by volume) and the Upper Flammability Limit (UFL) is 7.1 % v/v. This is similar to that of gasoline. The range is fairly restricted if compared to the flammable limits for carbon monoxide are 12.5% (lower flammable limit) and 74% (upper flammable limit), or even methane (5% and 15%, respectively).

3.2.1.3 Explosion Hazard

An explosion can be thought of as a rapid release of a high-pressure gas into the environment. The release must be rapid enough that the energy is dissipated as a pressure or shock wave. Explosions can arise from strictly physical phenomena such as the catastrophic rupture of a pressurized gas container or from a chemical reaction such as the combustion of a flammable gas in air. These latter reactions can occur within buildings or vessels or in the open in potentially congested areas.

Four features must be present in order for a vapour cloud explosion (VCE) to occur:

1. The release must be flammable;
2. A cloud of sufficient size must form prior to ignition, with ignition delays from 1 to 5 minutes considered the most probable for generating vapour cloud explosions;
3. A sufficient amount of the cloud must be within the flammable range. Experimental studies have demonstrated that there is a minimum mass of flammable material that is required to allow transition from a flash fire to a vapour cloud explosion. These estimates range from 1 ton to 15 ton. However, a few examples of VCEs with quantities as low as 100 kg for more reactive species such as hydrogen and acetylene has been witnessed;
4. Sufficient confinement or turbulent mixing of a portion of the vapour cloud must be present. Turbulence may arise by two mechanisms: (a) from a violent release of fuel under high pressure in a jet or from explosive dispersion from a ruptured vessel or (b) generated by the gas flow caused by the combustion process itself and interacting with the boundary conditions (i.e. obstacles).

Whereas the first two conditions are met following a large spill of condensate, the latter two conditions may be less easy. The rate of evaporation would determine the amount of vapour available for an explosion. Although the condensate is relatively volatile (RVP 49kPa), the evaporation rate may be low enough not to develop in a large explosive cloud. This postulation would need to be tested. Furthermore, since the transportation is primarily in the open, apart from narrow roads in build-up areas, and since the route does not have any tunnels, the chances of confined releases are very remote.

3.2.2 Route Hazard Rating

A semi-quantitative hazard rating was calculated using an estimate of the vehicle density, the number of bends in the road, blind rises and maximum vehicle speed along the route. The index represents a product of these factors, with vehicle speed weighed to the power “2”. Blind rises were considered to be twice as dangerous as bends in the road. The result is depicted in Figure 3-4.

Although the actual “index” does not mean much, the relative peaks indicate regions of increased hazards. Albeit not as significant, the first increased hazardous area was calculated to be at Maxixi. This is mainly due to the increased number of vehicles and the speed achievable on the road.

The road conditions (bends and blind rises), and increased traffic and aggressive driver behaviour along the road from Zandamela, Chidenquele Turn Off to Xai-Xai result in a significantly more hazardous section. This hazard rating is only again equalled when approaching Marracuene.

Although this rating provides a reasonable way of expressing the relative hazards along the route, a detailed risk assessment can only be completed with actual accident statistical data.

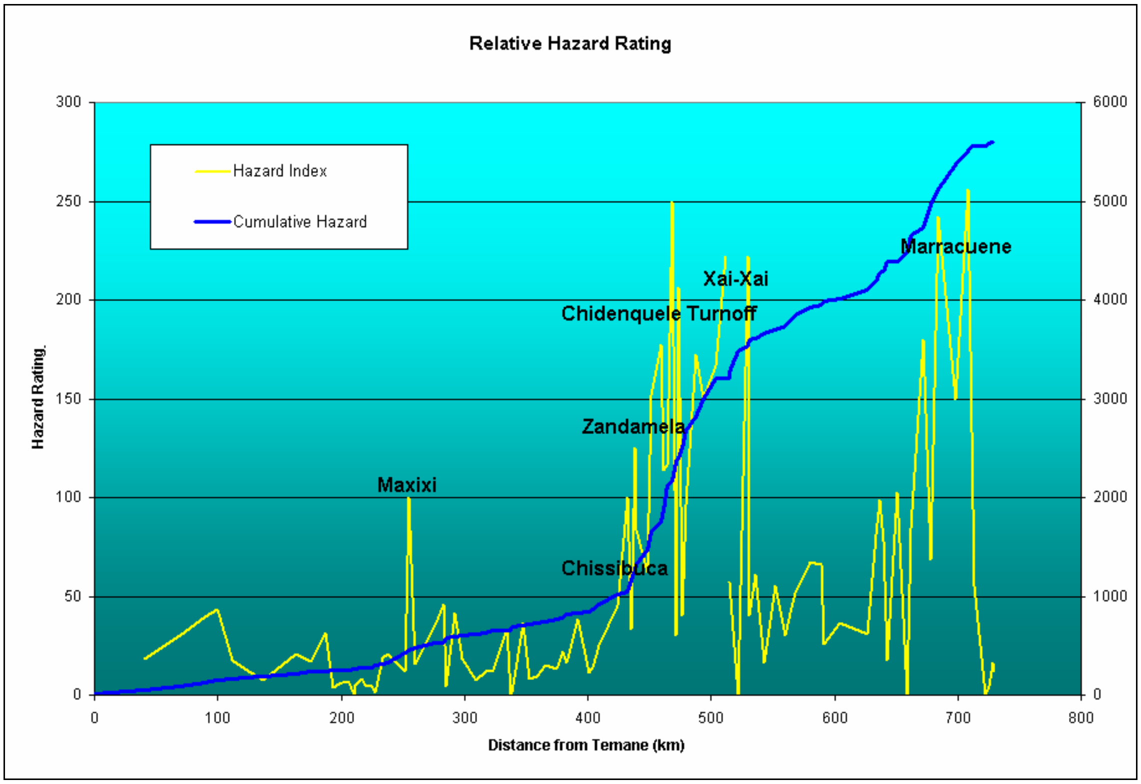


Figure 3-4: Estimated hazard rating along route from Temane to Petromoc tankfarm.

4 LOSS OF CONTAINMENT EVENTS

Once a hazard has been identified, it is necessary to evaluate it in terms of the risk it presents to the employees and the neighbouring community. Predictive hazard evaluation procedures have been developed for analysis of processes when evaluating very low probability accidents with very high consequences (for which there is little or no experience), and more likely releases with fewer consequences, but for which there may be more information available. The risk concept therefore addresses both the probability of an accident and the magnitude and type of the undesirable consequence of that accident.

A number of approaches may be employed to estimate incident frequencies. In a comprehensive assessment, the approach to quantify the probability of an accident event sequence would be to estimate it from basic causes with a statistical tool such as a *Fault-and-Event Tree Analysis*. With such an examination, the state of the system is defined in terms of events, including states of variables. Defining a top event and then specifying the cause events and logical relations between these cause events construct a fault tree. The main elements of the fault tree are therefore event definitions and logical gates (i.e. "AND" and "OR" gates). As an illustration of the technique, the top event, for example, a "TANK RUPTURE", is developed to the first level as "PROTECTION FAILED" <u>*OR*</u> "TANK OVER-PRESSURIZED". Each of the latter two *branches* could similarly be expanded down to the *root* causes, for which data are available in terms of their probability of occurrence.

For those countries with a history of hazardous goods accidents, consulting historical records is an alternative and complimentary method for providing general failure data. In Mozambique, however, the number of such incidents is much less and not as well documented.

The approach in this assessment adopted historical information on vehicle accidents in South Africa applied to Petromoc's recent incident records (Section 2.3), spillage sizes recommended by the Dutch authorities in their recommended transport risk methodology, and perforation and ignition probabilities from literature.

4.1 South African Road Collision Statistics

Road collision statistics were obtained from the South African Statistical Services (StatsSA), and included detailed information up to 1998.

Table 4-1 is a summary of the number and severity of road accidents for the period 1989 to 1998. It is interesting to note that whilst the total collisions gradually increased, all accept those resulting in no injuries, decreased. This is even more obvious when the collisions per distance travelled (100 million vehicle-km) are considered (Table 4-2). In this table, it is clear that all collision rates have decreased steadily from 4.51×10^{-6} per vehicle-km (1990) to 3.931×10^{-6} per vehicle-km (1998).

Collisions numbers for light delivery, heavy and articulated vehicles according to severity and driving location are given in Table 4-3. The number of registered light delivery and heavy vehicles and distances travelled by these vehicles are summarised in Table 4-4. Of the total number of travelling vehicles, approximately 67% were loaded and 33% unloaded. The collision rates are summarised in Table 4-5 using the collision statistics and distances travelled for 1998.

Table 4-1: Ten-year road collision statistics up to 1998 classified according the severity of the accident (people in car accident itself) (StatsSA).

Collisions	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Fatal	9061	9174	9222	8378	7936	8140	8335	7850	7790	7260
Major	20816	20446	21711	20205	20445	22594	23988	22707	23059	21265
Minor	59383	59393	60495	55221	56291	60199	61716	54190	57391	52097
No Injury	345675	344274	353113	345681	349357	377064	406194	436027	417748	430983
Total	434935	433287	444541	429485	434029	467997	500233	520774	505988	511605

Table 4-2: Estimated collision rate for the period 1990 to 1998 (StatsSA).

All Vehicles	1990	1991	1992	1993	1994	1995	1996	1997	1998
Vehicle km Travelled (million)	96067	96513	97798	102280	111476	119189	126042	126897	130137
Collisions per 100 million vehicle-km									
Fatal	9.5	9.5	8.6	7.8	7.3	7.0	6.2	6.1	5.6
Major	21.3	22.5	20.1	20.5	20.3	20.1	18.0	18.2	16.3
Minor	61.8	62.6	56.5	55.0	54.0	51.8	43.0	45.2	40.0
No Injury	358.4	365.0	365.9	341.6	338.3	340.8	345.9	329.2	331.2
Total	451.0	459.6	451.1	424.9	419.9	419.7	413.1	398.7	393.1

Table 4-3: Goods transportation collisions for 1998.

Road Vehicle Type	FATAL		MAJOR		MINOR		NO INJURY	
	Cities/Towns	Other	Cities/Towns	Other	Cities/Towns	Other	Cities/Towns	Other
Light Delivery Vehicles	748	694	2633	1107	6954	2362	60534	8331
Heavy Commercial Vehicles	301	342	613	308	1266	783	16575	3321
Articulated Vehicles	21	18	43	11	106	44	932	167
All Vehicles	4270	2990	17197	4068	43308	8789	396052	34931

Table 4-4: Registered light delivery and heavy vehicles and estimated distances travelled (StatsSA).

	1991	1992	1993	1994	1995	1996	1997	1998
Registered Light Delivery Vehicles	1 093 698	1 122 837	1 150 220	1 177 135	1 203 770	1 402 333	1 600 896	1 666 769
- Vehicle km Travelled (million)	25 148	25 857	26 632	28 979	32 059	32 618	37 103	38 434
Registered Heavy Vehicles	210 297	215 900	221 048	226 054	231 340	275 557	319 774	323 809
- Vehicle km Travelled (million)	7 200	8 867	9 891	9 379	9 658	9 112	10 863	10 851

Table 4-5: Calculated goods transportation collision rates for 1998 (per 100 million km).

Road Vehicle Type	FATAL		MAJOR		MINOR		NO INJURY	
	Cities/Towns	Other	Cities/Towns	Other	Cities/Towns	Other	Cities/Towns	Other
Light Delivery Vehicles	1.9	1.8	6.9	2.9	18.1	6.1	157.5	21.7
Heavy Commercial and Articulated Vehicles	3.0	3.3	6.0	2.9	12.6	7.6	161.3	32.1
All Vehicles	451.0	459.6	451.1	424.9	419.9	419.7	413.1	398.7

Table 4-6: Number of collisions according to action of vehicles (1998).

ACTION	TOTAL	FATAL		MAJOR		MINOR		NO INJURY	
		Cities/Towns	Other	Cities/Towns	Other	Cities/Towns	Other	Cities/Towns	Other
Overtaking	6560	70	79	234	109	498	234	4354	982
Swerving	16945	162	135	649	229	1860	701	10982	2227
Slowing-Down	11991	31	42	217	62	924	204	9448	1063
Normal Travelling	165958	2262	1744	7540	2228	18437	4853	111674	17220
U-Turn	2695	12	12	68	19	243	30	2163	148
Pulling Away	24133	95	35	651	65	1710	83	20729	765
Stopping	31201	34	14	240	38	1392	126	28281	1076
Changing Lanes	5055	23	20	92	26	280	65	4279	270
Parking	7361	4	4	20	4	141	10	7005	173
Emerging/Entering Property	3313	9	1	45	6	177	14	2980	81
Stationary	52915	51	28	282	44	1943	136	49333	1098
Straightforward	100346	1270	763	5581	997	10779	1860	71644	7452
Turning Left	16089	48	37	358	71	1181	148	13604	642
Turning Right	30786	88	45	777	139	2720	266	25560	1191
Reversing	30162	50	7	247	8	804	28	28615	403
Other	6095	61	24	196	23	219	31	5401	140
TOTAL	**511605**	**4270**	**2990**	**17197**	**4068**	**43308**	**8789**	**396052**	**34931**

4.2 Derived Collision Frequency

The specific actions prior to an accident and their probabilities are summarised in Table 4-6. Nearly 98% of these actions can be categorised into:

- Routine (normal) travelling;
- Changing lanes; and,
- Stop and pulling off actions (i.e. left, right, forward movements).

The derived collision rate for all vehicles and accident severity for South Africa is 354 accidents per 100 million km (or 3.54×10^{-6} per km) for urban conditions and 39 accidents per 100 million km (or 3.9×10^{-7} per km) for rural conditions, respectively.

In an analysis of USA combination truck accident statistics, Saricks and Kvtek (1994) derived the mean interstate accident rates of 2.03×10^{-7} per km for rural and 3.58×10^{-7} per km for urban roads, respectively (a mean total of 2.44×10^{-7} accidents per km). In a later study Saricks and Tompkins (1999) obtained a mean total interstate accident rate of 3.15×10^{-7} per km. These accidents included commercial vehicles that resulted in (a) a fatality and/or (b) bodily injury to a person that required medical treatment away from the accident scene; and/or (c) one or more involved motor vehicles incurring disabling damage as a result of the accident such that the vehicle had to be towed from the scene. Similar rates to the USA are reported for Canada (Transport Canada), *viz.* 4.97×10^{-7} per km.

The South African statistical data for heavy commercial and articulated vehicles produces higher frequencies. Excluding injury incidents, the urban accident rates are calculated to be 4.0×10^{-7} accidents per km, and 2.6×10^{-7} accidents per km for "other" (rural) roads, respectively.

4.3 Loss of Containment Scenarios

The average condensate tanker load (Table 2-1) is about 24 tons. Based on typical inventories of 23 tons for atmospheric tankers, the accepted loss of containment scenarios used by the Dutch authorities is given below:

4. Release of the complete inventory ("Large Spill");
5. Release of 5 m^3 of the inventory ("Medium Spill"); and
6. Release of 0.5 m^3 of the inventory ("Small Spill").

A release of 0.5 m^3 from an atmospheric tanker would result in a small pool, and hence, especially in open road (rural) situations, this scenario may in most cases be omitted in the calculation. However, these three scenarios would be included in all subsequent calculations.

Van Gelder and Vrijling (1998) analysed a total of 123 road tanker accidents with hazardous material releases occurring during the period 1978-1997 in the Netherlands. The probability of an entire tank spillage was calculated to be 15%, whilst a release of 5000 litres was calculated to be 60% and 500 litres, 25%. These spillages only considered amounts above 100 litres.

4.4 Perforation and Spillage Rates

An analysis of road incidents involving tankers containing hazardous materials showed that releases could occur from two sources:

- *Puncture* or *rupture* following tanker collision or roll-over; and,
- *Failure* or *maloperation* of tanker equipment.

As observed with the Petromoc historical data (Table 2-2), 40% of the incidents were due to failure or maloperation of tanker equipment and not due to collisions, i.e. 60% resulted in spillage due to vehicle accidents.

Not all collisions result in spillage. According to an analysis of UK collisions statistics, Lees (2001) reported the following spillage probabilities:

	Minor Collision	Medium Collision	Severe Collision
Rollover	25%	16.7%	58.3%
No Rollover	50%	16.7%	33.3%

To obtain similar probabilities, it was assumed that 50% and 25% of all fatal and major tanker collisions will result in large spills, respectively. Medium spillage would be from 20% of fatal accidents and 25% from major accidents. All minor and collisions resulting in no injuries will result in small to very small spills. A summary of the assumed breakdown is summarised in Table 4-7.

Table 4-7: Assumed fraction of accidents contributing to different condensate spill sizes.

MAGNITUDE OF INCIDENT	COLLISION SEVERITY			
	FATAL	MAJOR	MINOR	NO INJURY
Large Spill	50%	25%	0%	0%
Medium Spill	20%	25%	0%	0%
Small Spill	20%	25%	73%	10%
Very Small Spill	10%	25%	27%	90%
TOTAL	100%	100%	100%	100%

The likelihood of rollover is ~67% (Lees 2001). This was assumed to be the same whether in urban or rural areas. Due to the higher velocities along rural roads, it is possibly more likely to have rollover than in built-up areas. Using this information, the spillage probabilities were calculated to be 50%, 17%, 33% and 0% for fatal, major, minor and no injury accidents, respectively.

Using the perforation likelihood and collision rates for heavy commercial and articulated vehicles, the spill frequencies for South Africa were therefore estimated to be 1.24×10^{-7} per vehicle-km, in urban areas, and 8.66×10^{-8} per vehicle-km, in rural areas, respectively.

The Dutch authority cite spill frequencies of 8.38×10^{-9} per loaded tanker-km for motorways, 2.77×10^{-8} per loaded tanker-km for suburban and 1.24×10^{-8} per loaded tanker-km for urban zones, respectively (CPR 18E). An analysis of the UK road transport incident data for a four-year period yielded a spill frequency of

1.4×10^{-8} per loaded tanker-km for large spills (greater than 1.5 tonnes) resulting from collisions. These rates are almost an order of magnitude less than the South African statistics for heavy commercial and articulated vehicles.

4.5 Petromoc Condensate Road Collision Statistics

Very limited accident statistics for Mozambique could be obtained (Figure 2-19). There was no split between heavy, light and passenger vehicles, nor is it clear whether these numbers reflect only fatal accidents, or whether major and minor accidents were also included. Information obtained from the African Development Bank, suggest approximately 42 800 motor vehicles in Mozambique in 1986. Assuming the same average annual distance travelled by a vehicle as in South Africa, i.e. 20 000 km/yr, and the number of collisions in Mozambique for that year, i.e. 2348, the collision rate was estimated to be 2.74×10^{-6} per km. As discussed in Section 2.3, it is expected that only collisions resulting in casualties were reported. The corresponding South African rate for collisions resulting in casualties is this is 1.24×10^{-6} per km. This is more than twice less than the Mozambican collision rate.

Of particular interest, however, are the reported Petromoc tanker collisions for the annual period since the operations started in March 2004 (Section 2.3). Considering that the distance travelled by these tankers during the 12 months is 722 213 vehicle-kilometres (8 tankers per day, during a 3-day cycle), the accident rate is therefore calculated to be 1.38×10^{-5} per vehicle-km. This is 3.26 times the South African collision rates for heavy and articulated vehicles.

Using the Petromoc collision history for the transportation of condensate and assuming that the same urban/rural collision split for South Africa holds, two spillage frequency cases are illustrated. In the first instance, the perforation likelihood, generally accepted in the UK (Section 4.4), is adopted, and in the second case, the probability of spillage from the Petromoc collisions is adopted:

- UK perforation probability:
    - 4.04×10^{-7} per vehicle-km, in urban areas; and
    - 2.82×10^{-7} per vehicle-km, in rural areas.

- Petromoc perforation probability:
    - 6.62×10^{-6} per vehicle-km, in urban areas; and
    - 1.66×10^{-6} per vehicle-km, in rural areas.

The spillage rates for both cases are significantly higher than derived frequencies for South Africa (i.e. 1.24×10^{-7} per vehicle-km, in urban areas, and 8.66×10^{-8} per vehicle-km, in rural areas). Using the perforation probability from the Petromoc historical data, the spillage rate is nearly 40-fold that of the South African data.

4.6 Probability of Fire

A specific sequence of events and conditions is necessary to arrive at a situation where a spillage and subsequent fire will result as a result of transport. These are as follows:

- The transport tanker must be involved in a road collision;
- The collision must be severe enough to incapacitate the driver to such an extent that emergency actions cannot be initiated;
- The collision must be of a nature such that the tank containing the acetaldehyde is ruptured; or,
- The fuel tank is ruptured, resulting in a pool fire under the acetaldehyde tank. Such a fire need to be extensive, adequate enough to result in the boiling of acetaldehyde, followed by an explosion; or,
- In the event of an un-ignited spill, the release must be of a duration and rate that will lead to high dosages of ambient acetaldehyde.

Most references used to estimate the probability of ignition, analysed flammable liquids and gases in their studies. The Journal of Hazardous Materials (Bartenev *et al* 1996) reported the results of a statistical analysis of flammable gas pipeline failures, indicating that 64% of pipeline ruptures resulted in fires. Of these, 60% may be assumed to have occurred immediately (within the first few seconds), and 40% delayed ignition (after about 5 seconds). Cox, Lees and Ang (1990) suggested a more detailed analysis (Table 4-8). The Dutch Authorities (IPO 1994) also adopted this methodology.

Table 4-8: Probability of ignition (immediate and delayed).

Ignition Scenario	Probability
Ignition (non built-up area):	
All Flammable Liquids	6.5% per event
Low Reactive Gases:	
< 10 kg/s release	2% per event
< 100 kg/s release	4% per event
> 100 kg/s release	9% per event
Highly Reactive Gases:	
< 10 kg/s release	20% per event
< 100 kg/s release	50% per event
> 100 kg/s release	70% per event
Ignition (built-up residential area)	100% per event
Ignition (industrial)	50% per event
Ignition (near roads):	
< 50 vehicles per hour	50% per event
> 50 vehicles per hour	100% per event

None of the condensate transportation spillages of condensate has resulted in ignitions.

4.7 Accident Events and Frequencies

A quantitative risk assessment incorporates various distinct stages, including hazard assessment, dose-response analysis, the exposure assessment, and finally, a risk characterisation. As described in Section

3, the process of hazard assessment is aimed at determining whether particular substances could cause adverse impacts on human health. It serves to eliminate any unnecessary computations required in the subsequent steps, the complexity of which increases with each of these. Having identified the hazards associated with the transportation of condensate, the next step would be to select a representative set of failure cases.

A large release of a toxic, flammable or explosive substance may result in death, non-lethal injury or irritation for humans and in damage to property. The characterisation of risks associated with accidental releases of toxic and flammable substances include:

- Health risk assessment of toxic gas releases, typically based on *probit analysis* and on the calculation of downwind distances to various acute exposure guidelines;
- Analysis of thermal radiation effects; and
- The evaluation of effects arising due to vapour cloud explosions.

4.7.1 Toxic Cloud Formation

Typically, the calculations would require the outflow rate from the tanker, its separation into liquid, droplets and vapour phases, the evaporation of any liquid spillage and the eventual atmospheric dispersion processes. This would be required to estimate (a) the air concentration and dosage, for a toxic compound, and/or (b) the explosion amount, for a flammable substance.

Toxic exposure to vapours may be from an evaporating pool or unburned substances and toxic combustion products emitted during a fire. In the case of open fires, plume rise due to the high temperature of the cloud, is normally very significant, and no lethal effects are expected. In this case exposure calculations are therefore not necessary.

No acute inhalation consequences would be calculated due to the relatively low toxicity of condensate vapours and the buoyancy of a burning pool cloud.

4.7.2 Thermal Radiation from Pool and Flash Fires

Thermal radiation is considered to be the main consequences following a spillage of condensate. It would therefore be required to simulate the pool burning rate and the subsequent thermal radiation levels at increasing distances from the accident.

A flash fire is a non-explosive combustion of an unconfined vapour cloud. On ignition, the fire propagates back through the vapour cloud and burns as a flash fire. The major hazard of flash fires is the heat effect from thermal radiation. This may affect objects in the nearby vicinity of the flash fire or in the path of the flash fire whether on land or water. To compute the intensity of the thermal radiation and the aerial extent of the radiation effects produced by a flash fire, knowledge of the flash fire plume temperature, size and dynamics during the propagation of the flash fire plume in the vapour cloud must be known.

The detailed simulation of flash fires and its consequences is not an easy task. As a result, flash fires are often treated in a similar fashion as a burning pool fire. Studies to simulate flash fire plume dynamics has recently received increasing attention due to the growing instances of transport of large quantities of flammable fuels such as liquefied natural gas (LNG), liquefied petroleum gas (LPG), methane, propane, ethane, coal gas, etc. over land and water. Nonetheless, this assessment would simulate it together with pool fires.

4.7.3 Explosion Overpressure

Following a delayed ignition of a vapour cloud, depending on obstruction, either a flash fire or blast overpressure (explosion) would result. In open road situations, the vapour cloud is unconfined, and it is only necessary to include flash fires. In densely populated or confined areas, the occurrence of an explosion cannot totally be excluded.

In general, there are three combustion modes, namely

- Fire burning;
- Detonation; and,
- Deflagration.

These modes differ fundamentally in their propagation mechanisms and are determined by the rate at which the fuel vapour and air mix together. When the fuel vapour is not mixed with sufficient air prior to ignition, it results in diffusion fire burning. Burning of fuel in diffusion fire burning is inefficient and the flash fire plume velocity is not large enough to cause any over-pressures.

Detonation occurs in combustible mixtures of fuel vapour and air, and is accompanied by the generation of shock waves caused by the burning of the flash fire. This shock wave compresses the fuel-air mixture in the vapour cloud to beyond its autoignition temperature resulting in high over-pressures causing vapour cloud explosions. The heat released from the combustion reaction sustains the shock wave.

Deflagration results in laminar fire propagation in absence of any turbulence. The propagation of fire through this mechanism is determined largely by conduction and molecular diffusion of heat and species. Heat is produced by a reaction in the combustion zone of the fire as it propagates through the vapour cloud. Through conduction and molecular diffusion, heat is transferred ahead of the combustion zone into the preheating zone where the fuel-air mixture is heated, i.e. preconditioned for combustion resulting in laminar fire propagation. Molecular diffusion is a slow process, and thus laminar fire propagation is slow.

However, turbulent conditions may affect laminar fire propagation. The presence of low intensity turbulence in the fuel-air mixture ahead of the combustion zone may only wrinkle the fire front and enlarges its surface area, but with increasing turbulence intensity the fire front loses its smooth laminar character and breaks up into a combustion zone. In a highly turbulent mixture, combustion takes place in an extended zone in which combustion products and unreacted mixture are intensely mixed, resulting in high combustion rates, thereby causing a vapour cloud explosion. Thus deflagration, when enhanced by highly turbulent conditions, may lead to vapour cloud explosions.

As a result of ignition of the flammable vapour cloud, deflagration is the more likely mode of combustion to occur since the ignition energy required for deflagration is often less by an order than the ignition energy required for detonation.

The likelihood of explosion conditions occurring after an accidental spill would therefore need to be addressed.

4.7.4 Likelihood of Events

The event frequencies were determined using event trees

1. Release of the complete inventory ("Large Spill");
2. Release of 5 m^3 of the inventory ("Medium Spill"); and
3. Release of 0.5 m^3 of the inventory ("Small Spill").

A release of 0.5 m^3 from an atmospheric tanker would result in a small pool, and hence, especially in open road (rural) situations, this scenario may in most cases be omitted in the calculation. However, these three scenarios would be included in all subsequent calculations.

Although none of the Petromoc spillages resulted in a fire, the ignition probabilities provided in Section 4.6 were nonetheless employed, i.e.6.5% in rural areas and 20% in urban areas. The event trees constructed for condensate tanker spills, assuming UK perforation probabilities are given in Figure 4-1 and Figure 4-2, in urban and rural traffic environments respectively. The event trees using the estimated Petromoc perforation probabilities are given in Figure 4-3 and Figure 4-4, respectively.

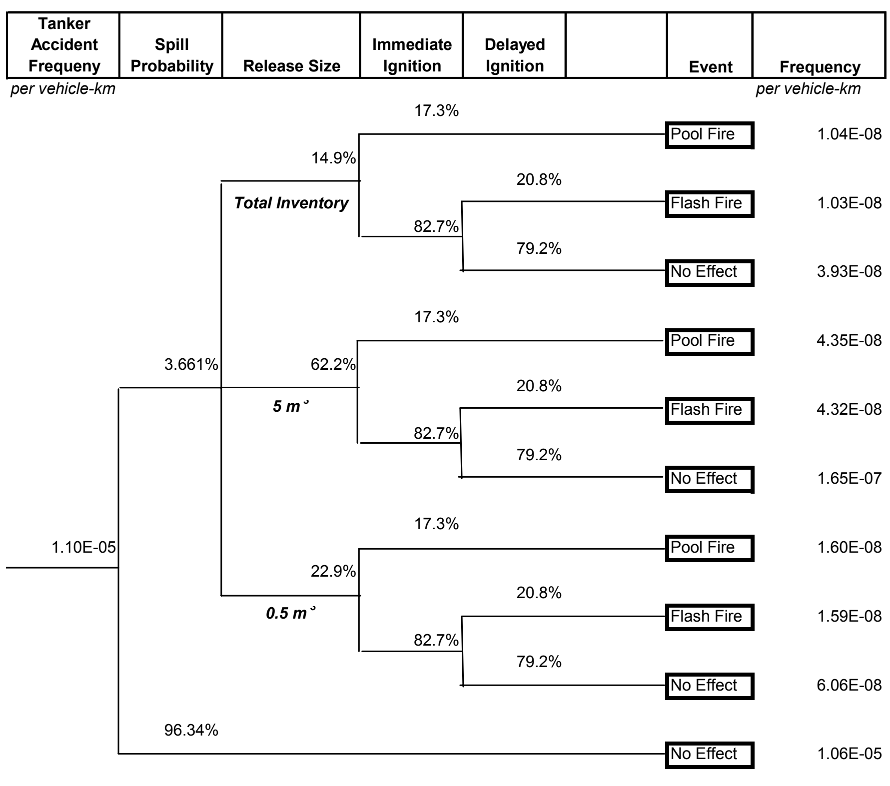


Figure 4-1: Condensate tanker spillage in urban conditions (UK tanker perforation probabilities).

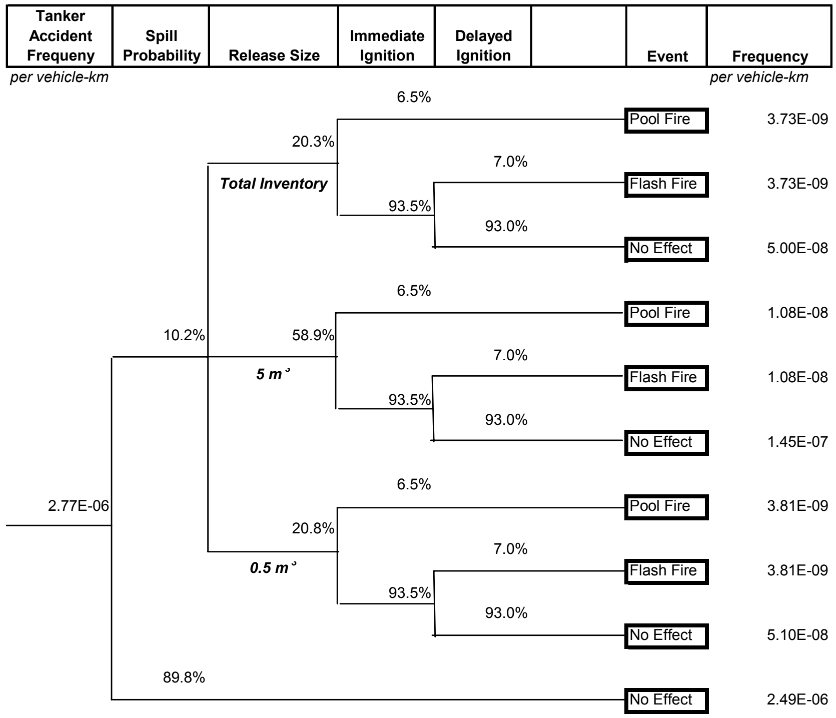


Figure 4-2: Condensate tanker spillage in rural situation (UK tanker perforation probabilities).

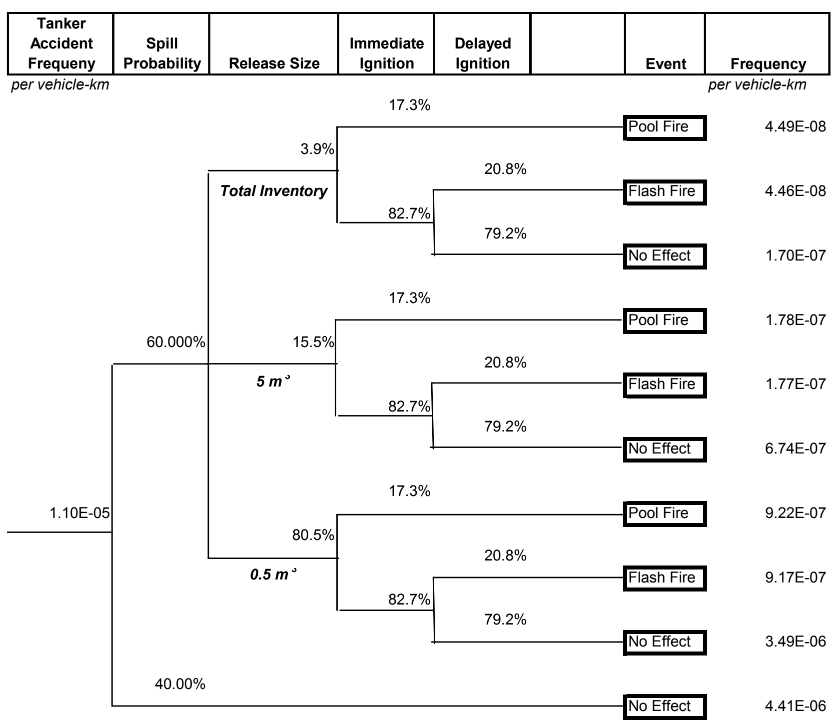


Figure 4-3: Urban condensate tanker spillage (Petromoc perforation probabilities).

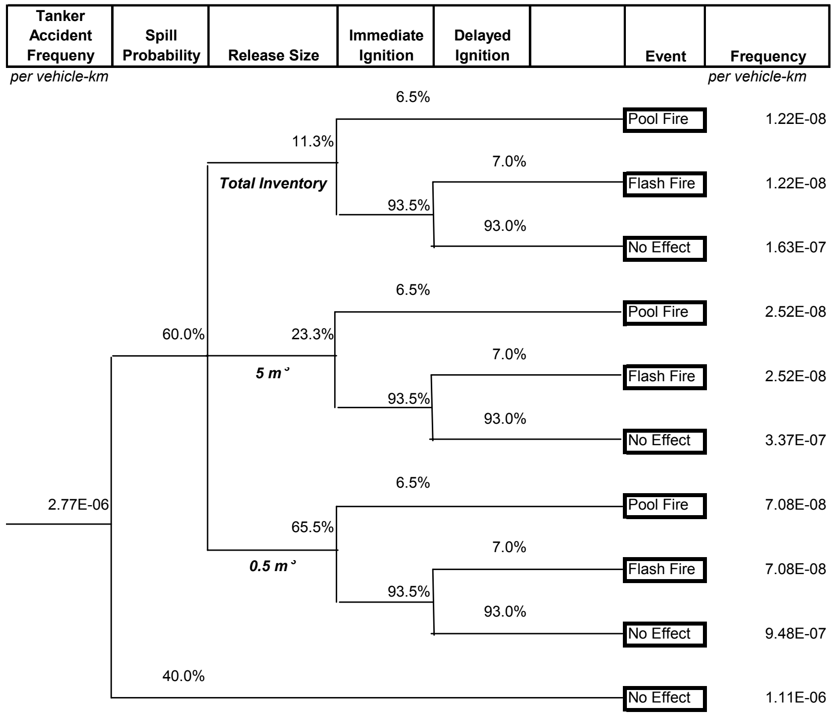


Figure 4-4: Rural condensate tanker spillage (Petromoc perforation probabilities).

The Petromoc perforation probabilities are regarded to represent the upper risk limit (most conservative). The risk assessment would use the event tree results for both cases thereby providing estimates of the lower and upper risks.

5 RISK ANALYSIS

As indicated previously in Section 3, a hazard is anything that has the potential to cause damage to life, the property, and the environment. Furthermore, it is a constant parameter (such as petrol, chlorine, ammonia, etc) that poses the same hazard wherever they are present. Risk, on the other hand, is the probability that a hazard will actually cause damage, and how severe that damage will be. Risk is therefore the probability that a hazard will manifest itself. For instance, the risk of a chemical depends upon the amount present, the process it's used in, the design and safety features of its container, the exposures, the prevailing environmental and weather conditions and so on. Risk analysis thus comprises a judgement of probability based on local atmospheric conditions and generic failure rates, and the severity of consequences based on the best available current technological information.

The calculation modes and risk methodology is described in detail in Appendix B. The following sections provide summaries of these calculations.

5.1 Incident Scenarios

A representative set of failure cases were defined in the previous section. Consideration was given to (a) thermal radiation from pool fires, (b) blast over-pressure from explosions and (c) the possible health risk as a result of a toxic gas due either to an un-ignited spillage or the combustion products from a pool fire or explosion.

5.1.1 Toxic Clouds

Due the relatively low volatility of the natural gas condensate, evaporation would be relatively slow. As shown in Table 5-1 the evaporation increases with increased ambient temperature and wind speed. However, the increasing wind speed results in increasing dilution of the vapour at a rate faster than the dilution. Therefore the highest downwind concentration occurs with lower wind speeds in spite of the higher evaporation rate. The maximum concentration was predicted for a wind speed of 1 m/s during very stable conditions ("F"). The predicted concentration near the edge of the pool is slightly above the IDLH value of 40 000 mg/m^3 for methylcyclohaxane, i.e. 45 000 mg/m^3. Although the vapour cloud would therefore not result in a very toxic hazard, prolonged exposure near the pool must be avoided.

Table 5-1: Calculated pool evaporation rate (kg/s) in the case of a total inventory spill.

Wind Speed (m/s)	Ambient Temperature (°C)				
	10	15	20	25	30
1	4.3	4.3	4.2	4.1	4.0
2	7.4	7.3	7.2	7.1	6.9
3	10.2	10.0	9.9	9.7	9.5
4	12.8	12.5	12.3	12.1	11.9
5	15.2	14.9	14.7	14.4	14.2
6	17.5	17.2	16.9	16.6	16.4
7	19.8	19.4	19.1	18.8	18.5
8	21.9	21.5	21.2	20.8	20.5
9	24.0	23.6	23.2	22.8	22.5
10	26.1	25.6	25.2	24.8	24.4

The risk through inhalation of the vapour from a condensate spillage is therefore low and does not require any further analysis.

In the case of open fires, plume rise due to the high temperature of the cloud is significant enough to result in low ground level concentrations and therefore little no lethal effects are expected from the combustion products, mainly nitrogen dioxide. In this case exposure calculations are therefore also not necessary.

5.1.2 Explosion Overpressure

Following a delayed ignition of a vapour cloud, depending on obstruction, either a flash fire or blast overpressure (explosion) would result. The distance to the lower explosion limit of the evaporated cloud resulting from a complete tanker spill and the amount of explosive material within the explosive limits are given in Table 5-2 under different atmospheric conditions.

Table 5-2: Calculated explosive amount (Mass) and distance to lower explosive limit (DLEL).

Wind Speed (m/s)	Atmospheric Stability											
	Convective		Unstable		Moderately Unstable		Neutral		Stable		Very Stable	
	Mass	*DLEL*	*Mass*	*DLEL*	*Mass*	*DLEL*	*Mass*	*DLEL*	*Mass*	*DLEL*	*Mass*	*DLEL*
1	6.1	4.0	11.8	7.7	20.3	13.6	31.3	19.4	36.6	21.7	42.7	25.4
2	5.0	3.8	9.7	7.6	17.1	12.8	25.6	18.1	29.5	20.1	34.5	23.4
3			9.1	7.2	16.0	12.6	23.8	17.7	27.3	19.5		
4					13.8	12.1	20.3	16.8				
5					12.5	11.7	18.3	16.2				
6	-				11.7	11.5	17.0	15.8				

The worst case occurs during very stable, calm wind conditions which would typically exist at night-time. Under these conditions, the mass calculated within the explosive limits is ~43 kg. In open road situations, the vapour cloud is unconfined, and this amount would rather result in a flash fire than an explosion. However, in densely populated or confined areas, the occurrence of an explosion cannot totally be excluded. Under these conditions the distances to various over-pressure values are given in Table 5-3.

Both the TNT Equivalent and the TNO Multi-Energy methods were used. A blast efficiency of 5% (low reactivity) and 15% (high reactivity) were used in the TNT Equivalent method and a Blast Class of 7 and 10 were used in the multi-energy method. Admittedly, a blast class of 7 to 10 applies to very confined spaces, which may not easily occur along the route. However, it is clear that even with ~43 kg in the explosion, significant damage could occur.

According to the TNT method for unconfined conditions, the ‘safe distance’ (i.e. 95% probability that no serious damage would occur beyond this distance) is calculated to be between 112 m and 144 m. Some damage to house ceilings and 10% window glass broken could also be broken at this distance. In confined conditions, this distance was calculated to be 320 m.

The table also includes the distance to the 50% expected lethality, i.e. an over-pressure of 145 kPa. For unconfined conditions, this distance is calculated to be between 8 and 10 m. For confined conditions, this distance could be up to 17 m. The probability of death beyond the 69 kPa is very low. The distance calculated for unconfined conditions is between 11 m and 14 m. For confined conditions, the distance is between 21 m and 23 m. Significant building damage (0.2% probability) can still occur up to 7 kPa, i.e. 50 m unconfined to 108 m confined.

The likelihood of explosion conditions occurring after an accidental spill would therefore need to be addressed. As discussed in Section 3, four features must be present in order for a vapour cloud explosion

(VCE) to occur:

1. The release must be flammable;
2. A cloud of sufficient size must form prior to ignition, with ignition delays from 1 to 5 minutes;
3. The amount of the cloud within the flammable range must typically be in the range from 1 ton to 15 ton, but could be as low as 100 kg for more reactive species such as hydrogen and acetylene;
4. Sufficient confinement or turbulent mixing of a portion of the vapour cloud must be present.

Although the resulting vapour cloud would be flammable, these arguments give the indication that an explosion would not be very likely. Furthermore, since the lethal distance to explosion overpressure is within the same order as the impact from thermal radiation (11 m to 23 m), the probability of death following a spillage would nonetheless be incorporated as part of the pool fire consequences.

Table 5-3: A summary of damage calculations from explosion of unconfined (TNT method) and confined (TNO Multi-Energy Method) vapour following large tanker spillage and delayed ignition.

Damage	Pressure (kPa)	Distance (m)			
		TNT Method		TNO Multi-Energy Method	
		5%	*15%*	*Class 7*	*Class 10*
'Safe distance' (probability 0.95 no serious damage beyond this value). Missile limit. Some damage to house ceilings; 10% window glass broken.	2.07	112	144	320	320
Limited minor structural damage.	2.76	101	122	241	241
Large and small windows usually shattered; occasional damage to window frames.	3.5	85	109	195	195
Minor damage to house structures.	4.8	67	87	148	148
Partial demolition of houses, made uninhabitable.	6.9	50	64	108	108
Corrugated asbestos shattered. Corrugated steel or aluminium panels, fastenings fail, followed by buckling. Wood panels (standard housing) fastenings fail, panels blown in.	10.0	38	48	80	80
Heavy machines (1.4 tonne) in industrial building suffered little damage. Steel frame building distorted and pulled away from foundations.	20.7	23	29	48	48
Wooden utilities poles (telegraph, etc.) snapped. Tall hydraulic press (18 tonne) in building slightly damaged.	34.5	16	21	34	34
Probable total destruction buildings. Heavy (3 tonnes) machine tools moved and badly damaged. Very heavy (12 000 lb/5443 kg) machine tools survived.	69.0	11	14	21	23
50% likelihood of death	145	8	10	<17	17

5.1.3 Thermal Radiation from Pool and Flash Fires

Thermal radiation is considered to be the main consequences following a spillage of condensate. It would therefore be required to simulate the pool burning rate and the subsequent thermal radiation levels at increasing distances from the accident.

A flash fire is a non-explosive combustion of an unconfined vapour cloud. On ignition, the fire propagates back through the vapour cloud and burns as a flash fire. The major hazard of flash fires is the heat effect from thermal radiation. This may affect objects in the nearby vicinity of the flash fire or in the path of the flash fire whether on land or water. To compute the intensity of the thermal radiation and the aerial extent of the radiation effects produced by a flash fire, knowledge of the flash fire plume temperature, size and dynamics during the propagation of the flash fire plume in the vapour cloud must be known.

The detailed simulation of flash fires and its consequences is not an easy task. As a result, flash fires are often treated in a similar fashion as a burning pool fire. Studies to simulate flash fire plume dynamics has recently received increasing attention due to the growing instances of transport of large quantities of flammable fuels such as liquefied natural gas (LNG), liquefied petroleum gas (LPG), methane, propane, ethane, coal gas, etc. over land and water. Nonetheless, this assessment would simulate it together with pool fires.

The purpose of considering worst-case scenarios is to identify areas in the community that may be affected or exposed, or individuals in the community who may be subject to injury or death from a condensate spillage from a road tanker. The calculated thermal radiation levels for the three spillage scenarios are given in Figure 5-1, Figure 5-2 and Figure 5-3 for 0.5 m^3, 5 m^3 and full contents, respectively.

It was estimated that a pool fire resulting from a small spill (0.5 m^3) would cause pain in 15 - 30 seconds and second degree burns after 30 seconds, at a distance of 15 m from the fire (4.7 kW/m^2). Similarly, there would be a 10% chance of fatality for instantaneous exposure or 30% chance of fatality for continuous exposure and a high chance of injury at a distance of 7 m (12.6 kW/m^2). There would be a 25% and 100% chance of fatality if people were exposed instantaneously at distance of 4 m (35 kW/m^2) and 3 m (60 kW/m^2), respectively.

These and the results for 5 m^3 spillage and full contents are all summarised in Table 5-4.

Table 5-4: Predicted distances to various consequences due to heat radiation.

Incident Size	**Thermal Radiation (kW/ m^2)**			
	4.7[(a)]	*12.6*[(b)]	*35*[(c)]	*60*[(d)]
0.5 m^3	15 m	7 m	4 m	3 m
5 m^3	49 m	29 m	13 m	10 m
full contents	95 m	59 m	28 m	20 m

Notes:

(a) - Cause pain in 15 - 30 seconds and second degree burns after 30 seconds

(b) - 10% chance of fatality for instantaneous exposure or 30% chance of fatality for continuous exposure and a high chance of injury

(c) - 25% chance of fatality if people were exposed instantaneously

(d) -100% chance of fatality if people were exposed instantaneously

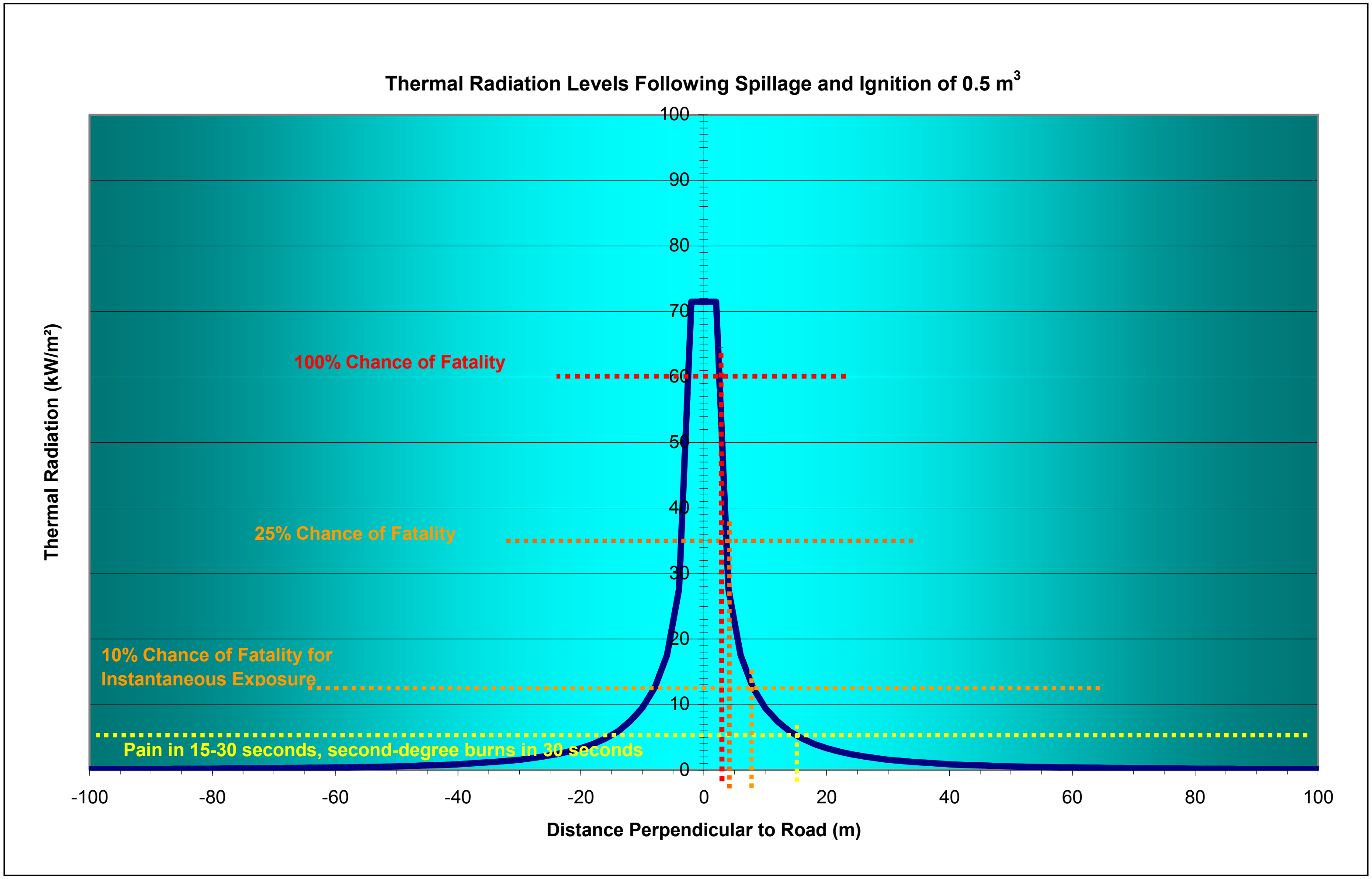


Figure 5-1: Calculated thermal radiation from spillage of 0.5 m^3 natural gas condensate on road.

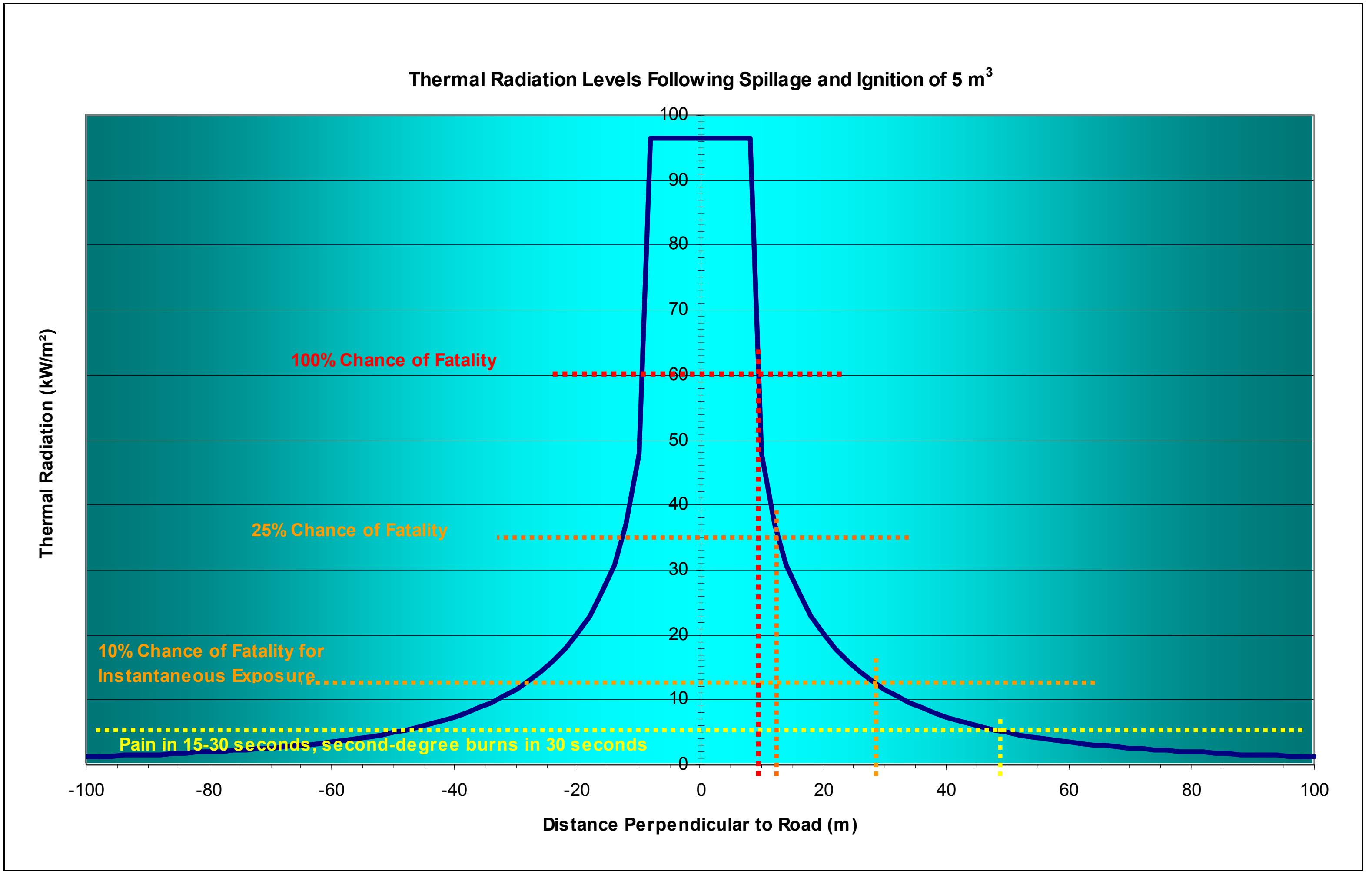


Figure 5-2: Calculated thermal radiation from spillage of 5 m^3 natural gas condensate on road.

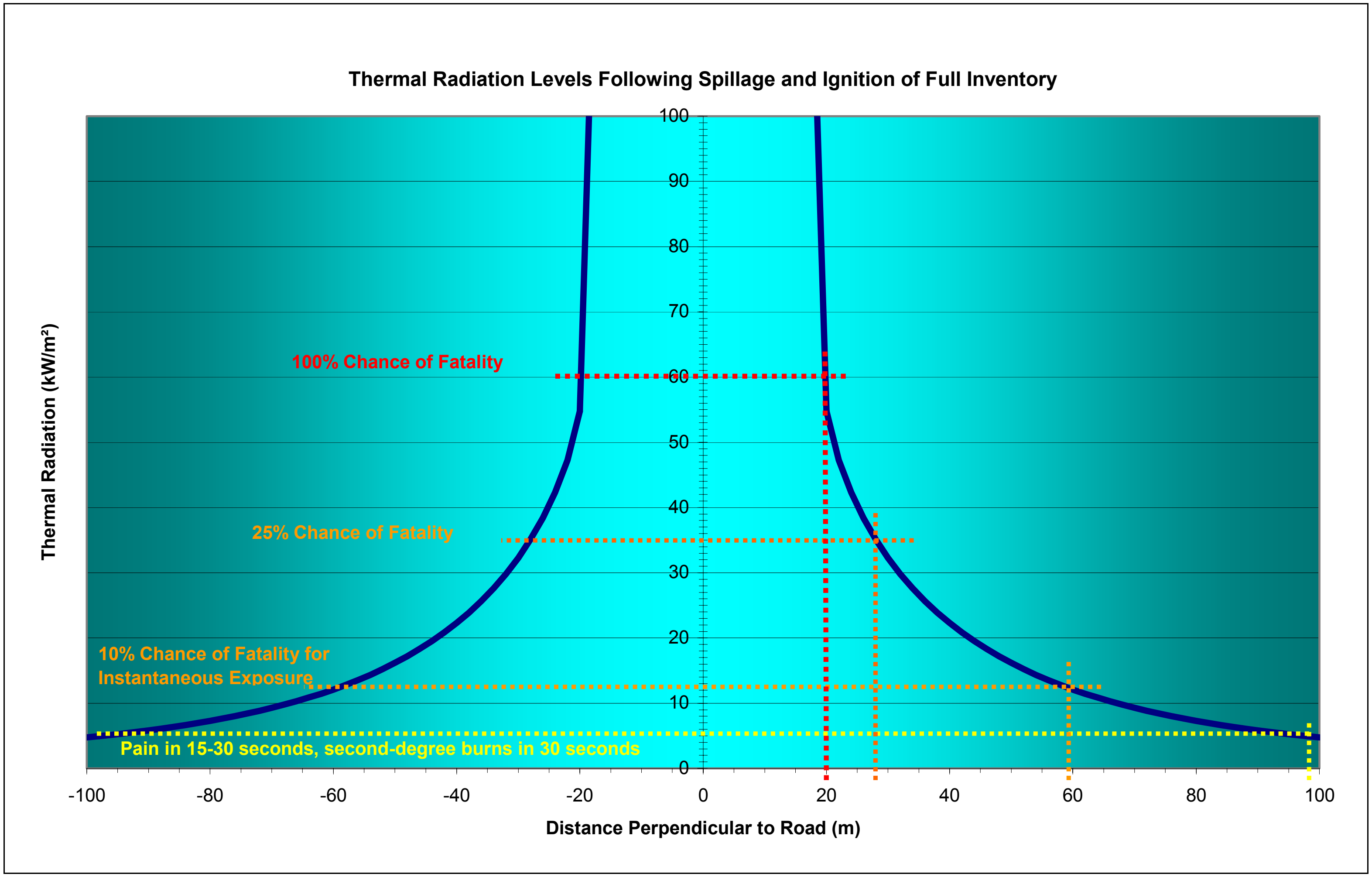


Figure 5-3: Calculated thermal radiation from spillage of entire contents of natural gas condensate tanker on road.

5.2 Risk Calculations

The previous sections dealt specifically with the predicted zone of impact without taking into account the probability of occurrence and the combined impacts. Risk, on the other hand is a product of the likelihood and the consequences. Previous considerations indicated that the likelihood of a vapour cloud explosion (delayed ignition) is considerably less than a pool fire (immediate ignition). Furthermore, the area of impact (lethal) was also shown to be less for an explosion than a jet fire. The overall risk of the road transportation is therefore essentially based on pool fire consequences.

5.2.1 Individual Risk

Possibly the most widely used risk parameter is the maximum individual risk parameter. For this parameter, the frequency of fatality is calculated for an individual who is presumed to be present at some specified location. The parameter is not dependent on the knowledge of the population at risk. The risk calculations, however, included the effect of wind speed and atmospheric turbulence. Differences between land-use, i.e. urban and rural locations, were also considered.

Among the most difficult tasks of risk characterisation is the definition of an *acceptable risk*. An attempt to account for risks in manner similar to those used in everyday life, the UK Health and Safety Exwcutive developed the "risk ALARP triangle". This involves deciding:

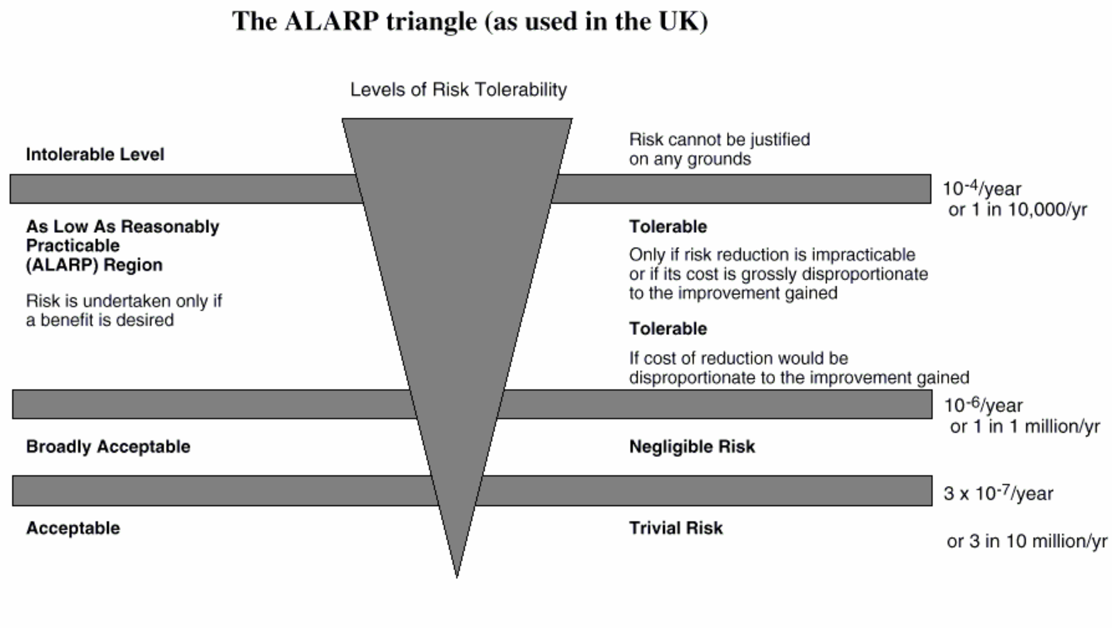
- Whether a risk is so high that something must be done about it;
- Whether the risk is, or has been made, so small that no further precautions are necessary; or
- If a risk falls between these two states that it has been reduced to levels as low as reasonably practicable (ALARP).

This is illustrated graphically, shown in Figure 5-4, below. ALARP stands for "As Low As Reasonably Practicable". As used in the UK, it is the region between that which is intolerable, at $1x10^{-4}$ per year, and broadly acceptable level of $1x10^{-6}$ per year, with a further lower level of risk of $3x10^{-7}$ per year being applied to either vulnerable or very large populations for land use planning (HSE 1989).

Table 5-5: Comparison of risk results for different locations along the transportation route.

Location	Distance To		`Maximum Risk (per year)
	$1X10^{-6}$ Risk Isoline (m)	$3X10^{-7}$ Risk Isoline (m)	
Urban			
Lower Estimate	18	30	$3.0x10^{-6}$
Upper Estimate	24	36	$4.9x10^{-5}$
Rural			
Lower Estimate	Not reached	17	$9.0x10^{-7}$
Upper Estimate	22	36	$5.0x10^{-6}$

Due to the limited historical data available for spillage of the condensate, a lower and upper risk was calculated. This range is primarily due to the considerably higher probability of perforation actually witnessed when compared to international norms. Table 5-5 summarises the calculated maximum distances to the broadly acceptable risk and risk level for vulnerable societies. The calculated maximum risk is $4.9x10^{-5}$ per year in urban conditions.



TYPICALLY ACCEPTABLE LAND-USE CATEGORIES

Category B (10^{-3}/year)

Some workplaces (e.g. parking areas, etc.) incorporating developments where the occupants would tend to be fit and healthy, and could be organised easily for emergency action - less than 100 occupants.

Category A (10^{-5}/year)

Housing, hotel and holiday accommodation. These are developments in use for 24 hours a day with an average mix of healthy, unhealthy, young and old. The building provides some protection against hazards. Greater than 25 but less than 75 people [Category A(a)]

Category C (10^{-6}/year)

Category A, but with more than 75 people [Category A(b)]. Retail, community and leisure. This includes small shops and community facilities where members of the public are present, but not resident - less than10 units. They may be in or out of doors, possibly in large numbers. Emergency action would be difficult to co-ordinate.

Category D ($3x10^{-7}$/year)

Highly vulnerable or very large facilities. Vulnerable facilities include hospitals, homes for the elderly, schools etc. Very large facilities are typically retail parks or shopping centres - more than 1000 people outdoors.

Figure 5-4: Decision making framework. The UK HSE land-use categories A to D are also included for illustration.

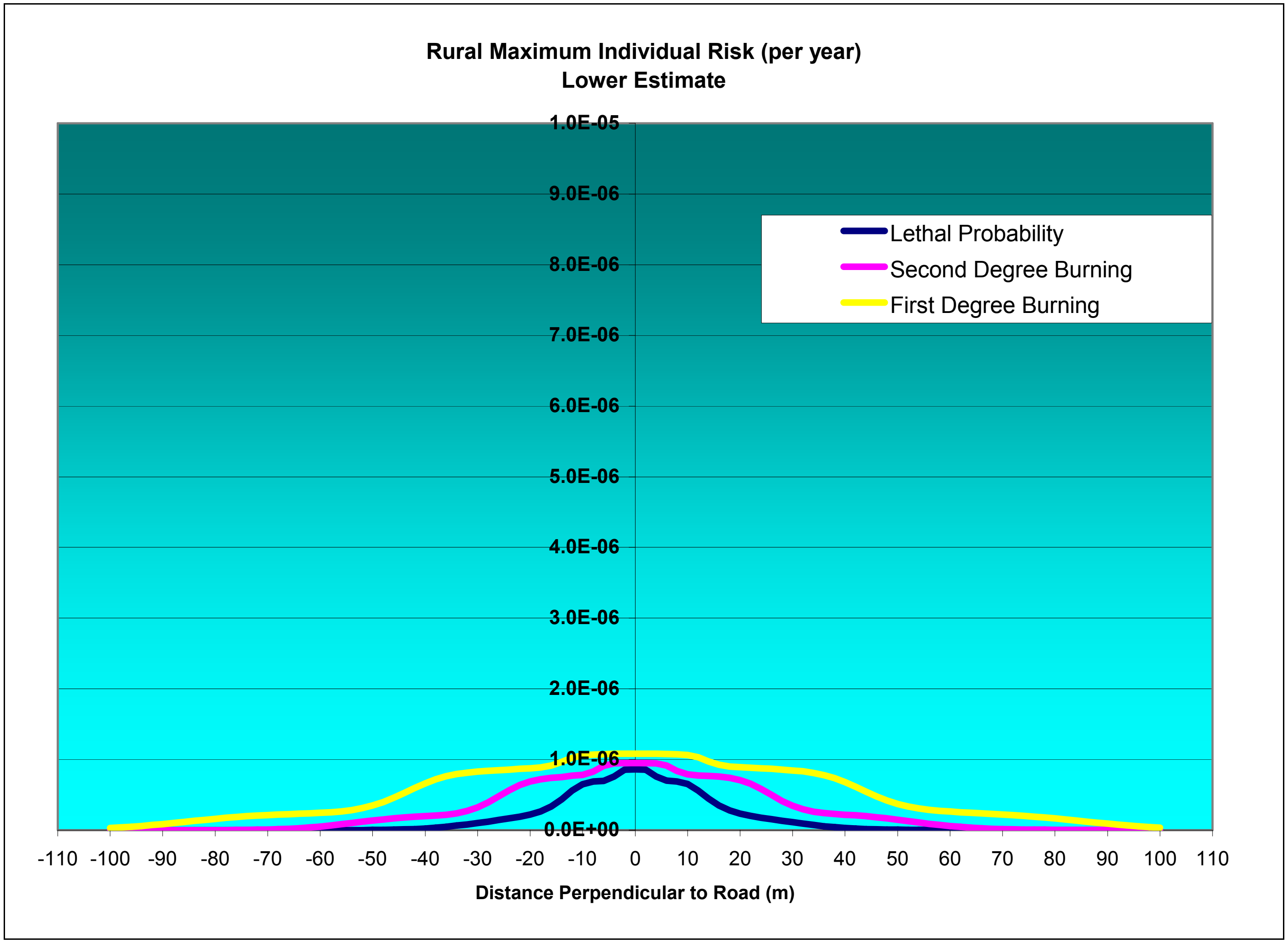


Figure 5-5: Risk transects for rural conditions – lower estimate.

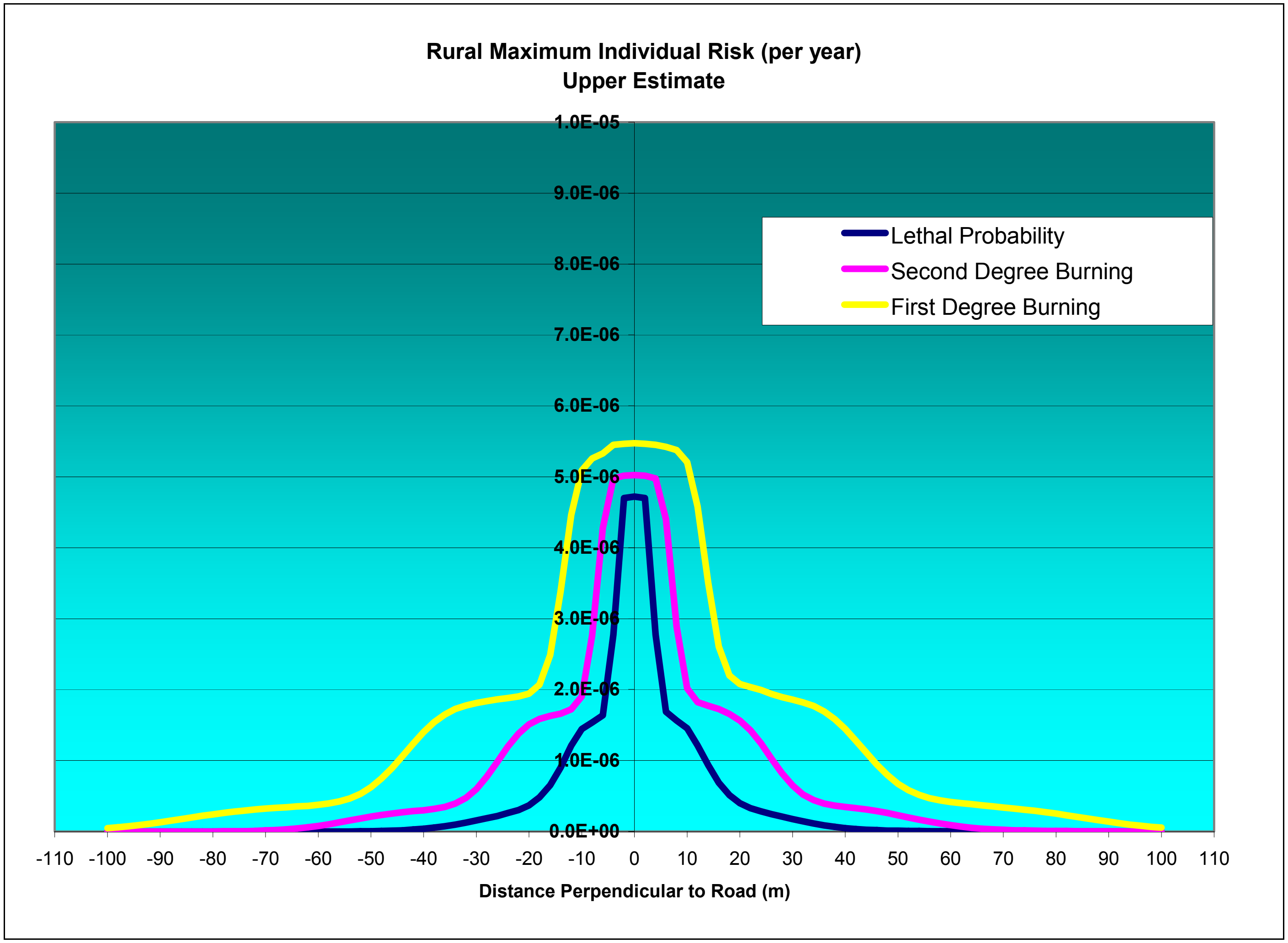


Figure 5-6: Risk transects for rural conditions – upper estimate.

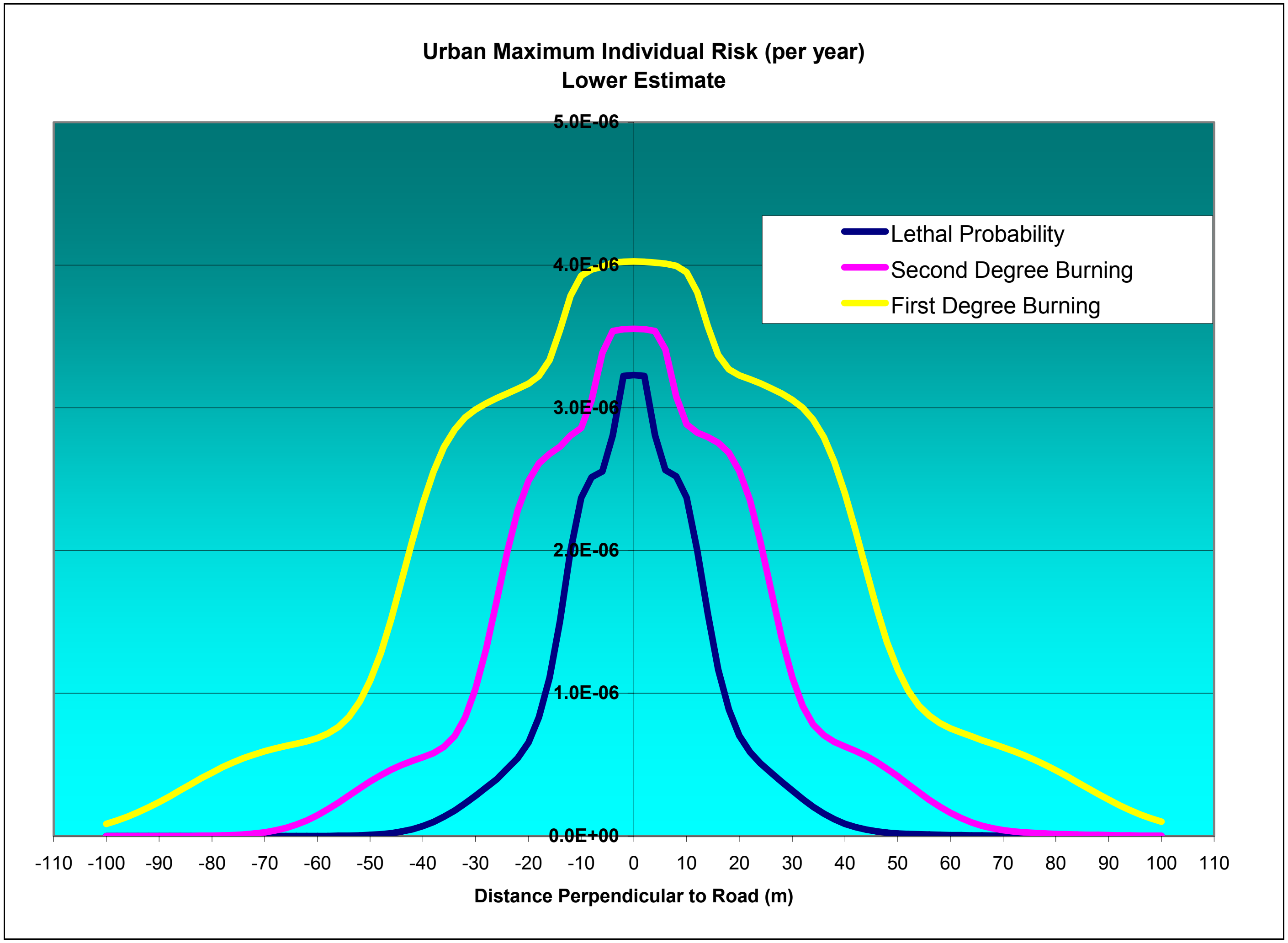


Figure 5-7: Risk transects for urban conditions – lower estimate.

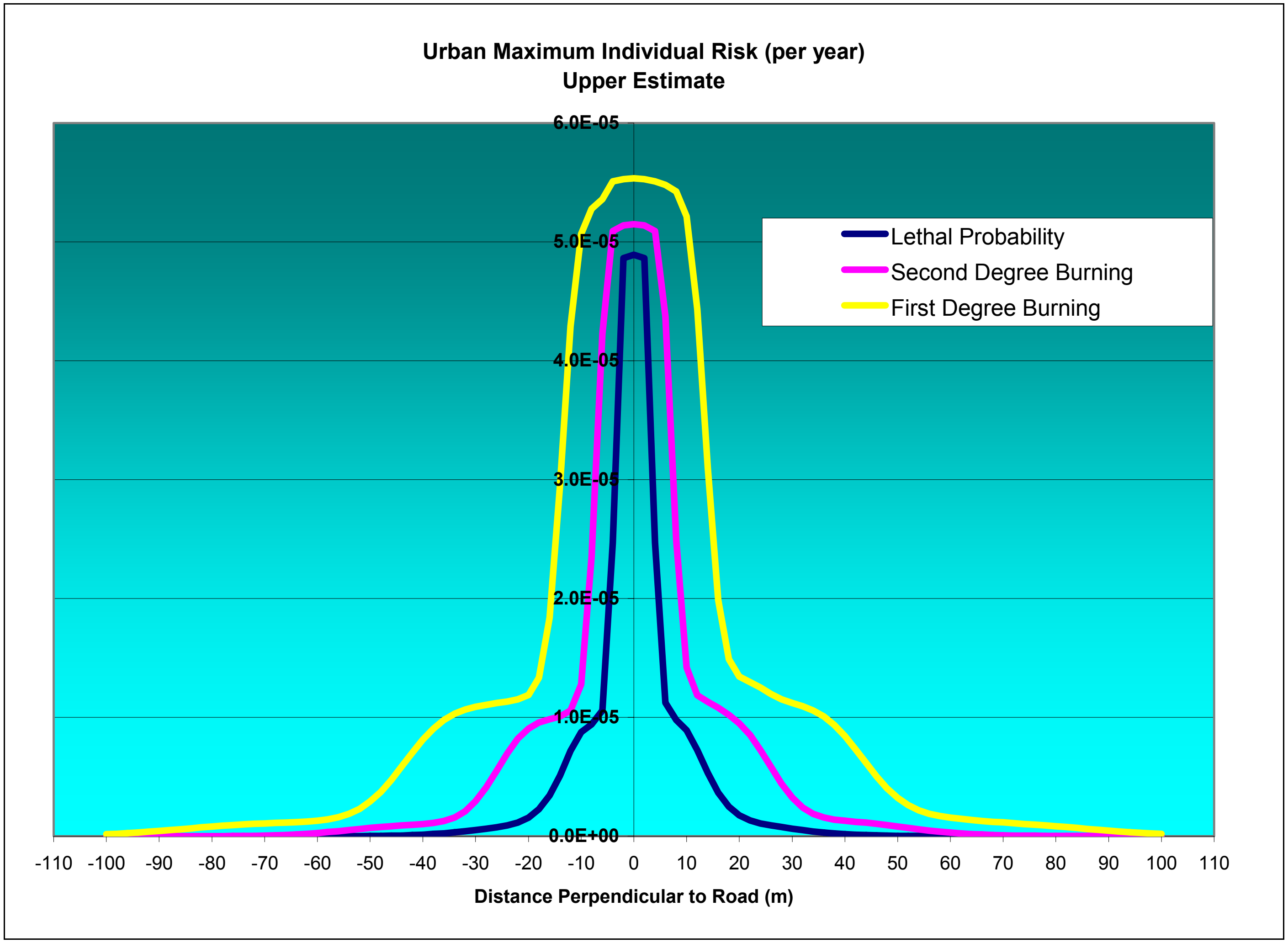


Figure 5-8: Risk transects for urban conditions – upper estimate.

These risk transects are also shown for rural conditions in Figure 5-5 (lower estimate) and Figure 5-6 (upper estimate), and urban conditions in Figure 5-7 (lower estimate) and Figure 5-8 (upper estimate), respectively.

Base on the UK HSE's ALARP triangle, the risk of transportation of condensate falls within the ALARP region. The calculated maximum risks, including the lower estimates, do not exceed the upper level for ALARP (i.e. $1x10^{-4}$ per year), however, the upper estimate in urban conditions closely approach this limit. It is therefore strongly recommended that additional mitigation measures be applied to reduce the maximum risk and hence the distance to the two risk criteria of $1.0x10^{-6}$ and $3.0x10^{-7}$ per person per year, respectively.

5.2.2 Societal Risk

Societal risk considers the risk of death from an activity to society as a whole and includes a measure of incident size. The societal risk criteria adopted in this investigation is that recommended in the Netherlands for dangerous goods transport (i.e. road, rail and pipelines) (MHPE, 1996), i.e. a risk of 10^{-4} per year per km for ten fatalities, a risk of 10^{-6} per year per km for 100 fatalities, and so on. If the societal risk crosses the recommended risk criterion line, the risk has to be reduced before the process should continue, and below the line, the risk needs to be reduced to "As Low As Reasonably Achievable", i.e. ALARA.

The population densities used in the calculations are given in Table 5-6. These are based on values typically encountered in similar zones of development in South Africa. Base on the inspection of the route, an estimate was made of the number of people on and near the road. These are observations are summarised in Figure 5-10.

Table 5-6: Population densities used in the calculation of societal risks (per m^2).

Location	Daytime	Night-time
Urban	0.018	0.0018
Suburban	0.004	0.0018
Rural	0.0004	0.00018

The results from the societal risk calculations for the upper and lower estimates (based on spillage assumptions) are illustrated in Figure 5-9. The societal risk acceptance for the transportation of dangerous goods is also drawn. **Both spillage assumptions (lower & upper estimates) result in a risk which is above the ALARA criterion and into the zone requiring risk reduction. It is therefore recommended to introduce risk reduction measures before transportation continues. It is appreciated that the onus rests with the operator to reduce the risk whilst a large part of the risk is due to external, uncontrollable hazardous sources. However, Petromoc has to immediately address all those aspects under their control which would reduce the risk. Therefore, the primary focus of risk reduction must initially be on improving driver alertness, behaviour and habits (see Section 6.2).**

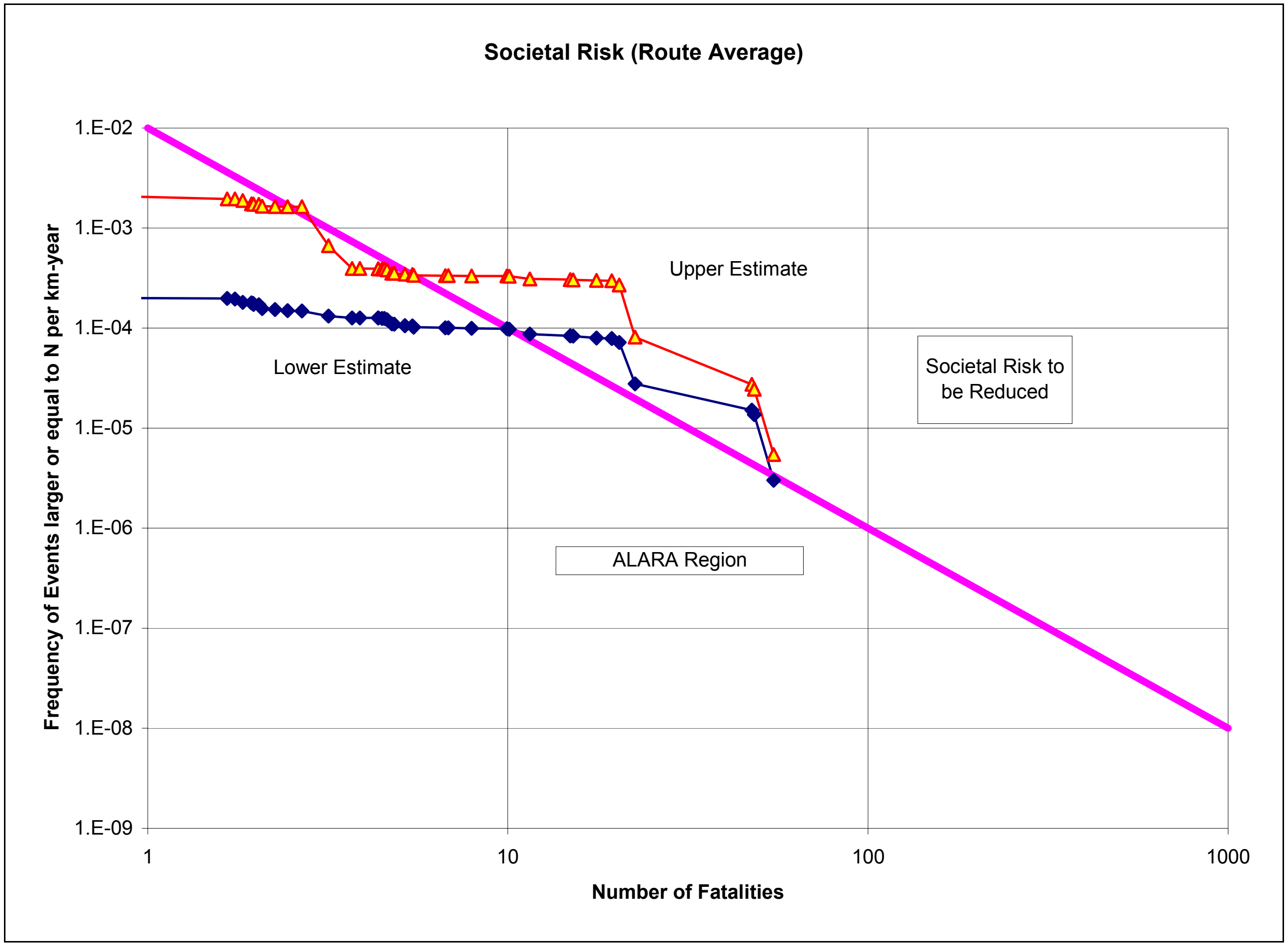


Figure 5-9: Societal risk curves for the transportation of condensate from Temane to Maputo using two spillage frequencies.

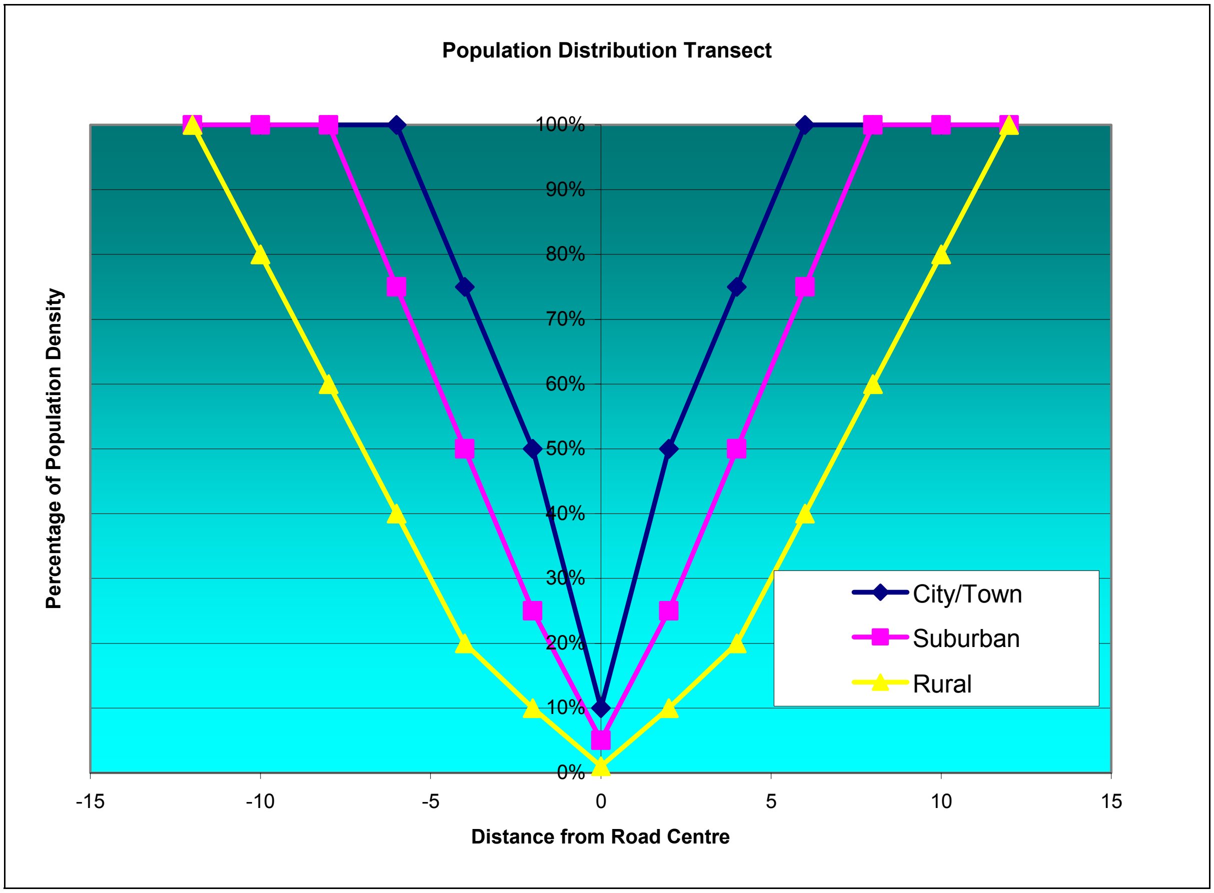


Figure 5-10: Assumed population fraction of population density from road centre.

6 TRANSPORT SAFETY CONSIDERATIONS

During the one year period 2004/2003, 12 incidents were reported by the transportation subcontractors. Of these, 67% involved vehicle collisions and the balance equipment failures (e.g. faulty valves and connectors). Two accidents resulted in loss in human lives. These occurred at 3 de Fevereiro and between Hunguane and Massinga, respectively. The latter accident also resulted in a large spillage of 16 000 litres. The cause of the first accident was driver fatigue, whilst the latter was due to an attempt to avoid a collision with other vehicles. In another accident at Bobole (Marracuene) a spill of 2 300 litres resulted after a front wheel tyre burst. Although the tanker rolled over, there were no human losses. Other, less severe accidents also occurred. Only one of these was due to a mechanical failure – a break defect. The other three were driver or third party errors. This record represents a serious message to improve the transportation operation to attain safety objectives set by Petromoc, and underlines the need for positive action by management to bring about the required improvement.

Driving is a demanding task which differs from most other industrial activities in the degree to which safety is dependent on the attitude, vigilance and driver skills. Moreover, the activity takes place in a predominantly third party environment, dominated by the actions of others, and away from the normal influence of supervisors and peers. It is not surprising therefore that 'driver error', in its broader sense, is a significant causal factor of the recorded road accidents.

The particular attitudes and skills required for constant safe driving must therefore be developed, if a programme does not already exist, and sustained by management strategies and intervention. So, while addressing all elements of road safety, particular emphasis should also be placed on management's role in influencing driver performance.

6.1 Vehicle Aspects

6.1.1 Classification of Vehicles

Employing the right vehicle for the job is an important aspect in any transportation operation. Vehicles may be classified according to whether they are rigid, articulated consisting of tractor and semi-trailer, or rigid chassis with full trailer. Each of these types may be further classified according to the number and arrangement of the axles. The number of axles required depends mainly upon the gross vehicle weight and upon any limitations on axle loadings imposed by official regulations.

The advantages of each of the three classes are summarised in Table 6-1. Two, three or four axles are sufficient for smaller payload requirement (up to about 20 tonnes) for the gross vehicles weights and axle load constraints imposed by authorities. Consequently rigid vehicles are used almost universally for this range of payloads; even the largest 4-axled rigid vehicles are preferred because of the advantages listed in Table 6-1. However, since the average condensate tanker load (Table 2-1) is 35 000 litres or about 25 ton, articulated vehicles are the next choice, unless the payloads are reduced.

For the payloads of up to about 40 tonnes, or where accessibility difficulties prevent the use of rigid vehicles, the articulated (tractor) semi-trailer type vehicle can be used. Alternatively, full-trailer vehicles could be considered. The disadvantage of a full-trailer vehicle lies in its poorer manoeuvrability particularly when reversing.

Table 6-1: Advantages of using different vehicle types.

Rigid Vehicles	Articulated Vehicles (Tractor/Semi-Trailer)	Rigid Vehicles with Full-Trailers
1. Rigid vehicles are inherently more stable than articulated vehicles and are therefore better suited for use in very hilly country. This is because articulated vehicles (tractor semi-trailer) are prone to 'jack-knife' in steep or slippery conditions, especially when severely braked. The increasing use of anti-skid brake systems on never models is however, reducing the problem. 2. Rigid vehicles are better suited for use on poor roads than articulated lorries. 3. On rigid vehicles it is simpler to install power-operated auxiliaries such as large discharge pumps	1. It is often possible to carry a greater payload for a given gross combination weight on an articulated chassis than on a comparable rigid chassis, mainly because it is easier to distribute the load in such a way as to take fullest advantage of the regulations governing axle loadings. 2. An articulated vehicle, by reason of the short wheelbase of the tractor, is more manoeuvrable than a comparable rigid lorry; however the tendency for the axle of the semi-trailer to cut-in when cornering needs consideration 3. The advantage gained by the ability of any tractor to be connected to any semi trailer enables the maximum flexibility of operation to be maintained. It is not necessary to take a semi-trailer out of service because its tractor requires maintenance; it may equally well be towed by another tractor of a similar type and coupling layout. 4. Semi-trailers require less maintenance than tractors. In view of this a large fleet requires fewer semi-trailers than tractors to take care of out-of-service time for maintenance. Alternatively where a short distance shuttle service is involved it is sometimes possible to handle three semi-trailers with one tractor, thus reducing the idle time of the tractor and its driver to a minimum. 5. Rigid vehicles and the tractors of articulated vehicles have approximately the same length of life, but the life of semi-trailers is generally longer. Consequently a fleet of articulated vehicles tends to have lower average replacement costs than a comparable fleet of rigid vehicles. However this applies only if the payload capacity of the semi-trailers remains adequate throughout their life and obsolescence for other reasons is not a factor.	1. Legislation may be such that greater loads may be carried on full trailer vehicles than on semi-trailers. 2. Under arduous road conditions full-trailer vehicles may be more suitable than semi-trailers. 3. For part of certain services the rigid vehicle alone may be used, for example in the delivery area at the end of a long distance journey after the trailer has been discharged, thereby providing flexibility of operation.

6.1.2 Vehicle Stability

Irrespective of the type of vehicle and axle configuration that are chosen it is essential to ensure that it is a stable unit. Vehicle stability depends upon the effects of the centre of gravity of the payload/tank (or body), its height and position relative to the axles and the stiffness or deflection of the suspension. To achieve a stable vehicle, arrangements must be made:

- To keep the centre of gravity of payload/tank/body as low as possible.
- For lateral stability the effective load should be distributed as evenly as possible on all axles.
- Suspensions - particularly parabolic leaf spring type and air systems - should be adequately supplemented by anti-roll bars, or secondary helper springs.

6.1.3 Ergonomics of the Drivers' Cabin

The cab is the workplace of the driver and hence its design and layout must be aimed at making him comfortable and facilitating control, thereby reducing fatigue. The main ergonomic features are summarised below and are offered as a check list:

- The vision from the driving position should be unobstructed over as wide a range as possible. (Windscreen pillars should be of minimum safe thickness to avoid blind spots, and windows should be provided in the rear corner panels particularly in the case of articulated vehicles, to provide better vision whilst reversing.)
- The windscreen and windows should be glazed with the best quality safety/laminated glass.
- The driver's seat should be comfortable and adjustable, both vertically and horizontally.
- The cab should be either adequately heated or ventilated, as governed by the particular climatic conditions. Due to the hot climatic conditions, cab roof and rear panel should be insulated.
- Similarly, the engine cowling and scuttle panels of vehicles with forward or semiforward control should be insulated in order to reduce heat transference from the engine. Similar insulation together with an anti-drumming compound should also be applied to the cab panels so as to reduce noise.
- Effective sealing should be incorporated to eliminate draughts and the ingress of fumes where controls project through floorboards and front panels.
- Provision should be made for carrying tools, drivers' papers, maps, and first aid kit.

6.1.4 Vehicle Performance

The performance of a vehicle, that is the load it may carry at a given speed for a given expenditure of power, depends upon the gross vehicle weight (GVW), road conditions (rolling resistances) and the net force available for propulsion, or net tractive effort (TE). Each of these factors requires consideration when a vehicle is selected, otherwise the performance could be unsatisfactory and the consequences will be inefficient and uneconomical operation. Underperformance may also hamper safe manoeuvrability of the vehicle.

Of these three factors affecting performance, road conditions (rolling resistances) are beyond the control of the fleet operator, whereas the gross vehicle weight and tractive effort, which depend both upon each other and on the road conditions, may be controlled. In view of this any logical system for the selection and application of chassis largely depends on road conditions.

The gross weight which a vehicle may haul at a given speed for a given expenditure of power in normal top gear, that is its performance in terms of gross vehicle weight ability, varies widely according to the nature of the road surfaces and the gradients to be climbed. Although the specific performance may differ between different manufacturers, an example of the extent of this variation is shown in Table 6-2 for a vehicle having a tractive effort of 8830N (900 kg).

Table 6-2: Example of recommended gross vehicle weight for different road surfaces and gradients.

Gradient	Road Surface		
	Good	Average	Poor
	Gross Vehicle Weight (GVW) in kg		
1% (1 in 100)	40 900	28 100	21 400
2% (1 in 50)	28 100	21 400	17 300
3% (1 in 33)	21 400	17 300	14 500

It is obviously quite possible that the current vehicles are appropriate, but it is recommended that the most appropriate vehicle and load be chosen for the current road conditions.

6.2 Accident Prevention

The current accident record of the vehicles transporting condensate from Temane is considerably higher than the statistics in South Africa and generally found internationally. Accident prevention should therefore receive considerable attention. Since the circumstances surrounding accidents vary widely, only general recommendations can be provided.

6.2.1 Vehicle Maintenance Programme

A badly maintained vehicle can be both dangerous and illegal. Management should therefore ensure roadworthiness of all vehicles by implementation of an effective maintenance programme which should include:

- Setting of appropriate maintenance standards.
- Establishment of schedules for inspection and testing.
- Ensuring check-lists cover all safety related items.
- Availability of appropriately qualified and equipped staff with efficient working facilities to inspect and maintain vehicles.
- An adequate supply of spare parts.
- An effective system for drivers to report defects which have an adverse effect on safety.
- A means of prompt and competent evaluation of reports with feedback to the driver on action taken or planned.
- A procedure for vehicles to be taken out of service until critical defects are rectified.
- Ready access for drivers to maintenance, inspection and current defect reports

6.2.2 Management and Supervision

Since human behaviour is the dominant element in road safety, influencing driver attitudes and performance must be a prime objective of managers and supervisors. They are best placed to develop each driver's skill and stimulate the required desire to achieve outstanding personal performance. If left on their own, a driver's approach to his job would normally be preconditioned by a variety of personal and environmental factors including local standards and attitudes to driving. However, with enforcement of Petromoc company standards, local norms could transcend to produce improved safety performance.

Managers and supervisors must have appropriate experience, and thorough initial training, motivation, regular assessment and retraining advocate careful driver selection as the means of achieving safe driving. To effectively implement these measures they must:

- Establish performance standards and objectives.
- Institute policy and procedures relating to:
  - driver selection, testing and training
  - communication and motivation
  - driver performance assessments
  - accident reporting, investigation, analysis and feedback
  - monitoring and control of driving activities
  - corrective strategies.
- Establish an action plan for implementing the above policies and objectives.
- Define safety requirements where statutes are considered inadequate.
- Clearly define accountability for safe driving performance.
- Demonstrate commitment by being personally involved in:
  - safety inspections and audits
  - safety meetings
  - investigation of accidents
  - recognition of individual and group achievement and by setting a good example.
- Monitor progress and performance.
- Liaise with other companies and regulatory bodies on industry standards.

First line supervisors are the vital link between management and driver and their role is crucial to road safety programmes. They are responsible for turning the objectives and policies of management into action and results. To be effective they must not only have a strong commitment to safety but must be familiar with all aspects of road safety and have sound supervisory and motivational skills.

To influence driver performance supervisors should:

- Set a good example.
- Ensure that safety is regularly seen as a prime objective
- Ensure that drivers are adequately trained and have a thorough understanding of the personal and environmental factors affecting driving performance.
- Include safety considerations in task briefings and informal discussions
- Encourage frank and effective communication on safety related matters.
- Organise general and specific safety promotions.
- Devise and take part in regular safety meetings.

- Encourage drivers to play an active role in reporting environmental factor changes, e.g. road conditions, traffic flow and vehicle performance.
- Participate in accident investigations.
- Carry out vehicle safety inspections on a regular basis.
- Carry out on-the-road driving performance checks on a regular basis.
- Record and review performance.
- Maintain visible supervision and day-to-day controls.
- Acknowledge good performance and safety related achievements
- Take corrective action where appropriate.

Although drivers must be encouraged to take personal responsibility for their own performance, supervisors still need to know and understand each driver and be sensitive to change of circumstances or personal behaviour which may indicate potential adverse influences on safety performance.

6.2.3 Driver Selection

Causes of accidents are usually attributable to one or more of the following factors:

- Ignorance of traffic regulations or approved practice. Excessive speed for the prevailing road and traffic conditions is responsible for the majority of highway accidents.
- A poor attitude by the driver towards other road users.
- Lack of driving skill.
- Other parties, including vehicles, other forms of transport (e.g. bicycles) and pedestrians.

The following qualities should be sought when appointing a driver:

- A proven safe driving record of heavy duty vehicle driving.
- A positive attitude to road safety.
- Physical fitness for the task.
- Integrity.

Before appointment candidates should have passed a health assessment to evaluate their suitability for the job. Maturity and experience are two additional aspects to be considered when appointing professional drivers - a minimum of 23 to 25 years is often found to be appropriate.

It may be a recommendation for Petromoc to conduct its own driving tests. Drivers should also be qualified in accordance with legal requirements and undertake the following tests with a qualified supervisor:

- Oral tests to assess knowledge of relevant legislation and general attitude to driving.
- Practical road test to assess driving skills, including vehicle handling, and general road behaviour including awareness of and attitude to hazards and other road users.
- A written test assessing ability to understand and cope with relevant documentation.
- A system of company driving permits for company and/or contractor personnel may, in certain circumstances, be an effective way of controlling these arrangements.

6.2.4 Driver Training

Training is a continuous process comprised of three elements:

- Induction Training:
  A properly organised and conducted induction programme will not only ease employees into new positions, but will also establish a concept of standards and priorities which to some extent will shape subsequent development.
- Job Training - the following topics should be included in job training programmes:
  - Statutory requirements and codes of practice.
  - Vehicle features, performance capabilities and method of operation.
  - Range of operating conditions.
  - Vehicle stability under varied conditions of load distribution and road conditions.
  - Driving techniques for respective vehicle types under various circumstances.
  - Accident prevention measures.
  - Responsibility for care, inspection and maintenance of vehicles and associated equipment.
  - Product knowledge.
  - Use and care of safety equipment, e.g. warning devices, protective clothing, fire extinguishers.
  - Action in case of breakdown.
  - Action in case of traffic accident.
  - Product related emergency procedures.
  - Life-saving first-aid techniques
  - Accident reporting
  - Factors affecting driver performance, e.g. attitude, health, fatigue, medicines, alcohol and drugs.
- Defensive Driver Training
  The features which distinguish safe drivers from others are the ability to maintain required levels of concentration, and to anticipate, assess and respond appropriately to potential hazards continuously over long periods. By exercising these skills Defensive Drivers maintain a space and time zone around the vehicle thus preventing the development of dangerous situations. Use of these techniques has been shown to reduce accident rates substantially. The Defensive Driver continually makes allowances for:
  - A lack of skill and knowledge or unpredictable actions on the part of other drivers.
  - Vulnerability and unpredictable behaviour of pedestrians and cyclists.
  - Unpredictable behaviour of animals.
  - Hazardous climatic conditions.
  - Hazardous road features, e.g. curves, hills, narrow roads, bridges, absence of signs or signals and obstructions.
  - Defensive Driver training raises the level of a driver's overall effectiveness by increasing awareness, placing more knowledge at a driver's disposal and sharpening skills of observation, perception, anticipation and planning.

Detailed inspection of motor vehicles at regular intervals generally results in a reduction of accidents due to defective equipment. Furthermore, a system implementing the following recommendations minimises the possibility of accidents:

- When engaging drivers, ensure that they are mentally and physically fit, sufficiently intelligent, and temperamentally suitable.
- Test the driving ability of every driver on engagement and give further training if necessary.
- Ensure that drivers conform to official traffic regulations. Set standards where official speed limits do not exist or are insufficient, and take immediate corrective action when drivers begin to develop bad driving habits.
- Although alcohol intake would not be allowed, since drivers are outside normal supervision, this cannot be ruled out. Measures must be put in place to test each driver before and whilst on route. If the driver is found to have broken this rule, immediate dismissal should follow.
- Keep all vehicles in safe mechanical condition by planned inspections and maintenance.
- Check tyres regularly to ensure that they are safe.
- Set up a suitable panel to examine accident reports in order to locate the hazards, determine the causes and contributing conditions, establish methods of accident prevention, and follow-up performance.
- Give refresher training courses.

A road safety programme must be based on known facts about the causes of accidents so that the best means of preventing them can be developed. This information can be obtained only by an adequate and accurate system of reports and records. Accidents should therefore be reported in writing on a special report form as soon as possible after they occur. Even the most minor accident should be reported, particularly where another vehicle or third party property may have suffered damage. The report should include all relevant information about

- weather and road conditions;
- speed;
- action taken; and
- a sketch showing the relative position of the vehicle involved.

A copy of the report and assessment of each accident should be filed on the driver's personal file or record. The advantages of this procedure are as follows:

- Remedial or disciplinary action can be taken if a driver's record shows a tendency to be careless or foolhardy. However, each accident should be considered very carefully before ascribing the blame.
- If an experienced and reliable driver is involved in an accident caused by the carelessness of others, records exonerating him from blame are to the driver’s and to the company's advantage.
- If legal action is taken against the company or the driver, or if a union raises complaint on behalf of a driver, full and accurate information on the case (also on previous cases involving the same driver) is readily available.

Incentive schemes for paying monetary awards to drivers for safe driving are not always effective in reducing accidents.

6.3 Emergency Procedures

Consequences of road accidents can often be minimised by effective emergency action at the scene. Action may be required to:

- Prevent any worsening of the situation created by the original accident, e.g. by deployment of warning devices or control of hazardous areas.
- Apply life saving first aid to injured persons.
- Contact the emergency services, i.e. ambulance, fire brigade or police.

7 CONCLUSIONS AND RECOMMENDATIONS

Injuries to drivers and third parties, damage to property, air and water pollution, hazards to public safety, and unfavourable publicity arising from these items, are some of the undesirable factors resulting from road accidents. In addition, financial loss results from the cost of repairing damaged vehicles, from providing alternative transport during the time vehicles are out-of-service, and from meeting third-party claims. Quantitative risk assessment has gained wide acceptance as a powerful tool to identify and assess the significant sources of risk associated with an industrial activity, including transportation of hazardous goods, such as condensate. A risk assessment may also serve to establish whether a process could continue to operate without any modifications or whether, through risk ranking, alternative risk control measures need to be introduced to reduce the likelihood of negative impact on the surrounding environment.

Risks form an inherent part of modern life. Some risks are readily accepted on a day-to-day basis, while others attract headlines even when the risk is much smaller, particularly in the field of environmental protection and health. For instance, the risk associated with driving a car of *one in ten thousand chance of death per year* ($1x10^{-4}$ per year) is acceptable to most people, whereas the risks associated with nuclear facilities (*one in ten million chance of death per year,* or $1x10^{-7}$ per year) are usually deemed unacceptable. The definition of levels of acceptable risks with regard to different situations came about as a result of the need of people to feel safe in their day-to-day activities, and to be protected from risks ranging from unsafe food to radioactivity.

A report by the British Parliamentary Office of Science and Technology (POST), "*Safety in Numbers? - Risk Assessment and Environmental Protection*", explains how public perception of risk is influenced by a number of factors in addition to the actual size of the risk. These factors were summarised as follows:

Control	*People are more willing to accept risks they impose upon themselves, or they consider to be "natural", than to have risks imposed upon them*
Dread and Scale of Impact	*Fear is greatest where the consequences of a risk are likely to be catastrophic rather than spread over time*
Familiarity	*People appear more willing to accept risks that are familiar rather than new risks*
Timing	*Risks seem to be more acceptable if the consequences are immediate or short-term, rather than if they are delayed - especially if they might affect future generations*
Social Amplification and Attenuation	*Concern can be increased because of media coverage or graphic depiction of events. Or reduced by economic hardship*
Trust	*A key factor is how far the public trusts regulators, policy makers, or industry. If these bodies are open and accountable (being honest, admitting mistakes and limitations and taking account of differing views without disregarding them as emotive or irrational) then the public is more likely to place credibility in them.*

In all societies, virtually all decisions involve some implicit or explicit assessment of risks. The acceptable level is often dependent on the individual's priorities in life. A starving person is more likely to eat unsafe food than otherwise. The aim in the risk assessment of a process plant is to aim at a common framework whereby society can get the best value for money from its investment in protecting health and the environment. A risk assessment should be seen as an important component of on-going preventative actions aimed at minimising, or hopefully, avoiding accidents. Re-assessments of risk should therefore follow at regular intervals, and/or after any changes that could alter the hazard, so contributing to the overall prevention programme and emergency response plan of the plant. Risks should be ranked in decreasing severity, and the top risk reduced to acceptable levels.

To establish the probability of death and/or injury due to the transport of a hazardous substance, it was required to:

- Estimate the probability of a spill occurring using vehicle collision statistics for Mozambique, and in particular, Petromoc;
- The tank perforation likelihood;
- Ignition probabilities; and,
- Estimate the consequences as a result of such a spill (toxic vapours, fire or explosion).

A very detailed risk assessment considers all possibly accidental spill/leak scenarios. The probability of these spills occurring would then be determined using some type of failure mode analysis, such as Fault-and-Event trees. In this investigation, however, three representative spill sizes in accordance with the Dutch transport risk methodology, were included, namely, (a) full tanker inventory, (b) 5 m^3 and (c) 0.5 m^3. Each spill can then result in an un-ignited vapour cloud, a delayed ignition or an immediate ignition. An un-ignited vapour cloud could potentially result in a toxic gas, a delayed ignition in a flash fire or an explosion, and an immediate ignition in a pool fire. The likelihood of each of these outcomes was calculated using event trees.

7.1 Assessment Results Summary

7.1.1 Toxic Inhalation

Due the relatively low volatility of the natural gas condensate, evaporation would be relatively slow. The evaporation rate increases with increased ambient temperature and wind speed. However, the increasing wind speed results in increasing dilution of the vapour at a rate faster than the dilution. Therefore the highest downwind concentration occurs with lower wind speeds in spite of the higher evaporation rate.

The maximum concentration near a large spillage was predicted to be 45 000 mg/m^3. This concentration is slightly higher than the IDLH[1] value of 40 000 mg/m^3 for methylcyclohaxane. The concentration drops below the IDLH value within 10 m from the spillage. Therefore, although the vapour cloud would not result in a very toxic hazard, prolonged exposure near the pool must be avoided.

In the case of open fires, plume rise due to the high temperature of the cloud is significant enough to result in low ground level concentrations and therefore little no lethal effects are expected from the combustion products, mainly nitrogen dioxide.

2

[1] This value was developed by the National Institute of Occupational Safety and Health (NIOSH), and refers to a maximum concentration to which a healthy person may be exposed for 30-minutes and escape without suffering irreversible health effects or symptoms that impair escape (ranging from runny eyes that temporarily impair eyesight to a coma). IDLHs are intended to ensure that workers can escape from a given contaminated environment in the event of failure of the respiratory protection equipment.

7.1.2 Explosion Overpressure

Following a delayed ignition of a vapour cloud, depending on obstruction, either a flash fire or blast overpressure (explosion) would result. The maximum distance to the lower explosion limit of the evaporated cloud resulting from a complete tanker spill is 25.4 m under calm, night time atmospheric conditions. The amount of explosive material within the explosive limits under these conditions is 42.7 kg. The minimum distance was calculated to occur under convective (very unstable) daytime conditions, viz. 4 m with only about 5 to 6 kg in the flammable region.

In open road situations, the vapour cloud is unconfined, and this amount would rather result in a flash fire than an explosion. However, in densely populated or confined areas, the occurrence of an explosion cannot totally be excluded.

For unconfined conditions, the ‘safe distance’ (i.e. 95% probability that no serious damage would occur beyond this distance) is calculated to be between 112 m and 144 m. Some damage to house ceilings and 10% window glass broken could also be broken at this distance. In confined conditions, this distance was calculated to be 320 m. The distance to the 50% expected lethality, i.e. an over-pressure of 145 kPa, was calculated to be between 8 and 10 m. For confined conditions, this distance could be up to 17 m. The probability of death beyond the 69 kPa is very low. The distance calculated for unconfined conditions is between 11 m and 14 m. For confined conditions, the distance is between 21 m and 23 m. Significant building damage (0.2% probability) can still occur up to 7 kPa, i.e. 50 m unconfined to 108 m confined.

However, the likelihood of explosion conditions occurring after an accidental spill is low due to the relatively small amount in the explosive limits, i.e. less than 100 kg. Nonetheless, since the lethal distance to explosion overpressure is within the same order as the impact from thermal radiation (11 m to 23 m), the probability of death following an explosion of a spillage was incorporated as part of the pool fire consequences.

7.1.3 Thermal Radiation from Pool and Flash Fires

Thermal radiation is considered to be the main consequences following a spillage and subsequent ignition of the condensate. A flash fire is a non-explosive combustion of an unconfined vapour cloud. On ignition, the fire propagates back through the vapour cloud and burns as a flash fire. The major hazard of flash fires is the heat effect from thermal radiation. The results for a spillage of 0.5 m^3, 5 m^3 and full contents are summarised in Table 7-1.

Table 7-1: Predicted distances to various consequences due to heat radiation.

Incident Size	Thermal Radiation (kW/m^2)			
	4.7[(a)]	*12.6*[(b)]	*35*[(c)]	*60*[(d)]
0.5 m^3	15 m	7 m	4 m	3 m
5 m^3	49 m	29 m	13 m	10 m
full contents	95 m	59 m	28 m	20 m

Notes:
(a) - Cause pain in 15 - 30 seconds and second degree burns after 30 seconds
(b) - 10% chance of fatality for instantaneous exposure or 30% chance of fatality for continuous exposure and a high chance of injury
(c) - 25% chance of fatality if people were exposed instantaneously

(d) -100% chance of fatality if people were exposed instantaneously

7.1.4 Maximum Individual Risk

The maximum individual risk is calculated for an individual who is presumed to be present at some specified location. The parameter is not dependent on the knowledge of the population at risk. The risk calculations, however, included the effect of wind speed and atmospheric turbulence. Differences between land-use, i.e. urban and rural locations, were also considered. The results are summarised in Table 7-2.

Table 7-2: Calculate maximum individual risks for different locations along the transportation route and the distances to acceptable levels.

Location	Distance To		`Maximum Risk (per year)
	$1X10^{-6}$ Risk Isoline (m)	$3X10^{-7}$ Risk Isoline (m)	
Urban			
Lower Estimate	18	30	$3.0x10^{-6}$
Upper Estimate	24	36	$4.9x10^{-5}$
Rural			
Lower Estimate	Not reached	17	$9.0x10^{-7}$
Upper Estimate	22	36	$5.0x10^{-6}$

Due to the limited historical data available for spillage of the condensate, a lower and upper risk was calculated. This range is primarily due to the considerably higher probability of perforation actually witnessed when compared to international norms. The table summarises the calculated maximum distances to the broadly acceptable risk ($1x10^{-6}$ per year) and risk level for vulnerable societies ($3x10^{-7}$ per year). The calculated maximum risk is $4.9x10^{-5}$ per year in urban conditions.

As used by the UK Health and Safety Executive, a risk value between that which is intolerable, at $1x10^{-4}$ per year, and broadly acceptable level of $1x10^{-6}$ per year, is regarded to be reduced to ALARP – "As Low As Reasonably Practicable" – region. Base on this ALARP triangle, the risk of transportation of condensate falls within the ALARP region. The calculated maximum risks, including the lower estimates, do not exceed the upper level for ALARP (i.e. $1x10^{-4}$ per year), however, the upper estimate in urban conditions closely approach this limit. It is therefore strongly recommended that additional mitigation measures be applied to reduce the maximum risk.

7.1.5 Societal Risk

The maximum individual risk takes no cognisance of the population density. The societal risk is presented as the frequency and severity (lethality) corresponding to each of the spill cases considered in the investigation. The approach adopted is to arrange the accidents in the order of decreasing fatalities (per year). The cumulative frequencies are then calculated in the same order, i.e. the lowest frequency corresponds to the highest fatality. Plots of the cumulative frequency (**F**), vs. severity (**N**) were prepared for different sections along route, different population densities and incident definitions.

The societal risk criteria adopted in this investigation is that recommended in the Netherlands for dangerous goods transport (i.e. road, rail and pipelines) (MHPE, 1996), i.e. a risk of 10^{-4} per year per km for ten fatalities, a risk of 10^{-6} per year per km for 100 fatalities, and so on. Above the recommended societal risk criterion line the risk has to be reduced and below the line, the risk needs to be reduced to "As Low As Reasonably Achievable", i.e. ALARA. Both spillage assumptions (lower & upper estimates) result in a risk which is above the ALARA criterion and into the zone requiring risk reduction.

7.2 Conclusions

Considering the calculated maximum individual risk, the transportation of condensate could be regarded "tolerable", but above the risk criteria normally adopted as broadly acceptable by the general public. When the population density is included, the societal risk clearly indicates that the risk is above the norm accepted in countries such as the Netherlands. Accordingly, immediate risk reduction measures must be implemented to reduce risk to As Low As Reasonably Practicable or Achievable (ALARP or ALARA).

7.3 Recommendations

Although a large part of the risk can be attributed to external, uncontrollable hazardous sources, e.g. poor road conditions, pedestrians, other bad driver behaviour, etc., Petromoc has to immediately address all those aspects under their control which would reduce the risk. Therefore, the primary focus of risk reduction must initially be on improving driver alertness, behaviour and habits. This includes strict checking of abuse of narcotic substances, such as alcohol.

Spillage occurs as a result of mechanical failure of the tank or the vehicle, driver misjudgements or third party involvement. Causes of accidents are usually attributable to one or more of the following factors:

- Ignorance of traffic regulations or approved practice. Excessive speed for the prevailing road and traffic conditions is responsible for the majority of highway accidents.
- A poor attitude by the driver towards other road users.
- Lack of driving skill.
- Other parties, including vehicles, other forms of transport (e.g. bicycles) and pedestrians.

Since third party activities are not easily controlled, the emphasis on risk reduction must be on ensuring minimal mechanical failure and driver errors.

The current accident record of the vehicles transporting condensate from Temane is considerably higher than the statistics in South Africa (more than 3-fold) and generally found internationally. Accident prevention should therefore receive considerable attention. Since the circumstances surrounding accidents vary widely, only general recommendations (more detail in Section 6) can be provided.

1. Employing the right vehicle for the job is an important aspect in any transportation operation.
   a. Rigid vehicles are inherently more stable than articulated vehicles and are therefore better suited for use in very hilly country and on poor roads. This is because articulated vehicles (tractor semi-trailer) are prone to 'jack-knife' in steep or slippery conditions, especially when severely braked.
   b. Irrespective of the type of vehicle and axle configuration that are chosen it is essential to ensure that it is a stable unit. Vehicle stability depends upon the effects of the centre of gravity of the payload/tank (or body), its height and position relative to the axles and the stiffness or deflection of the suspension.

c. The design of the driver's cab must be aimed at making him comfortable and facilitating control, thereby reducing fatigue.
d. The underperformance of a vehicle may hamper safe manoeuvrability of the vehicle. It is obviously quite possible that the current vehicles are appropriate, but it is recommended that the most appropriate vehicle and load be chosen for the current road conditions.

2. A badly maintained vehicle can be both dangerous and illegal. Management should therefore ensure roadworthiness of all vehicles by implementation of an effective maintenance programme.
3. Since human behaviour is the dominant element in road safety, influencing driver attitudes and performance must be a prime objective of managers and supervisors. With enforcement of Petromoc company standards, local norms could transcend to produce improved safety performance.
4. Managers and supervisors must have appropriate experience, and thorough initial training, motivation, regular assessment and retraining advocate careful driver selection as the means of achieving safe driving.
5. First line supervisors are the vital link between management and driver and their role is crucial to road safety programmes. They are responsible for turning the objectives and policies of management into action and results. To be effective they must not only have a strong commitment to safety but must be familiar with all aspects of road safety and have sound supervisory and motivational skills. Although drivers must be encouraged to take personal responsibility for their own performance, supervisors still need to know and understand each driver and be sensitive to change of circumstances or personal behaviour which may indicate potential adverse influences on safety performance.
6. The following qualities should be sought when appointing a driver:
    a. A proven safe driving record of heavy duty vehicle driving.
    b. A positive attitude to road safety.
    c. Physical fitness for the task.
    d. Integrity.
7. It is recommendation that Petromoc conduct its own driving tests.
8. Training is a continuous process comprised of three elements:
    a. Induction Training
    b. Job Training
    c. Defensive Driver Training
9. Detailed inspection of motor vehicles at regular intervals generally results in a reduction of accidents due to defective equipment.
10. A road safety programme must be based on known facts about the causes of accidents so that the best means of preventing them can be developed. This information can be obtained only by an adequate and accurate system of reports and records. Accidents should therefore be reported in writing on a special report form as soon as possible after they occur. Even the most minor accident should be reported, particularly where another vehicle or third party property may have suffered damage. The report should include all relevant information about
11. Incentive schemes for paying monetary awards to drivers for safe driving are not always effective in reducing accidents.
12. Consequences of road accidents can often be minimised by effective emergency action at the scene. Action may be required to:
    a. Prevent any worsening of the situation created by the original accident, e.g. by deployment of warning devices or control of hazardous areas.
    b. Apply life saving first aid to injured persons.
    c. Contact the emergency services, i.e. ambulance, fire brigade or police.
13. Every tanker should be equipped with:

a. Fire-fighting appliances;
b. Tool kit for emergency repairs to vehicle;
c. Mechanical brake of a size suitable for the mass of the vehicle and tank contents, and the wheel size;
d. Two amber lights independent of the electrical system of the tanker;
e. Placards for warning of spill (toxic cloud and fire warning); and,
f. Protective equipment.

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9 APPENDIX A: MATERIAL SAFETY DATA SHEET

Material Safety Data Sheet

Gas Condensate

1 Chemical product and company identification

Common name	: **Gas Condensate**	**Code**	:
Supplier	: Sasol Petroleum Temane Limitada Predio Progressor Avenida 24 de Julho 2096, 3Ô Andar Maputo Mozambiqe Tel: +2581 49 7705 Fax: +2581 49 7707	**MSDS#**	:
Synonym	: Natural gas liquids.	**Validation date**	: **2003/05/20.**
Trade name	: Gas Condensate	**Print date**	: 2003/05/20.
Material uses	: Fuel oil in boilers and indusrial furnaces for steam generation and air heating for drying purposes.	**Prepared by**	: **Lehlohonolo B Mothebe**
Manufacturer	: Sasol Petroleo Temane Limitada Distrito de Inhassoro Provincia de Inhambane Mozambique Tel: +258 238 2155/2386.	**In case of emergency**	: SOUTH AFRICA: 0800 11 28 90 INTERNATIONAL: +27 17 610 4444

2 Composition / information on ingredients

Name	CAS #	% by weight	Exposure limits
Natural Gas Condensate	68919-39-1	100	Not available.

3 Hazards identification

Physical state and appearance : Liquid.

Emergency overview : DANGER!!

HIGHLY FLAMMABLE LIQUID AND VAPOR.
VAPOR MAY CAUSE FLASH FIRE.

Keep away from heat, sparks and flame. Keep container closed. Use only with adequate ventilation.

Routes of entry : Ingestion. Inhalation. Skin. Eye contact.

Potential acute health effects

Eyes : Hazardous in case of eye contact..

Skin : Hazardous in the case of skin contact.

Inhalation : Vapours may cause headache and slight dizziness.

Ingestion : Harmful: may cause lang damage if swallowed.

Continued on Next Page

Potential chronic health effects	:	***CARCINOGENIC EFFECTS***: *EU Category 2: Regarded as carcinogenic to humans based on animals studies* ***MUTAGENIC EFFECTS***: *Not listed.* ***TERATOGENIC EFFECTS***: *Not listed.*
Medical conditions aggravated by overexposure:	:	*There is no known effect from chronic exposure to this product. Repeated or prolonged exposure is not known to aggravate medical condition.*
Overexposure /signs/symptoms	:	*CNS depression, headache, nausea, vomiting, cramping, anesthesia.*

See toxicological information (section 11)

4 First aid measures

Eye contact	:	*Check for and remove any contact lenses. In case of contact, immediately flush eyes with plenty of water for at least 15 minutes. Get medical attention.*
Skin contact	:	*In case of contact, immediately flush skin with plenty of water. Remove contaminated clothing and shoes. Wash clothing before reuse. Thoroughly clean shoes before reuse. Get medical attention.*
Inhalation	:	*If inhaled, remove to fresh air. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Get medical attention.*
Ingestion	:	*Do NOT induce vomiting unless directed to do so by medical personnel. Never give anything by mouth to an unconscious person. If large quantities of this material are swallowed, call a physician immediately. Loosen tight clothing such as a collar, tie, belt or waistband.*
Notes to physician	:	*Support respiratory and cardiovascular function.*

5 Fire fighting measures

Flammability of the product	:	*Flammable.*
Autoignition temperature	:	*Not available.*
Flash points	:	*Closed cup: -6°C (21.2°F).*
Flammable limits	:	*Not available.*
Products of combustion	:	*Carbon oxides (CO, CO2) nitrogen oxides (NO, NO2...)*
Fire hazards in presence of various substances	:	*Highly flammable in presence of open flames and sparks.* *Flammable in presence of shocks.*
Explosion hazards in presence of various substances	:	*Risks of explosion of the product in presence of static discharge.* *May explode in presence of shocks.*
Fire fighting media and instructions	:	*SMALL FIRE: Use DRY chemicals, CO2, water spray or foam.* *LARGE FIRE: Use water spray, fog or foam. DO NOT use water jet.*
Protective clothing (fire)	:	*Wear MSHA/NIOSH approved self-contained breathing apparatus or equivalent and full protective gear.*
Special remarks on fire hazards	:	*As for any combustible hydrocarbon. Use air supplied breathing equipment. Avoid breathing vapour or fumes. Cool exposed containers with water spray.*
Special remarks on explosion hazards	:	*Not available.*

6 Accidental release measures

Small spill and leak	:	*Absorb with an inert material and put the spilled material in an appropriate waste disposal.*
Large spill and leak	:	*Keep away from heat. Keep away from sources of ignition. Stop leak if without risk. Absorb with DRY earth, sand or other non-combustible material. Do not get water inside container. Do not touch spilled material. Prevent entry into sewers, basements or confined areas; dike if needed. Call for assistance on disposal.*

Continued on Next Page

7 Handling and storage

Handling : *Keep away from heat, sparks and flame. Keep container closed. Use only with adequate ventilation. To avoid fire or explosion, dissipate static electricity during transfer by grounding and bonding containers and equipment before transferring material. Use explosion-proof electrical (ventilating, lighting and material handling) equipment.*

Naturally Occurring Radioactive Materials (NORM).
*NECSA coding 4793*001 : Ra-226 in Bq/g <0.07*
Pb-210 in Bq/g <0.15

Industry experience indicates that natural gas contains small amounts of radon, a naturally-occurring radioactive gas. The solid decay products of radon, called radon daughters, can accumulate inside production and process equipment handling natural gas liquids. Scales, deposits, and sludges from this equipment may have a significant accumulation of this NORM.

Storage : *Store in a segregated and approved area. Keep container in a cool, well-ventilated area. Keep container tightly closed and sealed until ready for use. Avoid all possible sources of ignition (spark or flame).*

8 Exposure controls, personal protection

Engineering controls : *Provide exhaust ventilation or other engineering controls to keep the airborne concentrations of vapors below their respective occupational exposure limits. Ensure that eyewash stations and safety showers are proximal to the work-station location.*

Personal protection

Eyes : *Splash goggles.*

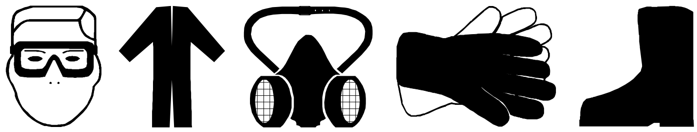
Body : *Chemical resistant protective suit.*

Respiratory : *Wear appropriate respirator when ventilation is inadequate.*

Hands : *Gloves, Butyl rubber.*

Feet : *Chemical resistant safety boots.*

Protective clothing (pictograms) :



Personal protection in case of a large spill : *Splash goggles. Full suit. Boots. Gloves. Suggested protective clothing might not be sufficient; consult a specialist BEFORE handling this product.*

Product name	Exposure limits
Natural Gas Condensate	Not available.

9 Physical and chemical properties

Physical state and appearance : *Liquid.*

Color : *Clear liquid. (Light.)*

Odor : *Hydrocarbon.*

Taste : *No data available.*

Molecular weight : *Not applicable.*

Molecular formula : *Not applicable.*

pH (1% soln/water) : *Not applicable.*

Boiling/condensation point : *IBP=65°C (149°F), FBP=257°C, Mean Average Boiling point = 153°C.*

Melting/freezing point : *No data available.*

Critical temperature : *No data available.*

Specific gravity : *0.75 (Water = 1)*

Continued on Next Page

Vapor pressure	:	No data available.
Vapor density	:	No data available.
Volatility	:	No data available.
Odor threshold	:	No data available.
Evaporation rate	:	No data available.
VOC	:	No data available.
Viscosity	:	No data available.
$LogK_{ow}$	:	No data available.
Ionicity (in water)	:	Not available.
Dispersion properties	:	Not available.
Solubility	:	Insoluble in cold water.
Physical chemical comments	:	No additional remark.

10 Stability and reactivity

Stability and reactivity	:	The product is stable.
Conditions of instability	:	Heat, open flames.
Incompatibility with various substances	:	Avoid contact with strong oxidizing agents and strong acids.
Hazardous decomposition products	:	Flue gas, carbon monoxide, aldehydes in the case of incomplete combustion.
Hazardous polymerization	:	Will not occur.

11 Toxicological information

Toxicity to Animals	:	LD50: Not available. LC50: Not available.
Chronic effects on humans	:	Not available.
Other toxic effects on humans	:	No specific information is available in our database regarding the other toxic effects of this material for humans.
Special remarks on toxicity to animals	:	No additional remark.
Special remarks on chronic effects on humans	:	No additional remark.
Special remarks on other toxic effects on humans	:	No additional remark.

12 Ecological information

Ecotoxicity	:	Paraffins are not toxic to Pseudomonas putida even at high concentrations of 100 000 ppm. Only a maximum of 5 % inhibition was observed.
BOD and COD	:	Not available.
Biodegradable/OECD	:	Paraffins are not readily biodegradable.
Mobility	:	Not available.
Products of degradation	:	Possibly hazardous short term degradation products are not likely. However, long term degradation products may arise.
Toxicity of the products of biodegradation	:	Not available.
Special remarks on the products of biodegradation	:	No additional remark.

Continued on Next Page

13 Disposal considerations

Waste information : *Waste must be disposed of in accordance with federal, state and local environmental control regulations.*

Waste stream : *Not available.*

Consult your local or regional authorities.

14 Transport information

Regulatory information	UN number	Proper shipping name	Class	Packing group	Label	Additional information
DOT Classification	*UN 3295*	*HYDROCARBONS LIQUID, N.O.S.*	*CLASS 3: Flammable liquid.*	*II*		-
TDG Classification	*UN 3295*	*HYDROCARBONS LIQUID, N.O.S.*	*CLASS 3: Flammable liquid.*	*II*		
IMDG Class	*UN 3295*	*HYDROCARBONS LIQUID, N.O.S.*	*Class 3: Flammable liquid.*	*II*		-
IATA-DGR Class	*UN 3295*	*HYDROCARBONS LIQUID, N.O.S.*	*CLASS 3: Flammable liquid.*	*II*		-

15 Regulatory information

HCS classification : *CLASS: Flammable liquid having a flash point lower than 37.8°C (100°F).*

U.S. Federal regulations : *TSCA 8(b) inventory: Gas Condensate*

SARA 302/304/311/312 extremely hazardous substances: No products were found.
SARA 302/304 emergency planning and notification: No products were found.
SARA 302/304/311/312 hazardous chemicals: No products were found.
SARA 311/312 MSDS distribution - chemical inventory - hazard identification: No products were found.

SARA 313 toxic chemical notification and release reporting: No products were found.

Clean Water Act (CWA) 307: No products were found.

Clean Water Act (CWA) 311: No products were found.

Clean air act (CAA) 112 accidental release prevention: No products were found.

Clean air act (CAA) 112 regulated flammable substances: No products were found.

Clean air act (CAA) 112 regulated toxic substances: No products were found.

State regulations : *No products were found.*

California prop. 65: No products were found.

EU Regulations

Hazard symbol(s) :

Classification : Highly flammable, Toxic

Risk phrases : *R11- Highly flammable.*
R45- May cause cancer.
R65- Harmful: may cause lung damage if swallowed.

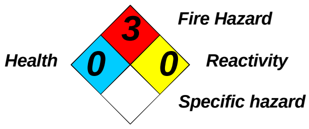
Continued on Next Page

Safety phrases : *S9- Keep container in a well-ventilated place.*
S16- Keep away from sources of ignition - No smoking.
S53- Avoid exposure - obtain special instructions before use.
S60- This material and its container must be disposed of as hazardous waste.
S62- If swallowed, do not induce vomiting: seek medical advice immediately and show this container or label.

EINECS Number : *272-896-3*

16 Other information

National Fire Protection Association (U.S.A.)



References : - LOLI Database: The regulated Chemicals List of Lists.
- CHEMINFO: Canadian Centre for Occupational Health and Safety, Issue: 97-3 (August, 1997).- BDH; Hazard Data Disk, Version 3.- CESARS: Chemical Evaluation and Retrieval System, Produced by: Ontario Ministry of Environment and Michigan Department of Natural Resouces, Issue:97-3 (August, 1997).- TOMES Plus System: Toxicology, Occupational Medicine & Environmental Series: incorporating:- MEDITEX, HAZARDTEXT, 1st Medical Response Protocols, INFOTEXT, HSDB, CHRIS, OHM/TADS, IRIS, NIOSH Pocket Guide, RTECS, NJ Fact Sheets, North American Emergency Response Guides, REPROTEXT, REPROTOX, TERIS, Shepard's Catalog of Teratogenic Agents.

Other special considerations : No additional remark.

Date of printing : ***2003/05/20.***

Date of issue : ***2003/05/20.***

Date of previous issue : ***No Previous Validation.***

Version : ***4***

Verified by : ***Paul Gravett.***

Notice to reader

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10 APPENDIX B: GENERAL RISK CALCULATION METHODOLOGY

There are various parameters used to express the risk to persons from accidents. These fall into two broad categories, namely:

- Measures of risk to individuals - generally referred to as “Individual Risk”; and,
- Measures of risk to society - generally referred to as “Societal Risk”.

The main steps required estimating the risk of a facility is

1. Estimate the likelihood of the incident;
2. Calculate the outflow rate, the subsequent evaporation and atmospheric dilution, taking operating and local atmospheric conditions into account;
3. Predict the thermal radiation levels (in case of fires), explosion overpressure and downwind concentrations;
4. From the predicted thermal radiation, overpressures and concentration levels, estimate the consequences using an appropriate consequence model;
5. The risk is then expressed as the product of the incident frequency, the likelihood of a specific atmospheric condition and the probability of lethality (or injury).

10.1 Physical Effects Models

10.1.1 Emission Rate Simulations

The rate of release during an accidental spill depends primarily on the amount of material in the ruptured tank and the diameter of the opening through which the material is able to flow. The extent of evaporative losses from the spill is dependent on the nature of the substance, the storage conditions (dimension of tank, storage temperature and pressure), degree of containment of the spill (e.g. presence of a bund), and the prevailing meteorological conditions. Wind speed, atmospheric stability and ambient temperature represent the most important meteorological parameters in terms of the extent of evaporative losses from spills. Evaporation rates increase with increases in $(\text{wind speed})^{0.8}$, and linearly with temperature. However, strong winds promote the dilution of airborne matter proportionally. Calm winds (< 1.5 m/s) therefore provide worst-case conditions for dispersion. Atmospheric stability, which is a function of both mechanical (wind shear) and thermal turbulence, provides a measure of the extent of vertical mixing within the boundary layer. Very unstable conditions, also referred to as convective conditions, frequently characterise the daytime and may give rise to enhanced ground level dispersion from tall stacks. Neutral atmospheric conditions give rise to the worst daytime dispersion potential for ground level emissions and releases from relatively short stacks. Stable conditions (nighttime) suppress vertical movement, and hence ground level releases could remain concentrated for long distances.

The model is able to account for the following parameters in the calculation of release rates:

- gaseous and liquid releases;
- physical properties of chemical released;
- various source configurations (including vertical, horizontal and spherical vessels, pressurised and non-pressurised vessels, refrigerated and non-refrigerated vessels, and various pipe sizes);
- location and orientation of leak;
- various leak sizes;

- hydraulic liquid height;
- transient and instantaneous releases;
- choked and unchoked flows;
- two-phase outflows (i.e. aerosol, vapour and liquid outflows);
- variations in release duration's;
- calculation of champagne effect (apparent liquid level rise); and,
- realistic depressurisation calculations of pressure vessels and subsequent thermodynamic changes inside the vessel.

The flow of compressible fluids, like gases and vapour-liquid mixtures (two-phase flows) may become critical or 'choked'. Choked flow occurs when the downstream pressure is low enough for the velocity of the fluid to reach the maximum flow velocity possible (i.e. the speed of sound) in the mixture. Further lowering of the downstream pressure does not increase the mass flux, and the flow rate is therefore independent of the containment pressure. When the upstream pressure increases, the critical mass flow rate will increase but only due to the increasing density of the out-flowing chemical.

Two-phase outflows may develop when a pressurised liquefied gas flows through a pipe and the local pressure in the pipe becomes lower than the saturation pressure of the flowing liquid. This occurs due to the decrease of pressure along the pipe as a result of friction. The liquid becomes superheated and a gas phase may appear due to vaporisation of the liquid (flashing). The HAWK model is able to estimate the vapour, airborne aerosol and liquid fractions of the release. The liquid fraction contributes to the chemical pool on the ground, whereas the aerosols remain airborne until they precipitate out to form a pool or are evaporated. The rainout fraction is largely a function of the droplet size, whereas the rate of evaporation of airborne droplets is dependent on the extent of air entrainment and the thermodynamic state (temperature, density) of the mixture.

The driving force for the evaporation process is the vapour pressure of the chemical, evaluated at the surface of the chemical pool. Since vapour pressure is a strong function of temperature, knowledge of the surface temperature of the evaporating pool is required. The surface temperature, in turn, depends on many variables as listed below:

- radiative heat transfer by solar insolation;
- long-wave radiation from the atmosphere absorbed by the pool;
- long-wave radiation emitted by the pool;
- evaporative cooling;
- convective heat transfer from the atmosphere into the pool; and,
- heat conduction from the substrate (e.g. concrete) into the pool.

Heat conduction from the substrate is dependent on the nature of the substrate (concrete versus tar or gravel), and the extent of the liquid pool spread. A steady state pool surface temperature is obtained by solving the heat balance consisting of the above list. This temperature then determines the vapour pressure, or *escaping tendency* of the chemical from the pool.

The overall vapour transfer is governed by the mass transfer coefficient. This coefficient is dependent on the following factors:

- pool dimensions;
- ambient meteorological conditions;
- diffusivity of compound in air; and,
- the kinematic viscosity of the vapour.

The method of Raj and Morris (1987) is used to calculate heat from net solar radiation. In the absence of actual solar radiation measurements, the methods of De Bruin and Holtslag (1982) have been employed. Long-wave atmospheric and pool radiation is calculated using the Stefan-Boltzmann Law. The two-layer model of Kawamura and MacKay (1987) has been adopted whereby both the ground and liquid heat transfer coefficients are used to establish an effective heat transfer. Finally, evaporative heat loss is accounted for by solving the energy conservation equation, taking into account the effect of wind speed in the mass transfer.

The HAWK model is able to account for the spread of uncontained pools, and the containment of pools within bunds. The presence of bunds reduces the evaporation rate, and by virtue also the size of a bund fire, by limiting the pool area. Bunds also provide for longer contact times between the liquid and the surface thus reducing the heat conduction from the surface to the evaporating liquid.

10.1.2 Dispersion Simulation Methodology for Accidental Releases

Accidental emission scenarios, outlined in the section above, cannot be simulated with relatively simple, *steady-state* dispersion models. The dispersion model must be able to simulate *unsteady* conditions and heavier-than-air gas clouds. Furthermore, “heavy” vapour clouds behave differently from clouds of neutral density in several important aspects. Denser-than-air releases spread radially under the influence of gravitational forces. This self-induced flow produces a shallow cloud with increase horizontal extent. The heavy cloud thus spreads both downwind and upwind, and is flatter in shape. At the front of the so-called “gravity current”, a head will develop with a strong vorticity. This velocity field is deterministic in nature and will replace, for the duration of the gravity spreading, the random atmospheric turbulence. Following the gravity spreading, the vertical variation of density in the cloud causes a stable stratification in the cloud thus reducing the potential for vertical dispersion. The effects of density will eventually be dispersed and dispersion will become passive.

In addition to the ability to simulate unsteady emissions and heavy clouds, the HAWK model allows calm, or no-wind conditions, and spatially and temporally varying wind fields produced by complex topography. The software package consists of a group of Lagrangian Puff-type models, each applicable to a different dispersion mechanism (eg. neutral or buoyant normal gases, heavy gases, particles etc.). The choice of the dispersion mechanism is done automatically by the code, depending on the factors listed above. The various models in the code were borrowed from internationally published articles, the accuracy of which is discussed by the respective authors. The HAWK model uses a Gaussian Puff model for non-heavy clouds. Owing to their wide use, relative simplicity and reasonable accuracy, this model has been adopted to simulate neutrally or positively buoyant plumes. In this approach, the plume is represented by the super-positioning of serially released clouds, or puffs. The distribution within each cloud or puff, is assumed to be Gaussian, or Normal:

$$\chi(x,y,z,t) = \frac{MV_T D}{(2\pi)^{2/3}\sigma_x\sigma_y\sigma_z}\exp\left[-\frac{1}{2}\left\{\left(\frac{x-x_o}{\sigma_x}\right)^2+\left(\frac{y-y_o}{\sigma_y}\right)^2\right\}\right]$$

where, *D* is the decay term due to chemical decay or washout in rain; *M* the quantity of matter generated at the outset (g); $\sigma_x, \sigma_y, \sigma_z$ the dispersion coefficients in x, y and z co-ordinate system; x_o, y_o, z_o the initial puff position in x, y and z co-ordinate system; and, V_T the vertical dispersion terms, include modifications due to a limited mixing depth (e.g. ground surface, at bottom, capped by an inversion aloft), and particle settling.

The heavy gas module is based on the model originally proposed by Kaiser and Walker (1978) with modifications due to Eidsvik (1980) and others. More detail on the model is provided in Appendix A. This model has also been used in different software packages (eg. Radian Corporation's Charm7 Model). In validation studies performed by Radian Corporation it was found that the heavy gas model generally over predicted the observed concentrations, but within a factor of two. This is especially the case when the gas density is only slightly higher than that of air. In a later evaluation of heavy gas models, Hanna *et al* (1991) indicated that no single heavy gas dispersion model is a clear improvement over the other. All the models predicted mostly within a factor of two of the observed concentrations. It may be that stochastic processes in the atmosphere will prevent models from reducing the uncertainty much below about 50% of the mean observations.

Typical parameters required for input into the HAWK, include short-term meteorological data for case-study runs, on-line data for real-time simulations, or frequency tables for simulating long-term atmospheric conditions. Source data would typically include stack dimensions and operating conditions, tank size, shape hole sizes and the conditions inside the tank, etc. In the case of pipelines, it is essential to supply the pipe diameter, the pipe length, operating conditions and the hole size. It is also necessary to supply any containment conditions, e.g. inside building or bund dimensions.

10.1.3 Thermal Radiation Simulations

The thermal radiation model used in investigation assumes that the flame behaves as a grey cylinder emitting thermal radiation from its surface at a uniform level. This model is also referred to as the "Cylindrical Flame Model" as opposed to the relatively simplistic "Point Source Model". The point source model (or inverse square law) applies to the propagation and spatial distribution of radiation emitted by a point of energy in a homogeneous medium. According to the inverse square law, the intensity of thermal radiation contributed by the flame at a distance, *d*, from a point source (center of a sphere) is given by the equation:

$$q = \frac{Q}{4\pi d^2} \qquad (2)$$

Where,

q	=	intensity of thermal radiation at the target (kW/m^2)
Q	=	the rate of energy emission at the source (kW)
d	=	distance of target from the source (m)

Although the above model is widely used in industry, it cannot accommodate atmospheric conditions such as wind speed (flame tilting), neither does it account for radiative flux along the full flame length. The cylindrical flame model, on the other hand, attempts to include these.

The radiative flux from the cylindrical flame surface to a target located at a distance, *d*, from the centre of the spill fire is given by:

$$q = \tau F \varepsilon q_{\max} \quad (3)$$

Where,

τ	=	atmospheric transmissivity to thermal radiation from the fire
F	=	a geometric factor which is a measure of the fraction of energy emitted by the flame that is intercepted by the target
ε	=	average emissivity of the flame
q_{max}	=	maximum (black body) surface emissive power of the flame

The few factors are quite a complex set of equations and will not be repeated here.

10.1.4 Vapour Cloud Explosion Methodology

Although the characteristics of blast waves from vapour cloud explosions are known to be substantially different from those resulting from a TNT explosion, it is common in explosion investigations to establish an "equivalent TNT yield" for the vapour cloud explosion. The principal reason for this is that the characteristics of TNT explosions, including the blast effects and the relationship of the peak incident overpressure wave to the distance from the centre of the explosion and to the charge mass of TNT have been well established from extensive experiments and weapons tests. Lees (1980) summarised some of these findings, including Baker's (1973) results. This TNT data can be used, therefore, to estimate the blast wave distance for different overpressures.

However, in the presence of structures near potential explosion points, the use of the TNT equivalence method is not recommended. Instead, the use of gas charge explosion studies would be superior. One-dimensional numerical studies of gas change explosions were carried out by several groups of researchers using different numerical techniques. These studies resulted in several sets of *blast curves*. Among these, the most frequently usd and widely accepted are the Baker-Strehlow (Strehkow *et al*, 1979) blast curves for spherical free air explosions and the TNO (Mercx and Van den Berg, 1997) blast curves for hemispherical explosions. These ideas are also called the *Multi-Energy* concept.

In both Baker-Strehlow and TNO methods, a stoichiometric fuel/air mixture located within the confined and/or congested region defines the source of energy. The flame speed or initial explosion strength is determined by empirical approaches based on the degree of confinement and obstruction within the source region as well as the distance available for flame acceleration (Mercx and Van den Berg, 1997). As discussed above, one-dimensional numerical curves based on gas charges provide a better representation of VCE blast parameters than the TNT equivalence method. However, the one-dimensional curves are idealized symmetric representations that cannot describe the impact of non-symmetric vapour cloud shape, the location of turbulence generating obstacles, or the ignition location. Nevertheless, by simplifying real world scenarios, blast curve methods are still most frequently used as the engineering tool.

The Multi-Energy method requires the selection of a "source or blast strength", taking into account the degree of obstruction by obstacles within the vapour cloud, the ignition energy and the degree of confinement. The initial blast strength index used in the TNO method is divided into ten classes. These classes can be obtained from a combination of three "blast source strength factors", defined as follows.

- Obstruction:
  - **High**
    Closely packed obstacles within gas cloud giving an overall volume blockage fraction (i.e. the ratio of the volume of the obstructed area occupied by the obstacles and the total volume of the obstructed area itself) in excess of 30 % and with spacing between obstacles less than 3 m.
  - **Low**
    Obstacles in gas cloud but with overall blockage fraction less than 30 % and/or spacing between obstacles larger than 3 m.
  - **None**
    No obstacle within gas cloud.
- Parallel plane confinement:
  - **Yes**
    Gas clouds, or parts of it, are confined by walls / barriers on two or three sides.
  - **No**
    Gas cloud is not confined, other than by the ground.
- Ignition strength:
  - **High**
    The ignition source is, for instance, a confined vented explosion. This may be due to the ignition of part of the cloud by a low energy source, for example, inside a building.
  - **Low**
    The ignition source is a spark, flame, hot surface, etc.

The results of categorising are expressed in a matrix in Table 10-1 that gives the Multi-Energy method strength class numbers corresponding to the various combinations of the boundary and initial conditions.

Table 10-1: Initial blast strength index

Blast strength	Ignition energy	Obstruction	Parallel plane Confinement	Multi-Energy	Class

	Ignition energy		Obstruction					
	Low	*High*	High	Low	No			
	(L)	(H)	(H)	(L)	(N)	(C)	(U)	
1		H	H			C		7-10
2		H	H				U	7-10
3	L		H			C		5-7
4		H		L		C		5-7
5		H		L			U	4-6
6		H			N	C		4-6
7	L		H				U	4-5
8		H			N			4-5
9	L			L		C		3-5
10	L			L			U	2-3
11	L				N	C		1-2
12	L				N		U	1

10.2 Consequence Simulation Models

The first approach to be adopted in the assessment of toxic vapours normally involves the comparison of modelled concentrations to exposure guidelines, including occupational exposure limits (threshold limit values, TLVs), *Immediately Dangerous to Life or Health* (IDLH) and *Emergency Response Planning Guidelines* (ERPGs), or in the event that ERPGs are not yet available, *Temporary Emergency Exposure Limits* (TEELs). ERPGs were developed by the American Industrial Hygiene Association and are defined as the maximum concentrations that individuals could be exposed to for a period of one hour before certain health effects would occur. The definition of TLV, IDLH, each of the three ERPGs and TEELs, and a number of additional thresholds is given in the text box below.

The method adopted by the USA-EPA in their *Vulnerability Analyses* of offsite consequences includes the prediction of a concentration footprint for two accident scenarios, namely a “worst case” scenario and an “alternative” scenario. These are defined in the *Technical Guidance for Hazards Analysis* (EPA 1987).

The first scenario, i.e. the "worst case" scenario, assumes a total loss of the contents of the largest storage container of the most extremely hazardous substance, or in the case of a pipeline, a released in 10 minutes. The “alternative” scenario is less conservative and reflects a more probable, but normally less severe, accident scenario using the most frequent, local meteorological conditions.

Once the concentration footprints have been calculated, the EPA defines populations potentially affected by a spill as those within a circle that has as its centre the point of release and its radius the distance to the *toxic* (or *flammable*) *endpoint*, known as *Vulnerability Zones*.

The endpoint for each toxic substance is based on the following, in order of preference: (1) ERPG-2, and (2) Level of Concern (LOC) derived for extremely hazardous substances. The LOC is based on one-tenth of the IDLH level, or one-tenth of an estimated IDLH derived from toxicity data, if no IDLH is available. The *toxic endpoints* thus form the basis of what the US-EPA terms Offsite Consequence Analysis.

The "worst offsite consequences" is defined by the US-EPA as the maximum distance from the point of release to the endpoint (EPA, 1996).

DEFINITIONS OF VARIOUS EXPOSURE GUIDELINE VALUES

- Time-Weighted Average – Threshold Limit Values (TLV-TWA). This refers to the concentration for a normal 8-hour workday and a 40-hour workweek, to which nearly all workers may be repeatedly exposed, day after day, without adverse effects.

- Short Term Exposure -Threshold Limit Values (TLV-STEL). The concentrations to which workers can be exposed continuously for a short period (15 minutes) of time without suffering from (1) irritation, (2) chronic or irreversible tissue damage, or (3) narcosis of sufficient degree to increase the likelihood of accidental injury, impair self-rescue or materially reduce work efficiency, and provided that the daily TLV-TWA is not exceeded.

- Ceiling Exposure Limits -Threshold Limit Values (TLV-CEIL). The concentration that should not be exceeded during any part of the working exposure.

- Immediately Dangerous to Life or Health (IDLH). Developed by the National Institute of Occupational Safety and Health (NIOSH). The IDLH value refers to a maximum concentration to which a healthy person may be exposed for 30-minutes and escape without suffering irreversible health effects or symptoms that impair escape (ranging from runny eyes that temporarily impair eyesight to a coma). The IDLHs are intended to ensure that workers can escape from a given contaminated environment in the event of failure of the respiratory protection equipment.

- Emergency Response Planning Guidelines (*ERPG-1*, *ERPG-2* and *ERPG-3*). ERPGs, developed by the American Industrial Hygiene Association, are applicable to the maximum concentrations that individuals could be exposed to for a periods of one hour before certain health effects would occur. The definition of each of the three ERPGs are given as follows:

ERPG-1 The maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to an hour without experiencing other than mild, transient adverse health effects or without perceiving a clearly defined objectionable odour.

ERPG-2 The maximum airborne concentration below which it is believed nearly all individuals could be exposed for up to one hour without experiencing or developing irreversible or other serious health effects or symptoms that could impair an individual's ability to take protective action.

ERPG-3 The maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to an hour without experiencing or developing life-threatening health effects.

- Temporary Emergency Exposure Limits (*TEEL-0*, *TEEL-1, TEEL-2* and *TEEL-3*). The USA DOE Emergency Management Advisory Committee's Subcommittee on Consequence Assessment and Protective Action developed TEELs as an interim method to allow for the preliminary identification of hazardous or potentially hazardous situations for emergency planning. The definition of each of the four TEELs are given as follows:

TEEL-0: The threshold concentration below which most people will experience no appreciable risk of health effects.

TEEL-1: The maximum concentration in air below which it is believed nearly all individuals could be exposed without experiencing other than mild, transient adverse health effects or perceiving a clearly defined objectionable odour.

TEEL-2: The maximum concentration in air below which it is believed nearly all individuals could be exposed without experiencing or developing irreversible or other serious health effects or symptoms that could impair an individual's ability to take protective action.

TEEL-3: The maximum concentration in air below which it is believed that nearly all individuals could be exposed without experiencing or developing life-threatening health effects.

- Level of Concern (LOC). The LOC concentration is derived for extremely hazardous substances from the IDLH value - the LOC being based on one-tenth of the IDLH level, or one-tenth of an estimated IDLH derived from toxicity data, if no IDLH is available.

- **Lethal concentration (LC)**. A concentration by which a given percentage of the exposed population will be fatally injured. The $\mathbf{LC_{50}}$, refers to the concentration of airborne material the inhalation of which results in death of 50% of the test group. The period of inhalation exposure could be from 30 min to a few hours (up to 4 hours).

- **Lethal dose (LD)**. A dose by which a given percentage of the exposed population will be fatally injured. The $\mathbf{LD_{50}}$, refers to the quantity of material administered, either orally or by skin adsorption, which results in death of 50% of the test group.

- **One-Time Population Exposure Limit (EPEL)**. The EPEL is defined as the concentration to which the population, on the basis of present knowledge, can be exposed, once only in a lifetime, for a short duration (30 minutes to 2 hours), with, as a maximum consequence, a benign and reversible (curable) sickness phenomenon.

More recently, the USA-DOE Emergency Management Guide calls for the use of TEELs when ERPGs are not available. Furthermore, it is recommended that, for the application of TEELs, the air concentration be calculated as the peak 15 minute, time-weighted average.

It is customary to use a dose-response analysis in establishing the effect of toxic vapours and thermal radiation on human beings. Dose-response analysis aims to relate the intensity of the phenomenon that constitutes the hazard to the degree of injury or damage, which it can cause. *Probit Analysis* is possibly the method mostly used to estimate probability of death, hospitalisation or structural damage.

10.2.1 The Probit Consequence Model

The concept of the Probit Consequence Model is best described by way of an example for chlorine. Chlorine was used as a chemical agent during the First World War by both German and Allied forces to induce fatalities. Extensive research was conducted by the Germans at the Kaiser Wilhelm Institute, headed by Haber (see Lees, 1980). Haber's research incorporated the effectiveness of chemical agents on military troops, and used cats, rodents, dogs and monkeys in his experiments. An important finding, *Haber's Product Law*, was that the same toxic effect was obtained at the same value of the mortality product,

$$\chi t = \text{constant}$$

Where χ is the concentration and *t* is time.

Toxicologists now support the more general relationship of

$$\chi t^m = \text{constant}$$

or

$$\chi^n t = \text{constant}$$

for acute toxicity, where *m* is usually less than 1, and $n = 1/m$.

The dosage is related to the product law, defined by Equation 1, as follows:

$$dosage = D = \int \chi^n dt$$

This dosage could then be used to determine the acute (i.e. or lethal or non-lethal) effects.

In loss prevention and risk assessment it is necessary to relate the intensity of some phenomenon such as heat radiation from a fire, over-pressure from an explosion or toxic gas concentration from a toxic gas release to the degree of injury or damage that can result from it.

A distinction should be made between *dosage*, which is the concentration-time profile, and the *dose*, which is the amount actually retained and which depends on the breathing rate and the fractional retention. In this investigation, the dosage will be used to determine the severity of the exposure, whenever possible.

The probit (probability unit) *Y* is related to the probability *P* by the equation:

$$P = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{Y-5} \exp\left(-\frac{u^2}{2}\right) du$$

The *probit* is a random variable between 0 and 10, with a mean of 5 and variance of 1. So, for instance, a *probit* of 5 corresponds to a 50% probability. A *probit* of less than 2.7 corresponds to a 1% probability and a *probit* of 7.3, to a 99% probability. The probability-*probit* relationship is only near linear between 4 and 6, and curves sharply below 4 and above 6, respectively.

Once the *probit* is known, the probability of lethality may be obtained from the above relationship.

A general form of the *probit* function, applicable to toxic gas releases, is expressed as:

$$Y = A + B \ln D$$

Where *A* and *B* are constants. *D* is the measure of intensity of the causative factor, which harms the vulnerable resource, and in this case, the *dosage*.

10.2.2 The Effects from Thermal Radiation Exposure

Human fatality is a function of heat flux and exposure time. Lees (1980) reported such variations and those of Eisenberg *et al* (1975) are summarised in Table 10-2. Eisenberg et al expressed this information by the following probit equation

$$Y = -14.9 + 2.56 \ln(tI^{4/3} \times 10^{-4})$$

where,

Y	=	the probit
I	=	thermal radiation intensity (W/m^2)

Table 10-2 A summary of range of thermal flux levels and their potential effects (Eisenberg *et*

***al*, 1975).**

Heat Flux (kW/m^2)	**Seconds Exposure For % Fatality**		
	1%	**50%**	**99%**
1.6	500	1300	3200
4	150	370	930
12.5	30	80	200
37.5	8	20	50

The Eisenberg model has been the most widely cited and used, however, alternative models have also been proposed. Most notably, a set of relationships were developed in the *Green Book* (CPR 16E) for persons protected and unprotected by clothing:

$$Y = -36.38 + 2.65 \ln\left(tI^{4/3}\right)$$ - Unprotected

$$Y = -37.23 + 2.56 \ln\left(tI^{4/3}\right)$$ - Protected

where the symbols *Y* and *I* are the same as before.

The *Green Book* also gives relationships for non-fatal injury:

$$Y = -39.83 + 3.02 \ln\left(tI^{4/3}\right)$$ - First degree burns

$$Y = -43.14 + 3.02 \ln\left(tI^{4/3}\right)$$ - Second degree burns

where the symbols *Y* and *I* are the same as before.

Other models include that proposed by Lees (2001) and Prugh (Lees, 2001). Figure 10-1 is a comparison of the different models assuming an exposure of 30 seconds. The *Green Book* model for protected persons is clearly more conservative than both the Eisenberg and Lees models.

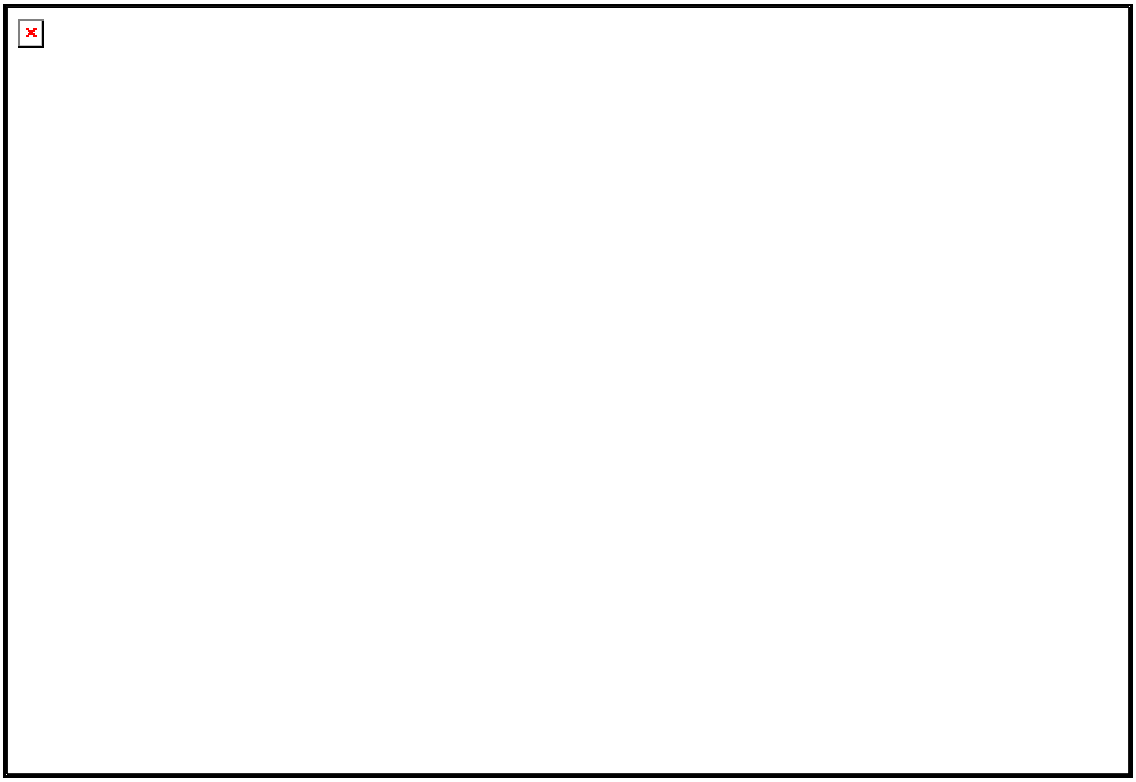

Figure 10-1: Illustration of the difference in predicting lethal thermal radiation levels.

Large fires could affect both humans and buildings (or equipment). Critical heat radiation levels are given in Table 10-3.

Table 10-3: A summary of range of thermal flux levels and their potential effects.

Heat Flux (kW/m^2)	Heat Flux
1.2	Received from the sun at noon.
2.1	Minimum to cause pain after 1 minute.
4.7	Will cause pain in 15 - 30 seconds and second-degree burns after 30 seconds.
12.6	30% chance of fatality for continuous exposure. High chance of injury. Wood can be ignited after prolonged exposure.
23	100% chance of fatality for continuous exposure to people and 10% chance of fatality for instantaneous exposure. Spontaneous ignition of wood after long exposure. Unprotected steel will reach thermal heat stress temperatures to cause failure.
35	25% chance of fatality if people are exposed instantaneously.
60	100% chance of fatality for instantaneous exposure.

10.2.3 Influence of Exposure and the Conditions of the Fire

When a fire gradually reaches its full extent, there is normally adequate time for nearby people to find safety. However, a sudden fire, without pre-warning, may not only be detrimental to nearby people, but also cause an obstruction to possible escape routes. Under such circumstances, the exposure duration would, in principle, be the same as the duration of the fire itself.

Escape from the fire is easier in areas in which few obstacles are present along the escape route, however, if shelter is sought, then the presence of buildings would be advantageous. In most cases, the presence of obstacles would be beneficial with regard to time requirements for finding adequate protection.

In urban areas and to a lesser degree, in built-up areas, the exposure duration is mainly determined by the time required to find an acceptable shelter. In open areas, the exposure duration depends on the time span required to escape to locations of harmless radiation level or a nearby shelter.

The Green Book (CPR 16E, 1992) and Lees (2001) reported on exposure durations ranging from as little as 10 seconds up to 60 seconds. However, both references indicate that these may be an overestimation, and that the duration may be considerably is less. The exposure is more likely the sum of the initial time required to react (about 5 seconds) plus the time required to reach a distance at which the radiation intensity is not higher than ~1 kW/m^2 (i.e. maximum solar heat radiation). The speed of escape has been quoted between 4 m/s and 6 m/s (Green Book 1992 and Hymes 1983, respectively). However, as a person escapes, the exposed heat radiation decreases and the effective "heat load" (product of exposure duration and heat radiation) reduces correspondingly.

A relationship is derived in the Green Book providing an estimate of the effective exposure, taking into account the reaction time and the time for escape to a safe distance.

10.2.4 The Effects from Vapour Cloud Explosions

An explosion may give rise to any of the following effects:

- Blast damage;
- Thermal damage;
- Missile damage;
- Ground tremors;
- Crater formation; and/or,
- Personal injury

These obviously depend on the pressure waves and proximity to the actual explosion. Of concern in this investigation are the “far distance” effects, such as limited structural damage and the breakage of windows, rather than crater formations. Table 10-4 is a more detailed summary of the damage produced by a explosion for various over-pressures (Clancey 1972). The most commonly used overpressure is the “0.3 psi” value. This corresponds to a “Safe Distance”, at which approximately 10% of glass windows are broken.

Table 10-4: A summary of damage produced by blast (Clancey, 1972).

Pressure (gauge)		Damage
Psi	kPa	
0.02	0.138	Annoying noise (137 dB), if of low frequency (10 - 15 Hz).
0.03	0.207	Occasional breaking of large glass windows already under strain.
0.04	0.276	Loud noise (143 dB). Sonic boom glass failure.
0.1	0.69	Breakage of windows, small, under strain.
0.15	1.035	Typical pressure for glass failure.
0.3	2.07	'Safe distance' (probability 0.95 no serious damage beyond this value). Missile limit. Some damage to house ceilings; 10% window glass broken.
0.4	2.76	Limited minor structural damage.
0.5 – 1.0	3.45 – 6.9	Large and small windows usually shattered; occasional damage to window frames.
0.7	4.83	Minor damage to house structures.
1.0	6.9	Partial demolition of houses, made uninhabitable.
1.0 – 2.0	6.9 – 13.8	Corrugated asbestos shattered. Corrugated steel or aluminium panels, fastenings fail, followed by buckling. Wood panels (standard housing) fastenings fail, panels blown in.
1.3	8.97	Steel frame of clad building slightly distorted.
2.0	13.8	Partial collapse of walls and roofs of houses.
2.0 – 3.0	13.8 - 20.7	Concrete or cinderblock walls, not reinforced shattered.
2.3	15.87	Lower limit of serious structural damage.
2.5	17.25	50% destruction of brickwork of house.
3.0	20.7	Heavy machines (1.4 tonne) in industrial building suffered little damage. Steel frame building distorted and pulled away from foundations.
3.0 – 4.0	20.7 – 27.6	Frameless, self-framing steel panel building demolished.
4.0	27.6	Cladding of light industrial buildings demolished.
5.0	34.5	Wooden utilities poles (telegraph, etc.) snapped. Tall hydraulic press (18 tonne) in building slightly damaged.
5.0 – 7.0	34.5 – 48.3	Nearly complete destruction of houses.
7.0	48.3	Loaded train wagons, overturned.
7.0 – 8.0	48.3– 55.2	Brick panels (20 – 30 cm) not reinforced, fail by shearing or flexure.
9.0	62.1	Loaded train boxcars completely demolished.
10.0	69.0	Probable total destruction buildings. Heavy (3 tonnes) machine tools moved and badly damaged. Very heavy (12 000 lb/5443 kg) machine tools survived.
300	2070	Limit of crater lip.

10.3 Setting of Risk Assessment Criteria

Among the most difficult tasks of risk characterisation is the definition of an *acceptable risk*. The distinction between risks, which are assumed voluntarily, and those, which are borne involuntarily, is a crucial one. The risk to which a member of the public is exposed from an industrial activity is an involuntary one. In general, people are prepared to tolerate higher levels of risk for hazards to which they expose themselves voluntarily. Kletz (1976) compiled some death rates resulting from well-studied risks.

Typical rates are given in Table 10-5.

Table 10-5: Death rates for some voluntary and involuntary risks (after Kletz 1976).

Risk	Fatality Rate *(Deaths Per Person Per Year)*
VOLUNTARY RISK:	(x 10^{-5})
Taking contraceptive pill	2
Playing football	4
Rock climbing	4
Car driving	17
Cigarette Smoking (20/day)	500
INVOLUNTARY RISK:	(x 10^{-7})
Meteorite	0.0006
Transport of petrol and chemicals (UK)	0.2
Aircraft crash (UK)	0.2
Explosion of pressure vessel (USA)	0.5
Lightning (UK)	1
Release from nuclear power station (at 1 km) (UK)	1
Run over by road vehicle	600
Leukaemia	800

Generally, people accept the relatively higher degree of risk of $1x10^{-5}$ per person per year (or *1 in a 100 000* chance) involved in many of the voluntary activities indicated in the table. Involuntary risks at the levels of $1x10^{-6}$ per person per year for natural disasters and $1x10^{-7}$ per person per year for man-made events appear to be acceptable. The involuntary risk rates suggest a level of risk to the public of between $1x10^{-6}$ and $1x10^{-7}$ per person per year as a possible criterion. This risk parameter may be compared with a statistically derived “acceptable” risk level. Although there is no clear-cut, acceptable involuntary risk, an evaluation of information presented above, suggests a risk of $1x10^{-4}$ and more chance of death per person per year could be considered “unacceptable” and must be reduced regardless of cost. A risk below $1x10^{-7}$ chance of death per person per year would be considered “acceptable” without further investigation or action.

Although still open to criticism, a considerable amount of progress has been made in establishing some risk criteria, notably in countries such as the Netherlands, the United Kingdom and Australia. The risk criteria used by the Dutch Ministry of Housing, Physical Planning and Environment are defined in the National Environmental Policy Plan (1989). The individual risk criteria, applied to the most exposed individual of the public, are:

Maximum Permissible Risk	$1x10^{-6}$ per year
Negligible Risk	$1x10^{-7}$ per year

Similarly, the risk criteria used by the United Kingdom Health & Safety Executive (HSE 1992) have been defined as follows:

Maximum Individual Tolerable Risk for Workers	$1x10^{-3}$ per year
Maximum Individual Tolerable Risk for the Public	$1x10^{-4}$ per year
Broadly Acceptable Maximum Individual Risk	$1x10^{-6}$ per year

It must be made clear that tolerability is not the same as acceptability.

> *"Tolerability refers to a willingness to live with a risk so as to secure certain benefits and in the confidence that it is being properly controlled. For a risk to be acceptable … means that we are prepared to take it pretty well as it is"* (HSE, 1992)

In a more refined attempt to account for risks in manner similar to those used in everyday life, the UK HSE developed the "risk ALARP triangle". This involves deciding:

- Whether a risk is so high that something must be done about it;
- Whether the risk is, or has been made, so small that no further precautions are necessary; or
- If a risk falls between these two states, that it has been reduced to levels as low as reasonably practicable (ALARP).

This is illustrated graphically, shown in **Figure 5-4**, below. ALARP stands for "*As Low As Reasonably Practicable*". As used in the UK, it is the region between that which is intolerable, at $1x10^{-4}$ per year, and broadly acceptable level of $1x10^{-6}$ per year, with a further lower level of risk of $3x10^{-7}$ per year being applied to either vulnerable or very large populations for land use planning.

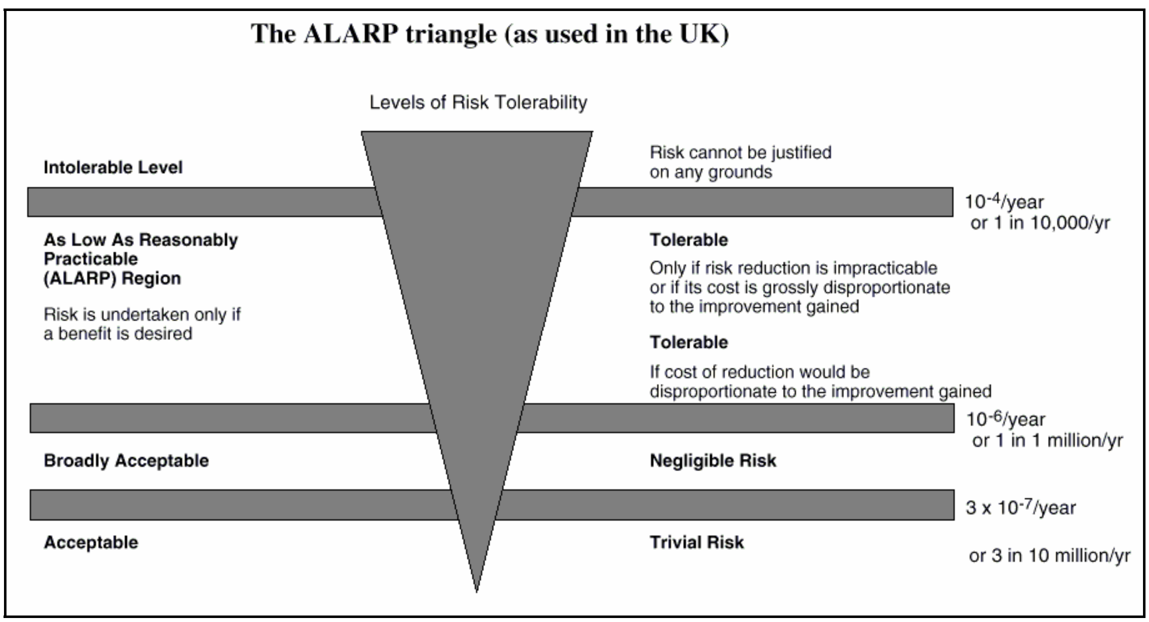

Figure 10-2: Decision making framework

10.3.1 Land-use Planning Criteria

The development of land in the vicinity of a hazardous installation should obviously take cognisance of the potential risk posed by its presence. Land-use guidelines, based on the probability of death, provide a valuable precaution to reduce the risk to nearby public, in addition to other measures controlling the risk on the pipeline itself.

Although Mozambique does not specifically prescribe risk levels, or guidelines, for planning purpose, it is normal to use a ranking system to define buffer zones around potential hazardous installations. The objectives of land-use planning controls should be based on the potential risk posed by the development. For instance, the possibility of exposure to toxic fumes (e.g. chlorine) may require slightly different mitigation measures than the possibility of being exposed to a fire or a vapour cloud explosion. However, all planning guidelines have the following objectives in common:

- To discourage inappropriate developments near a potential hazard installations; and,
- To attempt to structure growth so that developments involving small numbers of less vulnerable members of the public nearby the site are encouraged, whilst the largest developments involving the most vulnerable and sensitive are kept further away.

Development categories are used to represent the full range of different possible developments. The approach categorises developments according to several factors that determine the appropriate risk level:

- The inherent vulnerability of the exposed population;
- The proportion of the time and individual spends at the development;
- The size in terms of the number of people who may be present
- Whether they are likely to be in or out of doors and, if out of doors, how easily they might seek shelter;
- The ease of evacuation or other emergency measures;
- The construction of the building and the protection available to the harmful agent.

The UK Health and Safety Executive (HSE 1989) have developed a land-use planning guideline, dividing the land use into four categories, as summarised in Table 10-6 below.

Table 10-6: Land-use development categories.

Category	Description
A	Housing, hotel and holiday accommodation. These are developments in use for 24 hours a day with an average mix of healthy, unhealthy, young and old. The building provides some protection against hazards. Two population densities apply: a) Greater than 25 people b) Greater than 75 people
B	Some workplaces (e.g. parking areas, etc.) incorporating developments where the occupants would tend to be fit and healthy, and could be organised easily for emergency action - less than 100 occupants.
C	Retail, community and leisure. This includes small shops and community

	facilities where members of the public are present, but not resident – less than10 units. They may be in or out of doors, possibly in large numbers. Emergency action would be difficult to co-ordinate.
D	Highly vulnerable or very large facilities. Vulnerable facilities include hospitals, homes for the elderly, schools etc. Very large facilities are typically retail parks or shopping centres – more than 1000 people outdoors.

Furthermore, the levels of risk, which are considered significant enough such that a particular development should be opposed, are given in Table 10-7 below.

Table 10-7: Levels of risk at which development should be opposed

Development	Significant Risk
A	a) Less than 1 x 10^{-5} per year b) Less than 1 x 10^{-6} per year
B	No maximum risk level specified, but assumed that the risk of injury from major hazard is substantially less than risk of occupational injury, i.e. less than 1x10^{-3}
C	No specific criteria given; probably of the same order as Category A (b), i.e. 1 x 10^{-6} per year
D	Less than 3 x 10^{-7} per year

A similar manner of expressing acceptable risk levels also exists in Australia. The New South Wales Department of Urban Affairs and Planning (NSW 1990) has published acceptable risk levels for a new installation to which members of the public can be exposed (Table 10-8). The risk levels relate to a hypothetical person located permanently at the site boundary. The injury criteria are based on exceeding certain threshold levels of fire radiation, explosion overpressure or toxic gas concentrations.

Table 10-8: New South Wales Department of Urban Affairs and Planning (NSW 1990) Risk Criteria.

Parameter		Acceptable Risk (Per Million Per Year)
Fatality	Hospitals, schools, child care facilities and old age homes	0.5
Fatality	Residential area	1
Fatality	Commercial developments, retail centres, offices and entertainment centres	5
Fatality	Sporting complexes and active open space	10
Fatality	Industrial sites	50
Injury	Exceed 4.7 kW/m^2 in residential areas	50
Damage	Exceed 23 kW/m^2 in adjacent industrial facilities	50

10.3.2 Societal Risk Criteria

The risk criteria discussed so far are for individual risks. Societal risk criteria may similarly be treated as a single criterion or of two criteria curves, dividing the space into three regions, i.e. where the risk is unacceptable, where it is negligible and where it requires further assessment. This is similar to the ALARP principle, discussed in the previous section.

The Netherlands have developed a number of criteria primarily for use in risk assessments of factories (e.g. the Provinciale Waterstaat Groningen promulgated a criterion in 1979 and a more recent set of given by Ale 1991). Although societal risks are calculated in the UK, there are currently no formal criteria to judge its acceptability.

However, cannot be used without taking into account the physical extent of the risk, i.e. the road length. A slightly modified societal risk criteria has been adopted in the Netherlands, which is expressed per pipeline kilometre. This criterion is as follows: a risk of 10^{-4} per year per km for ten fatalities, a risk of 10^{-6} per year per km for 100 fatalities, and so on.