11. HAZARD ASSESSMENT

11.1 Introduction

11.1.1 Aims of the Assessment

This section presents the findings of the hazard assessment undertaken in relation to the presence of the existing Towngas pipelines and their interface with the proposed MOS Extension railway alignment.

This study is based on the Consultant's identification of the interfaces between the two alignments as required for the hazard assessment study.

The aims of this study are to examine the risks presented by the interfaces and identify risk mitigation measures for consideration during detailed design if risks are unacceptable.

11.1.2 Background to the Assessment

The Preliminary Environmental Review (PER) for the MOS Extension included a brief description of the various external hazards that had the potential to impact upon the proposed railway extension. The external hazards considered in the PER were hazards from LPG storage facilities, Petrol Filling Stations, the transport by road of Dangerous Goods, and the presence of the Towngas pipelines. Of these, the PER identified the hazards posed by the Towngas pipelines along the proposed railway route as being the major concern and recommended these for further assessment.

Accordingly, the EIA Study Brief required that a hazard assessment in relation to the Towngas pipeline system be undertaken following the criteria and guidelines for evaluating and assessing hazard to life as stated in Annex 4 of the TM.

11.1.3 Objectives of the Assessment

The main objective of this study is to examine the hazards posed by the construction and operation of the railway which may threaten the integrity of the gas pipelines. The study also assesses the hazards posed to passengers using the MOS Extension due to the proximity of the Towngas pipelines which run along, and in some sections across, the alignment. The assessment also takes into account the potential effects upon populations within new residential estates/developments that are to be constructed as part of the railway development schemes.

The study determines whether the risks posed by the gas pipeline to the proposed railway development are within the acceptable limits of the Hong Kong Risk Guidelines. Otherwise, mitigation measures are proposed.

11.1.4 Scope of Work

The EIA Study Brief states that the following objectives are to be satisfied during the hazard assessment:

- notify and seek the views from the gas supply company in relation to any proposed railway alignment and associated development in the vicinity of gas pipelines;
- conduct a study to identify and evaluate the extent of any potential impact or cumulative effect arising during the construction and operation of the proposed project, which is likely to threaten the integrity of the gas pipelines or the associated facilities, in the vicinity of the proposed railway alignment, depots or stations, including areas such as :
    - the effects of stray current inducted by the railway system on the corrosion protection system of the gas pipeline in the vicinity;
    - the effects of vibration induced during the construction and operation of MOS Extension;
    - the effects of any additional structural loading caused by any construction directly above the gas pipelines;
- include a Quantitative Risk Assessment expressing population risks in both individual and societal terms;
- compare the individual and societal risks with Government Risk Guidelines and comment on the acceptability of the assessed risk;
- identify risk management strategies required to render the risks acceptable;
- determine the social perception and acceptability of the potential risks;
- identify and assess practicable and cost effective risk mitigation measures.

The main focus of the study is on high pressure pipelines which pose the greatest hazard. Pipelines operating at lower pressures however, are also identified for consideration during the detailed design.

11.2 Brief Description of the proposed Railway

A general description of the proposed railway is included in the main *Section 2* of this report. The aspects of development and railway operations that are particularly relevant for the hazard assessment study are included in the following paragraphs.

All of the proposed stations will be on elevated structures. The concourses and platforms in the stations Sha Kok Street, City One, Chevalier Garden, Heng On and Ma On Shan (platform only) will have an 'open design' such that natural ventilation is adopted. The remaining stations at Tai Wai, Sha Tin Tau, Shek Mun and Lee On will be located either under or adjacent to the proposed property developments, and as such, these stations will be covered with one trackway semi-open to the atmosphere. Mechanical ventilation will be adopted at these stations.

The MOS Extension will operate between 0530 to 0100 hours. During the non-operating hours, works trains will operate to undertake routine maintenance. The traction power will be provided by a 25kV ac system. The MOS Extension will be equipped with Automatic Train Operation (ATO) capable of operating up to 30 trains per hour in each direction. The design of the ATO system will also allow fall back to Automatic Train Protection (ATP) mode by manual driving in case of ATO failure. Bi-directional signalling will be provided so that in case of blockage or failure of a section of one of the tracks, the other track can be used for bi-directional single-line working with the use of the emergency crossovers at reduced frequency.

The MOS Extension will initially operate with 4 car trains (which may be increased to 8 cars in later years depending on patronage). Each car is designed to carry a maximum of 287 passengers. The maximum number of passengers per train could therefore be as high as 1148 (based on 4-car operation).

The traffic projections for the initial year of operation in 2003 and for the year 2011 are given in *Table 11.2a*. These are based on the patronage data provided by KCRC in December 1998 [1]. The patronage data are provided in terms of AM peak hour flows and daily flows. Initially, during peak hours, trains will operate at a frequency of 2.5 minutes; this will increase to a frequency of 2 minutes in 2011. Peak hours are considered to be the busiest 2 hours in the morning (called am peak) and the busiest 2 hours in the evening (called pm peak). During off-peak hours, the frequency of the train service will be 6 minutes.

The data on number of passengers in and out of the proposed Chevalier Garden station (which is of interest to this study due to the stations proximity to the HP pipeline) during AM peak hour and daily [1] is given in *Table 11.2b.*

As part of the overall MOS Extension scheme, there are likely to be residential developments associated with the following stations. The precise details of the nature of these residential developments are not known at this stage.

- Tai Wai Depot;
- Sha Tin Tau Station;
- Shek Mun Station;
- Heng On Station; and
- Lee On Station.

Table 11.2a AM Peak Hour and Daily Flows for MOS in Years 2003 and 2011

Year 2003

Stations		AM peak						Daily	Offpeak		
		Northbound			Southbound			Each direction	Each direction		
From	To	Total	per train	per car	Total	per train	per car	Total	Total	per train	per car
TAW	STT	11000	458	115	27000	1125	281	122000	46000	297	74
STT	SKS	11000	458	115	25000	1042	260	114000	42000	271	68
SKS	CIO	9000	375	94	19000	792	198	89000	33000	213	53
CIO	SHM	6000	250	63	13000	542	135	64000	26000	168	42
SHM	CHG	6000	250	63	12000	500	125	63000	27000	174	44
CHG	HEO	5000	208	52	11000	458	115	54000	22000	142	35
HEO	MOS	3000	125	31	6000	250	63	32000	14000	90	23
MOS	LEO	2000	83	21	3000	125	31	16000	6000	39	10

Year 2011

Stations		AM peak						Daily	Offpeak		
		Northbound			Southbound			Each direction	Each direction		
From	To	Total	per train	per car	Total	per train	per car	Total	Total	per train	per car
TAW	STT	14000	467	117	32000	1067	267	151000	59000	381	95
STT	SKS	12000	400	100	30000	1000	250	143000	59000	381	95
SKS	CIO	11000	367	92	23000	767	192	115000	47000	303	76
CIO	SHM	9000	300	75	17000	567	142	87000	35000	226	56
SHM	CHG	7000	233	58	17000	567	142	83000	35000	226	56
CHG	HEO	6000	200	50	14000	467	117	68000	28000	181	45
HEO	MOS	4000	133	33	8000	267	67	43000	19000	123	31
MOS	LEO	2000	67	17	5000	167	42	23000	9000	58	15

Notes:

1\. Station legend : TAW - Tai Wai; STT - Sha Tin Tau, SKS - Sha Kok Street, CIO - City One,
SHM - Shek Mun, CHG - Chevalier Garden, HEO - Heng On, MOS - Ma On Shan, LEO - Lee On

2\. No. of trains per hour during peak assumed as 24 in the year 2003 and 30 in the year 2011.

3\. No. of trains per hour during off-peak assumed as 10 for the year 2003 and 2011.

3\. 4 hours of peak operation & 15.5 hours of off-peak operation assumed per day.

4\. The number of trains per day is derived as 4 x 24 + 10 x 15.5 = 251 in the year 2003.

5\. No. of cars per train is 4.

6\. Traffic for off-peak hour is derived from daily flow for one direction minus twice the am peak hour flow for both directions

Table 11.2b Passenger Flow through Chevalier Garden Station

	Year 2003	Year 2011
AM peak		
No. of passengers per hour - in	3000	4000
- out	1000	2000
No. of trains per direction	24	30
No. of passengers per train in both directions:		
- boarding	125	133
-alighting	42	67
-total	167	200
Daily total	26,000	38,000
Off-peak	10,000	14,000
Total no. of passengers		
No. of passengers per hour	666	933
No. of passengers per train in both directions - boarding & alighting	66	93

11.3 Brief Description of Towngas Pipeline

11.3.1 The Towngas Network

The Hong Kong and China Gas Company (HKCG) operate the Towngas network for the supply of gas to domestic and industrial consumers. The gas which is a mixture of hydrogen, methane and carbon dioxide is produced at the plant located in Tai Po and is supplied through a network of high pressure transmission pipelines (operating at 35 bar) to Shatin, Tai Po Tsai, Tuen Mun and to Lantau Island via Tsuen Wan. The gas in the high pressure pipeline enters either the intermediate pressure network (IPB, 4 to 7 barg) or the medium pressure network (MP, 7.5 to 240 kPa) via offtake stations. IPB is further stepped down via pressure reduction stations to lower intermediate pressure (IPA, 240 to 400 kPa) or MP level to supply local areas. The MP level form the major reticulation network in built-up areas. Before the gas is supplied to the consumers, the pressure is stepped down to low pressure level (either LPA, below 2kPa, or LPB, 2 to 7.5 kPa) through the various district governors.

11.3.2 Pipelines in Proximity to Proposed Railway

The pipeline network located in the vicinity of the proposed railway development (considered as 100 m on either side of the railway for the purpose of this study) include HP, IPB, MP and LP pipelines. A further IPB pipeline is also proposed to be located in the vicinity of the MOS Extension alignment. The identification of pipelines in the vicinity of the railway has been undertaken by the Consultants based on pipeline alignment drawings provided by HKCG which were then overlaid on railway alignment drawings provided by KCRC. This exercise has been undertaken solely for the purpose of hazard assessment and it is expected that the consultant appointed by KCRC for the detailed design studies will carry out an independent study of the Towngas and MOS Extension interfaces to confirm the above.

The HP pipeline to Shatin originates at the Tai Po Gas Production Plant and runs subsea along Tolo Harbour and Shing Mun River to the offtake station at the landfall point in City One, Shatin. At the off-take station, the pressure is stepped down to between 2.4 to 7 barg, to supply to the IPB network which supplies Kowloon and Hong Kong Island. The high pressure pipeline however, continues after the landfall point towards Ma On Shan alongside Tate's Cairn Highway and Sai Sha Road. The length of the HP pipeline from the off take station to Ma On Shan is around 5.9 km of which 2.3 km lies in the vicinity of the proposed railway between Shek Mun station and Chevalier Garden station. Between these stations, the HP pipeline runs parallel and to the west of the railway alignment until reaching Tai Shui Hang nullah where the HP pipeline crosses and then diverges from the railway alignment. Along this section, the railway alignment is also in the vicinity of the subsea HP pipeline, however as it is more than 150 m away, it is not considered further in this study. The location of HP gas pipeline with respect to the railway alignment is shown in *Figure 11.3s - Annex H, Volume 2 - Technical Annexes* between Shek Mun station and Chevalier Garden station.

Based on the traffic projections for the MOS Extension given in *Table 11.2a*, for the year 2003, the number of passengers travelling between Shek Mun and Chevalier Garden stations is predicted to be 500 per train (ie, 125 per car) towards Shek Mun and 250 per train (ie, 63 per car) towards Chevalier Garden during am peak hour and 174 per train (ie, 44 per car) in either direction during off-peak hours. For the year 2011, the number of passengers is predicted to be 567 per train (ie, 142 per car) towards Shek Mun and 233 per train (ie, 58 per car) towards Chevalier Garden during am peak hour and 226 per train (ie, 56 per car) during off-peak hours.

The HP pipeline lies close to the proposed Chevalier Garden station. Although no residential development is proposed at this station, there will be passengers at the station waiting to board the train or exiting the concourse after alighting. Based on data in *Table 11.2b*, the number of passengers at the station at any point of time is 167 during peak hours for the year 2003. During off-peak hours, the number of passengers at the station is assumed to be 33 based on passengers boarding and alighting from one train.

The HP pipelines, IPB pipelines and MP pipelines are found in close proximity to the proposed railway at various sections along the route. Of particular concern are the interfaces between the IPB/MP pipelines and the proposed railway which may result in conflict (eg where the Towngas pipeline crosses the rail alignment). In these situations, the conflict will require resolution during detailed design stage, possibly through the relocation of the pipeline or other measures. Such interfaces are highlighted in *Table 11.3a.*

The proximity of IPB/MP pipelines to the proposed railway, in terms of the length of pipeline within varying distances from the proposed MOS Extension alignment, is shown in *Table 11.3b.*

The locations of all the pipelines with respect to the railway are mapped in *Figures 11.3a-r* included in *Annex H of Volume 2 - Technical Annexes.*

Table 11.3a Interfaces between IPB/MP Pipelines and Railway

Pressure level	Nature of Interface
MP	2 crossings - one, upline of Tai Wai station and the other, under Tai Wai Station
IPB	Pipeline within 5m of railway upline of Sha Tin Tau station; also crossing under Sha Tin Tau station
IPB (proposed)	3 crossings - upline of City One station, under City one station and under Shek Mun station
MP	crossing downline of City One station
MP	2 crossings between Shek Mun station and Chevalier Garden station
MP	crossing under Heng On station
MP	crossing between Heng On station and Ma On Shan station
MP	crossing between Ma On Shan station and Lee On station
MP	crossing upline of Lee On station
MP	crossing of over-run tracks up-line of Lee On station

Note : Upline/downline is with reference to train movement from Tai Wai to Lee On.

The study's main focus is the railway's proximity to the 600 mm diameter HP pipeline (along Tate's Cairn Highway) due to the hazards posed by the high pressure of the gas and the associated consequences (ie mainly intense fires) in the event of a release.

Table 11.3b Proximity of Major Towngas Pipelines to the Rail Alignment

Pipeline (diameter)	Length of Pipeline (m)			
	< 5m	< 15m	< 50m	< 100m
HP600mm	15	350	2055	2278
IPB600mm	180	455	1145	4808
IPB750mm (proposed)	385	1155	2200	3182
MP400mm	162	735	3165	3695

Pipeline (diameter)	Length of Pipeline (m)			
	< 5m	< 15m	< 50m	< 100m
MP300mm	141	245	2220	2320

11.3.3 Pipeline Design Parameters

The composition and physical properties of Towngas are given in *Table 11.3c.*

Table 11.3c Gas Composition & Other Physical Property Data

Parameter	Details
Composition	
Hydrogen	48.1% (all by vol.)
Methane	29.4%
Carbon dioxide	19.5%
Carbon monoxide	3%
Average molecular weight	15.11 kg/kmole
Specific heat ratio	1.344
Heat of combustion	17.27 MJ/m^3 (28 MJ/kg)

The HP pipeline is constructed of steel, of specification API 5L X 52, in accordance with the design code IGE/TD/1 [2]. The nominal wall thickness for the pipe is 12.7 mm while the maximum allowable operating pressure (MAOP) is 35 barg. The pipeline meets the requirement for a design factor of 0.3 in built-up areas recommended in the various codes [2, 3& 4]. The pipeline is provided with internal epoxy coating, external fusion bonded epoxy coating, cold applied wrapping tape and cathodic protection by sacrificial magnesium anode. Cathodic protection by impressed current is provided only for the submarine section of the pipeline. A minimum earth cover of 1.1 m is generally provided for pipelines on land. The leak detection system uses low pressure sensors at above ground installations (AGIs). If required, the operator can initiate remote shutdown of valves at AGIs. IPB pipelines although operated at very low pressures (< 7 barg) have similar design specifications (material, pipe thickness etc) as the HP pipelines. The high level of safety margin provided for IPB is in view of the proximity of these pipelines to heavily built-up areas that are unique to Hong Kong. In addition to remote isolation at AGIs, manual isolation of intermediate sections in the HP and IPB network can also be achieved through manual ball valves located in underground chambers.

The MP/LP pipelines may be constructed of steel in some sections (such as road crossings or within the carriageway) although they are generally of polyethylene material (in the case of recent and new installations) or ductile iron (in the case of older installations). All three types of pipe material are found in the section of interest to this study. Cathodic protection is provided only for the steel sections. The earth cover for MP/LP pipelines is generally 0.45 m; for sections within the carriageway, it is 0.9 m. For special locations such as road crossings, railroad crossings or in locations where depth is not sufficient, additional protection such as steel casing and steel capping are provided for HP, IPB and MP pipelines.

11.4 Review of Codes of Practice

A brief review of the design codes for high pressure pipelines is provided below to highlight the various provisions that apply when pipelines are laid in proximity to a railway.

ASME B31.8 [3] specifies a design factor which is the same as that for the location class (except for location class 1), for pipeline crossing railroads or for parallel encroachment of pipelines and railroads (parallel encroachment is defined as that portion or the route of the pipeline which lies within, runs in a generally parallel direction to and does not necessarily cross the rights-of-way of railroads). For location class 3 and class 4 (which correspond to sub-urban and built-up areas respectively), design factors of 0.5 and 0.4 are recommended. It is also recommended to provide casings to withstand the superimposed loads for pipelines under railroads. An earth cover of 0.9 m is recommended.

BS 8010, section 2.8 [4] specifies the following for rail crossings of methane and hydrogen gas pipelines:

- an earth cover of 1.4 m between the top of the pipe or sleeve and the top of the rail for open cut crossings;
- a design factor of 0.3;
- nominal wall thickness of 11.91 mm or greater without impact protection;
- all the above requirements to apply for crossings and parallel encroachments (which is 15 m for methane pipeline operating at 35bar).

Based on the above, it can be said that the Towngas HP pipeline is mostly in conformance with the design criteria for parallel encroachments.

11.5 Other Populations in the Vicinity of Interfaces Between the HP Pipeline & MOS

The Risk Guidelines require that the risks to the proposed development (ie the MOS Extension) are considered together with the risk to existing developments. Consequently, in addition to the users of the MOS Extension, existing residential and road traffic populations in the vicinity of the HP gas pipeline who may be exposed to the hazards of the HP gas pipeline are also of interest to this study. The main residential and road developments in the vicinity of the 2.3 km section of the MOS Extension interfacing with the HP gas pipeline are given in *Table 11.5a*.

Table 11.5a Population in the Vicinity of Interface between HP Pipeline & MOS

Population Type	Distance from HP Pipeline (m)	Population
Residential Estate (Garden Vista)	200	2500
Residential Estate (Garden Vista)	150	2500
Residential Estate (Pictorial Garden Stage 1)	110	2880
Residential Estate (Pictorial Garden Stage 2)	75	2500
Residential Estate (Pictorial Garden Stage 2)	35	2500
Open Space in front of Pictorial Garden Stage 1	85	140
Open Space in front of Pictorial Garden Stage 2	40	125
Shatin Hospital	105	2000
Playground	65	20
Shatin Fisherman's New Village	75	576
Shatin Fisherman's New Village	100	864
School	50	1000
Tate's Cairn Highway (AADT = 67480)	10-20	500
Ma On Shan Road (AADT = 29990)	20-100	300

Note : AADT refers to Annual Average Daily Traffic which is published by Transport Department.

11.6 Consideration of Time Periods

Representative time periods are used to match as closely as possible the variations in levels of activity and the corresponding variation in population in the study area with time. *Table 11.6a* shows the time periods considered for the background population (ie residential and road traffic populations) while *Table 11.6b* shows the time periods considered for rail traffic.

Table 11.6a Definition of Time Periods for Background Population

Time Period	Definition	Proportion of Time
Night	9pm-7am	42%
Day	9am-5pm & 7pm-9pm	42%
Rush hour	7am-9am & 5pm-7pm	16%

The following assumptions are made regarding the distribution of population :

- for residential areas, the night time population is 100% of the total estimated population while the day and rush hour populations are both assumed to be 50% of the total estimated population. 10% of the estimated population is assumed to be in the open space in front of the residential blocks;

- for schools, the daytime population is assumed as 100% of the total estimated population while the night & rush hour populations are assumed to be zero;
- for Shatin Hospital 100% of the estimated population is assumed to be present at all times;
- for roads, traffic is assumed to be free flowing during day and night and therefore the population density is based on the AADT.

Table 11.6b Definition of Time Periods for Rail Traffic

Time Period	Definition	Proportion of Time
Night	0100-0530 hrs	19%
Off-peak	0530-0700hrs, 0900-1700hrs & 1900-0100hrs	65%
Peak	0700-0900hrs & 1700-1900hrs	16%

During night time, no passenger trains will operate on the MOS Extension. Works train and maintenance crews at specific sections of the track may, however be present. The number of passengers and the frequency of the train service will vary during peak and off-peak as explained earlier.

11.7 Meteorological Data

Windspeed, wind stability and direction data (based on information recorded at the Hong Kong Observatory station at Sai Kung) which has been adopted for modelling dispersion of gas releases is given in *Table 11.7a* of *Annex H* in *Volume 2 - Technical Annexes.*

11.8 Hazard Identification

11.8.1 Approach

This section of the report identifies the main hazards arising out of the proposed railway development in proximity to the high pressure (HP) gas pipeline (at 35barg). Pipelines operating at pressures less than 7 barg (ie, IP, MP and LP pipelines) are permitted to be laid in urban areas. This is in accordance with the international design codes [3,4] and is also the practice world-wide. The risks from these low pressure pipelines are considered to be acceptable according to the individual and societal risk criteria of the EIA Technical Memorandum. Furthermore, in Hong Kong, the design parameters for IP (7barg) pipelines are more stringent than specified in the design codes and are comparable to the design parameters for HP pipelines as explained in Section 11.3.3. Considering the above factors, this study has focused mainly on risks from the high pressure pipeline.

The hazards due to the interface between the railway and the gas pipeline include the following considerations:

- the hazards posed by the presence of the gas pipeline to the passengers using the railway (in addition to the existing residential and road traffic population); and
- the hazards posed by the construction and operation of the railway which may threaten the integrity of the pipeline.

The main approach to hazard identification relies on the Consultant's experience and understanding of the pipeline and railway operations. Reference to world-wide incident databases have also been made in identifying the potential hazards.

11.8.2 Main Hazards From the Gas Pipeline

The main hazard from the pipeline is loss of containment leading to a gas leak, fire, explosion and toxicity. The gas is flammable/explosive due to presence of methane, hydrogen and carbon monoxide. The gas is also toxic due to presence of carbon dioxide and carbon monoxide.

The loss of containment incidents could occur irrespective of the railway development. Therefore, the hazards to the railway operations due to such incidents are considered in this study in the same manner as any other development / population in the vicinity of the gas pipeline.

The hazards from the pipeline transport of gas are well understood based on extensive historical experience world-wide relating to pipeline transportation of oil and gas.

Loss of Containment Incidents

The principal causes for loss of containment, based on an analysis of world-wide incident databases, are:

- pipe corrosion - internal and external;
- third party interference due to work on other underground utilities, drilling for ground sampling, construction work on adjoining areas etc;
- pipe material defect;
- pipe construction defect;
- improper operations of the pipeline system;
- pipe defect caused by pressure cycling;
- external - flooding, subsidence etc.

The incident databases referred to in this study include the US Natural Gas Pipelines Database 1985 to 1994 [5] and the European Gas Pipelines Database 1970 to 1992 [6]. Further details are included in *Section 11.9.*

The causes listed above are external to the development of the MOS Extension and therefore could be considered as inherent to the gas pipeline system irrespective of the proposed railway development (factors due to railway development are included in later paragraphs). Loss of containment incidents could however affect rail passengers and workers and also the railway infrastructure where the railway development lies within the hazard zone of the gas pipeline. As shown in *Table 11.3b*, the proposed railway will lie within 50 m of the HP gas pipeline for a length of over 2 km.

Flammable & Toxic Effects of Towngas

Flammable effects

Town gas contains hydrogen, methane and carbon monoxide which are flammable.

The lower flammability limits (LFL) for hydrogen, methane and CO is given below:

LFL for hydrogen	:	4% (vol)
LFL for methane	:	5.3% (vol)
LFL for CO	:	12.5% (vol)

CO_2 does not contribute to flammability. The LFL for the gas mixture is estimated as 5.5%.

Toxicity

Town gas contains carbon dioxide and carbon monoxide which are toxic. Carbon dioxide is usually considered as a simple asphyxiant, although it is also a potent stimulus to respiration and both a depressant and excitant of the central nervous system. Concentrations of 20 to 30% result in unconsciousness and convulsions within 1 minute of exposure [7].

Carbon monoxide is a chemical asphyxiant. It combines with haemoglobin in the blood, thus displacing oxygen.

The IDLH (Immediately Dangerous to Life and Health) value for CO is 1200ppm while for CO_2 it is 4% [8].

The concentration corresponding to 1% fatality can be derived from probity equations assuming an exposure time of 10 minutes to 30 minutes. The probity equation for CO [9] is

$$Pr = -37.98 + 3.7 \ln Ct$$

The probity value for 1% fatality is 2.67. The concentration corresponding to 10 min and 30 min exposure for 1% fatality is given in *Table 11.8a*. Since the concentration of CO in the gas is only 3%, the equivalent concentration of the gas mixture is also derived, as shown in *Table 11.8a*.

Table 11.8a CO Concentrations Corresponding to 1% Fatality

Exposure time	Actual concn. of CO	Corresponding concn. of gas mixture
10 min	5907 ppm	19.69%
30 min	1969 ppm	6.6%
IDLH value	1200 ppm	4%

The concentration for 1% fatality corresponding to 30 minutes exposure is adopted to estimate toxic effects on residential populations. However, toxic effects are not considered for rail traffic since the gas is likely to be ignited by the train motion. Even if the gas cloud is not ignited, the duration of exposure for a passenger in a moving train provided with ventilation is limited and therefore unlikely to have any significant effects.

11.8.3 Main Hazards From the Proposed Railway Development

The main hazards from the proposed railway development both during construction and operation of the railway arise, from the proximity of the railway to the gas pipeline in general and in particular, from the crossings between the two alignments.

The proximity of the railway to gas pipelines operating at various pressures (HP, IBP and MP) is highlighted in *Table 11.3b* while sections where the two alignments cross each other are highlighted in *Table 11.3a*. The main focus of this study is the proximity of the railway to the HP gas pipelines.

Interfaces Between Railway and Pipeline

It is found that the existing HP pipeline alignment may interfere with the proposed viaduct foundations at the crossing near Tai Shui Hang Nullah. Under such cases, it may be possible to space the viaduct foundations in such a manner that conflict with the pipeline alignment is avoided.

If the conflict cannot be resolved through the detailed design of the viaduct foundations, it may be necessary to relocate the gas pipeline. Such a scenario would require the resolution of various issues associated with relocation of the pipeline at a later stage subsequent to the formulation of the detailed proposals. (It should be noted that, if necessary, for public infrastructure development projects such as railway, roads etc. utilities, including gas pipelines, are routinely relocated).

Relocation of the pipeline may also be required at station locations where a number of structures are to be erected since the foundation may interact with the existing Towngas pipelines (the interfaces of the MP and IPB pipelines are highlighted in *Table 11.3a*). Any relocation, be it from the interface with viaduct or station foundations, will involve the consideration of alternative alignments, the construction of the revised pipeline alignment, and the tie-in with the operating pipeline. These factors will need to be addressed and undertaken without causing undue disruption to the supply of gas either during the construction works or following the opening of the railway, and without causing undue risks to population in the vicinity including construction workers.

HKCG who will be responsible for undertaking pipeline relocations are expected to adopt necessary safety measures in accordance with the standard procedures and guidelines for relocation.

A brief description of the hazards resulting from the construction and operation of the MOS Extension are included in the following paragraphs. It is proposed that a hazard and operability study (or other systematic hazard identification techniques) be conducted during the detailed design to examine the various issues resulting from the interfaces between the railway and the pipelines both during construction and operation of the MOS Extension, including relocation of the pipelines.

Hazards During Construction of the Railway

Hazards during construction will principally arise from accidental damage to the pipeline during excavation, and damage caused by excessive loading and associated vibration due to the use of heavy duty machinery and/or piling in the vicinity of the pipeline. The greatest potential for these hazards exists at the crossing near Tai Shui Hang Nullah. At other locations, the pipeline is about 15 to 25m away from the railway development and therefore will not be affected by the construction activity.

The construction of the railway viaduct will involve the following activities:

- Site preparation and clearance;
- Construction of pier foundation. Pile foundation with a pile cap will be used. Typically, 4 (or possibly up to 8) large bored piles each of diameter 1 to 1.5 m will be excavated to several metres and back filled with cast in situ concrete. Pile caps will be cast in situ. These will require excavations of around 2 m to 4 m below ground over an area of approximately 6 m by 6 m, or could be larger around 10 m by 10 m. This will be followed by construction of the pier involving formwork, reinforcement, concreting and scaffolding; and
- Superstructure erection. This would involve the erection of pre-cast concrete box girders which are typically 2.5 m deep and have a span of 30 to 40 m. These pre-cast units will be delivered to the workface by special vehicles using part of the structure already completed. The precast units are then placed in position using an erection gantry supported on the piers.

At the crossing near Tai Shui Hang Nullah, it is anticipated that not more than one pier foundation will be constructed in the vicinity. The hazards during construction of this foundation are described below:

Hazards During Preparatory Work

Bore holes may be dug for ground sampling at locations where piles are to be constructed. Incorrect information on pipeline alignment or oversight by the contractor could lead to breach of pipeline. This can be avoided by following the procedures laid down in the construction safety plan which should be prepared by KCRC's contractor in accordance with their safety management system. This will minimise the hazards to the pipeline during this phase of construction.

Hazards due to Piling/Pile cap Construction

The main hazard during piling is the superimposed load on the pipeline due to use of heavy equipment for piling. Use of heavy machinery is not completely prohibited over locations where pipelines are buried underground. However, the impact of excessive loading must be considered whilst developing the construction plan for the railway. For example, the deployment of the machinery may be such that superimposed loads are minimised.

Excavations dug for pile cap installation is expected to be about 2 to 4 m deep and supported. The main hazard during excavation is damage to the pipeline from excavators and also collapse of the excavation (retaining wall) resulting in loss of ground.

KCRC and the consultants/contractors engaged by KCRC should be aware of the guidelines issued by EMSD [10] and also those issued by Towngas for construction in the vicinity of gas pipelines. These guidelines prohibit the use of mechanical excavators within 3 m of pipeline alignments. Procedures are also laid down for identification of the exact alignment of the pipeline. The construction plan should also include emergency procedures to be followed in the event of an incident involving the gas pipeline. A copy of these guidelines is included in the Annex H of Volume 2 Technical Annexes.

The effects of collapse of soil adjoining the excavation could extend up to the pipeline if the pipeline is say, within 5m from the foundation excavation. Although this is unlikely to cause failure of the pipeline, in order to minimise the potential for collapse of excavation, proper design/site control measures should be adopted.

Hazards during Superstructure Erection

The main hazard is the accidental fall of launching/erection equipment or partially built superstructure (before that particular span is completed). The structure could fall on to the ground and penetrate into the ground to cause damage to the pipeline. The potential for such an accident is considered to be low provided 'best practice' as stated in the construction plan is followed rigorously. Also, the IChemE Accident Database [24] shows that the most common cause of failure of pipelines during construction is excavation in its vicinity of the pipelines.

Hazards During Operation of the Railway

During the operational phase of the railway, the main hazards posed by the railway are :

- gas pipe corrosion induced by stray currents from the traction power system;
- vibration induced failure of gas pipe (due to train operation);
- train accidents causing breach of containment.

Stray current corrosion is caused by the leakage of electrical current from the track to nearby metallic structures such as pipes, bridges etc. Such electrical current leakages do not occur normally since the rail is isolated from the ballast and viaduct structure. Even if leakage occurs, all the viaduct structures are bonded to flow the current back to the rail. Conditions may however, deteriorate with time resulting in stray currents being transmitted to the buried steel structure. Such currents, which will be generated as pulses every time a train passes through the location, should however be relatively small under most circumstances. It is also noted that corrosion caused by ac traction (which is adopted for the MOS Extension) is much less severe than with stray dc current. Nevertheless, engineering measures should be adopted to control and monitor stray currents and minimise such effects on the pipeline.

Train movements can lead to vibration impacts in the vicinity and could cause damage to underground structures. However, vibration effects are not expected to be significant since floating slab track will be installed.

Train accidents such as derailments may lead to pipeline failure due to direct penetration of the wheels or due to excessive loading caused by the use of heavy machinery for salvage operations. This is discussed in further in *Section 11.9.*

The presence of the railway in the vicinity of gas pipeline may also exacerbate incidents of gas leakage due to the ignition potential presented by train movements and due to sparks from the overhead lines. This will be addressed further in *Section 11.10.3.*

11.8.4 Historical Incidents Due to Train-Pipeline Interaction

The most significant incidents world-wide which are of interest to this study, ie those involving a pipeline and a railway [11] are described in detail below:

San Bernardino, California (1989)

On 12 May 1989, a runaway freight train travelling at 90 mph derailed into a residential area killing four people and destroying six homes. 13 days later, 13,000 gallons of gasoline leaked from a 14" refined products pipeline buried in the railway right-of-way where the train derailed. The leaking gasoline ignited, killing two residents and injuring 31 others. The accident resulted in a risk assessment study on the interaction between pipelines and railway lines. A major finding of this study was that pipelines within 500 feet of railway lines do not pose a higher risk than those further away.

Asha-Ufa, Trans-Siberian Railway, USSR (1989)

On the night of 3rd June 1989, a pipeline carrying LPG began to leak close to the Trans-Siberian railway track between the towns of Asha and Ufa. The leak was about 800 m from the double railway track, and was at a slightly higher level where both systems passed through a wooded valley. The gas cloud drifted for a distance of up to 5 miles and is stated to have formed two large pockets in low lying areas along the railway line. Two trains approached this vapour cloud from opposite directions and, as they approached the area, their turbulence mixed up LPG mist and vapour with the overlying air to form a flammable cloud. Sparks from the trains ignited the cloud (electric overhead catenary wires for the locomotives) resulting in an initial explosion.

It appears that two explosions took place in quick succession, and a flash fire one mile wide raced down the tracks in both directions. A considerable part of each train was derailed and it is stated that one train collided with the other. The death toll was estimated as 645.

Review of Incidents

The first incident highlights the potential for damage due to excessive loading, during the derailment and later during the movement of heavy equipment to remove the wreckage. The conclusion by the risk assessment study that followed the accident [12] is based only on incident rates for pipelines within 500 feet of rail lines and away from the rail lines. The study [12] however, did not consider the consequences of a passenger train in the vicinity of pipeline failure.

The second incident highlights the potential for train movements to ignite flammable gas clouds resulting from pipeline failure. However, in this case, the leak involved LPG which tends to settle down and disperse slowly (on account of it being denser than air) as compared to natural gas or Towngas which is lighter than air.

11.9 Frequency Analysis

11.9.1 Definition

Frequency analysis involves the estimation of frequency of failures resulting in loss of containment. This section of the report examines the frequency of gas pipeline failures together with the contribution from railway incidents.

11.9.2 Pipeline Failure Frequency

The approach to frequency analysis is based on the application of historical data worldwide for similar systems modified suitably to reflect local factors. Although it may be preferable to use local data to estimate failure frequencies, such data are not sufficient to provide statistically significant results.

HKCG commenced operations on high pressure transmission network (35 barg pressure) in 1983 and the total length of high pressure network currently in operation is 112 km. The total pipeline operating years is therefore 1568 km-years assuming the current length of the network for the past 14 years. In reality, the network would have gradually expanded over the years and therefore the total pipeline operating years may be only about 50% of the above figure. The data on km-years is therefore not statistically significant to estimate failure frequencies. In comparison, the US Gas pipeline database is based on a total pipeline operating data of 5.2 million km years.

Furthermore, HKCG have not experienced any loss of containment failures in their high pressure transmission network since commencement of operations in 1983.

The approach used here therefore, is to examine the international failure databases and derive an appropriate failure frequency for the HKCG pipeline taking into account specific pipeline and environment features. The main failure databases considered are the failure database for US natural gas pipelines [5] and the failure database for the European gas pipelines [6].

A detailed breakdown on the various causes of failure reported in the incident database relating to onshore transmission pipelines is given in *Table 11.9a.* Some of the causes listed are not relevant to the HKCG pipeline while others may be more significant. The Consultant's recent study for a new Towngas HP pipeline [13] which was submitted to EMSD outlined a detailed discussion on failure causes that are relevant for the HKCG pipeline and the justification for adopting the failure rate given below. It is not proposed to revisit or include all of the details in this report. It is noted though that the pipeline under consideration in this study is about 5 to 10 years old. However, given that the wall thickness is 12.7 mm, and that recent inspection by HKCG (involving intelligent pigging of transmission pipelines after ten years of operation) found no significant loss of thickness due to corrosion, it appears unnecessary to consider a higher failure rate to account for the age of pipeline.

The failure rate for onshore gas transmission and distribution pipelines in the US, derived based on data for the period 1985 to 1994 [5] is adopted for the HP pipeline running along the MOS Extension.

Failure rate for HP Pipeline : *1.1×10^{-4} per km per year*

11.9.3 Consideration of Failure Frequency During Construction and Operational Phase of the Railway

The discussion above provides a general overview of the failure frequency which is adopted for the gas pipeline. In the paragraphs below, a discussion on the impact of the proposed railway development on the failure frequency is included.

The failure causes that are particularly significant for this study in relation to the proposed railway development, are failures due to third party damage, external corrosion due to stray currents, excessive loading and vibration.

As seen from *Table 11.9a*, third party damage contributes the most to pipeline failures. This is true of other databases such as the European Gas pipeline database [6], CONCAWE oil pipeline database [14] etc. The nature and frequency of third party damage is related to the environment in which the pipeline is located. Third party damage to transmission pipelines is most regularly caused by farming, excavation or similar activities as most of these pipelines are found mainly in either rural or suburban areas.

Table 11.9a Summary of Onshore Transmission Pipeline Incidents by Cause

Cause of Failure	Description of Cause	No. of Incidents 1985 to 1994	Percentage of Total Incidents
1 EXTERNAL FORCE		**281**	**53.9%**
Weather		**63**	**2.1%**
Earth Movement	Subsidence, landslides	17	3.3%
Heavy Rains/Floods	Washouts, floatation, scouring	38	7.3%
Lightning		2	0.4%
Cold Weather	Thermal stress, frozen components, frost heave	6	1.2%
Encroachment		***218***	***41.8%***
Third Party		194	37.2%
Previously damaged Pipe	Where encroachment occurred in the past	23	4.4%
Vandalism		1	0.2%
2 CORROSION		**122**	**23.4%**
External	Failure of coating/ CP	78	15.0%
Internal		38	7.3%
Stress Corrosion Cracking	Environmentally stimulated cracking phenomena	6	1.2%
3 WELDS &MATERIALS		**64**	**12.3%**
Defective Pipe Seam	Failure of longitudinal seams of ERW, DSAW & lap welded pipe	19	3.6%
Defective Fabrication Weld	Welds in branch connections, hot taps, weld-o-lets, sleeve repairs	12	2.3%
Defective Girth Weld		15	2.9%
Construction Damage	Wrinkle bends, gouges	6	1.2%
Defective Pipe	Manufacturing defects - hard spots, laminations	12	2.3%

Cause of Failure	Description of Cause	No. of Incidents 1985 to 1994	Percentage of Total Incidents
4 EQUIPMENT & OPERATIONS		**29**	**5.6%**
Equipment Failure	Malfunction of control or relief equipment, failure of threaded components, gaskets & seals	17	3.3%
Incorrect Operation		12	2.3%
5 OTHER		**25**	**4.8%**
Miscellaneous	Cause known but doesn't fit above	3	0.6%
Unknown		22	4.2%
TOTAL		**521**	**100%**

Pipelines in developed areas are also susceptible to third party damage due more to interference from utility/underground service works. However, such excavation work are well controlled in Hong Kong. Nevertheless, failures may still occur due to inadequate site control and supervision.

Approximately 15 m of the HP pipeline is within 5 m of the MOS Extension (including the crossing near the Tai Shui Hang nullah) while about a further 2 km of the pipeline is between 15 m to 25 m from the railway (and separated by a road). The section within 5 m is more susceptible to risk of damage from railway construction.

The probability of failure during the construction period (which will be a very short period, say less than one month, if construction in the vicinity (within 5m of the pipeline) of the crossing near Tai Shui hang Nullah is considered, which is the closest point) is subject to the construction methods, construction planning, site control and supervision etc. The hazards due to construction are largely dominated by human error. Important factors influencing the likelihood of human error will include, for example, incorrect information on pipeline alignment being used, inadequate training and supervision of personnel at site, inadequate understanding of the potential hazards etc. . The probability of failure during construction is assumed to be one order of magnitude higher than the operational phase i.e $1x10^{-3}$ /km/year. If the construction period is assumed to be one month in the most exposed area (which is the section of the pipeline within 5m of the alignment), this translates to a failure frequency of approximately $1x10^{-6}$ /year (the pipeline length used to estimate this frequency is 15m which lies within 5m of the alignment). During the operational phase, the presence of the railway may contribute to an increase in the pipeline failure frequency (due to stray current corrosion or vibration) or may exacerbate the consequences (due to additional ignition sources). There is not sufficient data to conclude that proximity to a railway increases the frequency of failure. As referenced earlier, the risk assessment study carried out on hazardous liquid pipelines in California [12] concluded that there was no difference between the incident rates for pipelines within 500 feet (ie, 150 m) of a rail line and pipelines away from rail lines.

As regards corrosion effects due to stray current, these can be monitored and mitigation measures incorporated as necessary. Effects due to vibration will need to be examined but may not be significant as dampening measures are incorporated as part of noise control. As regards potential for gas pipeline failure due to derailment, this is found to be low as illustrated in the following paragraphs. Based on the above, it can be concluded that there may not be any justification to consider a higher failure frequency for the gas pipeline (during the operational phase of the railway) on account of proximity to railway.

11.9.4 Pipeline Failures Caused by Train Derailment

The impact of a derailed train could result in the following:

- cause indentation on the pipe (local collapse) due to the additional load on the pipe exerted by the wagon weight or lifting equipment; or
- the derailment of a high speed train may result in it travelling at high speed through the upper layers of the ground and thereby acting as a 'plough' with the train wheels penetrating sufficiently to expose the pipe and rupture it. It is the experience of British Rail that a derailed train once it leaves the tracks has not ploughed deeper than the depth equivalent to the radius of the wheels, normally about 0.46 m. Furthermore, the BR guidelines for running pipe under railtrack state a minimum depth of 1.1 m.

Based on the above, it can be established that pipeline failure as a secondary event following derailment has a very low frequency.

The frequency of derailment is given as 1×10^{-3} per km per year [15]. Assuming derailment from one of the tracks only could affect the pipeline of length 2.3 km alongside MOS rail, this gives a frequency of 2.3×10^{-3} per year. The probability of derailment affecting a pipeline is dependent on the following:

- the direction of deviation of derailed train;
- whether the derailed train travels far enough to impact the pipeline;
- whether the derailment containment fails;
- whether the pipeline fails.

The probability of deviation of derailed train towards the pipeline is assumed as 0.5. Based on data on various derailments [16], the probability of a derailed train travelling more than 5 m from the track is conservatively estimated as 0.1. Derailment containment is provided for sections of the track laid on viaduct. The track section in the vicinity of the gas pipeline is laid at grade and it is likely that there may not be any derailment protection. The probability of failure given derailment is conservatively assumed as 0.1.

Based on the above, the frequency of pipeline failure due to derailment is derived as 1 x 10^{-3} /km/year x 0.5 x 0.1 x 0.1 = 5 x 10^{-6} /km/year. This is much lower than the failure frequency for the pipeline due to other factors (given as 1.1 x 10^{-4} /km/year) and therefore not considered any further. It is also noted that any impact from derailment is limited to some distance from the track, say 5 to 10 m while the pipeline is mostly at 15 to 25 m distance from the track (except for the section at the crossing where the railway is on viaduct which will have derailment containment).

11.9.5 Hole Size Distribution

The hole size distribution as given in *Table 11.9b* is assumed. The distribution given in the table is based on various incident databases which are discussed in the Consultant's recent study on a Towngas pipeline [13]. Although the probability of a full bore rupture may be extremely low due to the design factor of 0.3 and wall thickness greater than 11.9 mm, it is nevertheless considered by assigning a low probability.

Table 11.9b Hole Size Distribution

Category	Hole Size (inch)	Proportion
Rupture	Full bore	5%
Puncture	4"	15%
Hole	2"	30%
Leak	1"	30%
	10mm	20%

11.10 Consequence Analysis

11.10.1 Definition

Consequence analysis involves the following steps:

- source term; and
- effects modelling.

The source term comprises the application of appropriate discharge rate models to define the release rate, duration and the quantity of release. The source term outputs form the inputs to effects modelling such as dispersion modelling, fire modelling and explosion modelling.

11.10.2 Source Term

The release rate and release rate variation with time for failures of the high pressure gas pipeline of 600 mm diameter have been estimated based on standard equations for gas release. For large releases such as a 100 mm hole and full bore rupture, the empirical correlation developed by Bell and modified by Wilson [17] is adopted. The results are presented in *Table 11.10a.*

All the releases are modelled assuming 5.9 km pipeline section (which has an inventory of about 55 tonnes), ie the section between the offtake station at City One (where a remote isolation valve is located) and the end of the pipe after Chevalier Garden station. It can be seen from the above table that even assuming immediate isolation, the discharge rate does not decrease with time for releases from the 10 mm and 25 mm hole sizes. The variation in discharge rate with time is also not significant for releases from the 50 mm hole. The release rate for the full bore rupture is based on the release from one end of the pipe only, essentially at the end of pipeline. The duration of any release from a full bore failure could be higher and the rate of drop for the 100 mm hole and full bore failure lower if remote isolation at the off-take station is not achieved (in which case the inventory in the 8 km submarine section will be included). Furthermore, there is a proposal to extend the HP pipeline further beyond Chevalier Garden station, which may contribute additional inventory.

Table 11.10a Discharge Rate Versus Time for Various Hole Sizes in HP Pipeline

t (min)	Q (kg/s) for various hole sizes				
	10mm	25mm	50mm	100mm	Full bore (600mm)
0	0.4	2.6	10.3	41.4	1464
1	0.4	2.6	10.3	40.4	167
5	0.4	2.6	9.9	35.4	5.9
10	0.4	2.5	9.6	30.4	0.1
15	0.4	2.5	9.2	26.0	<0.1
20	0.4	2.5	8.9	22.3	0
25	0.4	2.5	8.5	19.2	0
30	0.4	2.4	8.2	16.4	0
35	0.4	2.4	7.9	14.1	0
40	0.4	2.4	7.6	12.1	0
45	0.4	2.4	7.3	10.4	0
50	0.4	2.3	7.0	9.0	0
55	0.4	2.3	6.8	7.7	0
60	0.4	2.3	6.5	6.7	0

11.10.3 Scenarios Following Gas Release

General

The scenarios following a gas release may include:

- fire ball;
- jet fire;
- flashfire;
- explosion;
- unignited toxic release;
- safe dispersion.

Figure 11.10a shows an event tree for various outcomes following a release and the associated probabilities. A brief description of the development of the event tree is given in the following paragraphs.

Orientation of Release

The consequences of a Towngas release following a pipeline failure are dependent on the release rate and the orientation of the release. Failures that occur on the top portion of the pipeline will result in vertical jet releases (unobstructed) and will be governed by momentum jet dispersion/fires. Failures that occur from the bottom portion of the pipeline will lose momentum due to impingement/ obstruction with the surrounding earth (considering buried depth at 1.1 m) and therefore will result in a buoyant plume rise. The relative proportion of failures occurring from either the top or bottom (including side) portion of the pipeline is dependent upon how the failures are caused. Failures due to third party damage are more likely to occur from the top while corrosion failures are more likely to occur at the bottom. However, the probability of failures from either the top or from the bottom are assumed equal.

The orientation of the release may not be relevant for large failures such as those from a 100 mm hole or full bore failure. Large failures such as ruptures are more likely to result in an upward release following the displacement of any earth cover. However, to account for the effects due to the presence of a buoyant gas cloud at or near ground level in the event of any obstruction to an upward release, 50% of 4" failures are assumed to be obstructed while full bore failures are assumed to be completely unobstructed.

Ignition of Release

A full bore rupture will be characterised by a very high initial rate followed by a rapid drop. This can cause a large crater with a significant amount of earth cover being removed. Immediate ignition of such releases may result in a fireball followed by a jet fire. Since the fireball is transient while the jet fire continues for a long time, it is found that the effects of a jet fire from a rupture are as significant or have greater damage potential than those compared to fireball effects.

For all other release cases, immediate ignition would result in a jet fire. Ignition of releases from the top of the pipeline will give rise to a vertical jet flame (unobstructed). It is also likely that releases from the top may be slightly inclined, such that it may cause damage as a result of direct impingement on structures, buildings and persons in the vicinity. This is particularly relevant where buildings and structures are in close proximity to the pipeline. Inclined jets (including those releases which are angled and not nearly vertical) may cause more damage than would result from radiation effects only (from a vertical jet). Ignition of releases from the side or bottom section of the pipeline may result in a diffused jet whereby the jet due to impingement on surrounding earth cover may be deflected upwards accompanied by turbulent mixing.

The ignition probability for releases in the open amidst residential areas and high density traffic are assumed to be high. Immediate ignition may occur due to electrostatic generation or sparks associated with say violent ruptures. Also, immediate ignition may be caused by road vehicles caught within the immediate vicinity of the failure. Furthermore, the probability of ignition may be increased due to the proximity of the railway track. Train movements, sparks from the overhead catenary etc are potential ignition sources related to the railway.

A value of 0.5 is assumed for ignition of massive leaks. Given the high potential for ignition, assuming a high ignition probability is also consistent with the assumption that the cloud will ignite earlier than the time required to disperse to lower flammability levels.

Dispersion of Release

In the event the release is not ignited immediately, the dispersion of the cloud may be modelled as a momentum jet for vertical releases and as buoyant gas plume for obstructed releases. The distance to LFL is estimated in both cases. For vertical releases, the LFL concentration is more likely to be reached within the momentum phase of the jet. In the case of obstructed releases resulting in buoyant gas dispersion, delayed ignition will result in a flashfire. The flame will flashback to the source leading to a diffused jet flame, a flame characterised by lesser intensity as compared to a momentum jet flame. While this may lead to an increased flame jet, the effects are modelled as being identical to a momentum jet flame.

Since the gas is buoyant, even if the release is obstructed, the gas may still rise due to buoyancy and therefore the potential for flashfire effects at ground level could be limited (the rising gas plume may be within the LFL with potential to affect high rise buildings). The potential for vapour cloud explosion is not considered significant for a buoyant gas plumes and has therefore not been modelled any further.

Due to the presence of CO in the gas, in addition to flammability considerations, toxic effects are also required to be estimated. Both for vertical releases and obstructed releases, the distance to 1% fatality concentration due to CO are estimated.

11.10.4 Scenarios Affecting Train Passengers

The scenarios affecting the train passengers are the same as described above - jet fire, fireball and flashfire. However, the possibility of these events impacting passengers in a train depends on the following:

- whether the train is stationary at the scene of the incident;
- whether a passing train is brought to a halt as a result of the incident;
- whether a passing train continues to travel past the scene of the incident.

It is assumed that unless the train is stopped by the incident or is stationary at the time of incident, the train will continue to run so as to reach the nearest station. While passengers may be impacted by radiation effects or direct flame impingement during the passage of the train through the hazard zone, or due to secondary fires (in the event of train components catching fire), as long as the train does not get stopped and reaches the station where passengers can be evacuated safely, the risks to passengers are likely to be less than if the train were stationary at the scene of the incident or brought to a halt by the incident.

It is further assumed that only jet fire events and fireball events will affect the train operations. The possibility of flash fires also exists but is expected to be low since it is dependent on the wind direction (the probability of wind being in the direction of the railway alignment is considered to be 0.5 maximum). Additionally, since the released gas will be lighter than air, the presence of a 2 m high concrete barrier along the trackside (while at grade) may result in an uplift of the cloud, and even if the rising plume were to be ignited by the catenary, it may not cause a passing train to stop in the vicinity of incident. It may at most result in an external fire. In the estimation of the outcome frequency, flash fires are considered as jet fires.

The nature of the impact from a jet fire will depend on whether or not the jet flame is oriented towards the train/track (ie inclined jet) as these can cause immediate damage to the catenary and the train due to direct impingement.

The event tree shown in *Figures 11.10b & c* (for peak and off-peak periods respectively) depicts the various outcome scenarios. The jet fire and fireball frequencies are based on the outcome frequencies given in *Figure 11.10a* considering both vertical and diffused jets and also flashfires that are followed by jet fires.

Further description of the various intermediate events are described in the following paragraphs.

Jet Flame Orientation Towards Train/Track

In the event of jet flame impingement on the train/track, it could cause failure of the catenary and thereby cause a passing train to stop. This may result in engulfment of the train by the jet flame causing fatal burn injuries to persons within as a result of radiation through the train windows. The extent of train length affected by the jet flame is estimated as a proportion of twice the width (at the top) of the cone to the train length (which is 100 m). The probability of fatality of passengers within this train length is assumed as 50% while passengers in the rest of the train are assumed to escape.

A 10% probability is assumed for a jet flame orientation towards the train/track. This scenario is however, dependent on the proximity of the railway to the gas pipeline and the nature of the failure in the gas pipeline. The flame envelope (ie, flame length) is modelled in RISKPLOT (the Consultant's risk integration software) for different hole sizes together with the relative location of the pipeline and the railway.

Where the inclined jet flame does not cause the train to stop, the surface heat flux from the jet on the passing train may still be sufficient to cause fatal burn injuries to passengers during their exposure for the time period that the train passes through the flame envelope (as given by flame width at the tip of the cone). Assuming a surface heat flux of $200 kW/m^2$, the duration of exposure corresponding to a thermal dose of $1000 (kW/m^2)^{4/3}s$ is about one second. At a speed of 60 km/hr (ie, 16 m/s), this corresponds to a travel distance of 16 m through the flame envelope. Passengers standing near the windows (assumed as 30%) may be exposed to this level of radiation resulting in 1% fatality.

In the case of jet flames that are not inclined towards the train/track, it is assumed that the probability of radiation from the vertical jet causing damage to the catenary is low. Where such damage results in stoppage of a train, the effects are limited to damage caused by radiation from the vertical jet, which will be less severe than that from impinging jets. It is likely that passengers may disembark from the train by forcing open the train doors to try and escape from the scene of the incident. In the event passengers disembark on the trackside instead of into the cess, they could run the risk of being in a collision with a train approaching from the opposite direction. This however, is not modelled.

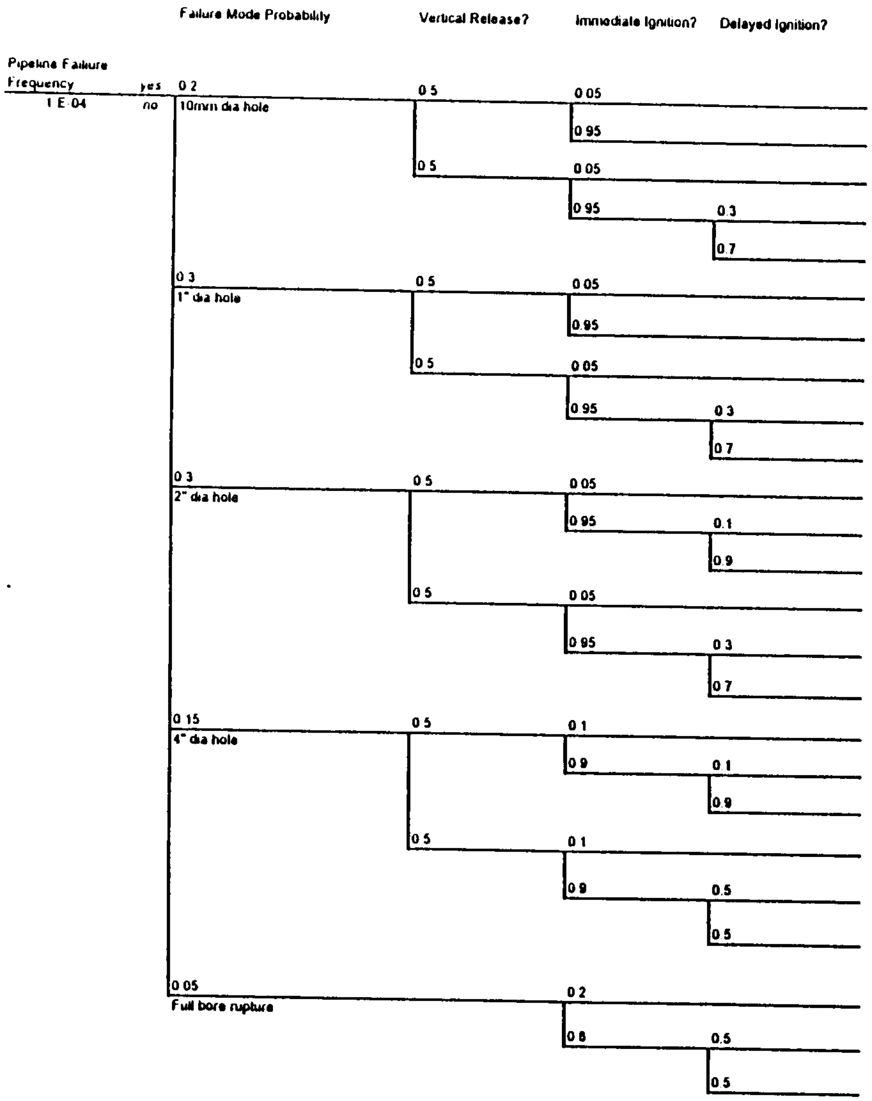
Train within Fireball Diameter

It is assumed that 100% fatality of passengers will occur for any passing train or stationary train which is engulfed by a fireball at the scene of an incident.

Probability of Stationary Train in the Vicinity of Incident

The probability of a stationary train at the scene of the incident is dependent mainly on a train stopping due to signals. This is considered to be generally very low and therefore assigned a value of 0.001 during peak hours and 1×10^{-4} during off-peak hours.

FIG 11.10a EVENT TREE FOR TOWNSGAS RELEASE FROM PIPELINE



Consequence Outcome	Consequence Name	Outcome Frequency for each failure mode	Ignition Probability for each failure mode
Vertical jet flame	TG_10mm_VJ	5.50E-07	0.19
Vertical jet dispersion		1.05E-05	
Diffused jet flame	TG_10mm_DJ	5.50E-07	
flame	TG_10mm_FF/DJ	3.14E-06	
Dispersion - toxic effects	TG_10mm_Tox	7.32E-06	
Vertical jet flame	TG_1in_VJ	8.25E-07	0.19
Vertical jet dispersion		1.57E-05	
Diffused jet flame	TG_1in_DJ	8.25E-07	
Flash fire followed by diffused jet flame	TG_1in_FF/DJ	4.70E-06	
Dispersion- toxic effects	TG_1in_Tox	1.10E-05	
Vertical jet flame	TG_2in_VJ_I	8.25E-07	0.24
Vertical jet flame	TG_2in_VJ_D	1.57E-06	
Vertical jet dispersion		1.41E-05	
Diffused jet flame	TG_2in_DJ	8.25E-07	
Flash fire followed by diffused jet flame	TG_2in_FF/DJ	4.70E-06	
Dispersion - toxic effects	TG_2in_Tox	1.10E-05	
Vertical jet flame	TG_4in_VJ_I	8.25E-07	0.37
Vertical jet flame	TG_4in_VJ_D	7.43E-07	
Vertical jet dispersion		6.68E-06	
Diffused jet flame	TG_4in_DJ	8.25E-07	
Flash fire followed by diffused jet flame	TG_4in_FF/DJ_D	3.71E-06	
Dispersion - toxic effects	TG_4in_Tox	3.71E-06	
Fireball followed by vertical jet flame	TG_FBR_FB/VJ	1.10E-06	0.60
Vertical jet flame	TG_FBR_VJ_D	2.20E-06	
Vertical jet dispersion		2.20E-06	
		1.10E-04	0.25

Figure 11.10b: Event Tree for Risk To Rail Passengers (peak period)

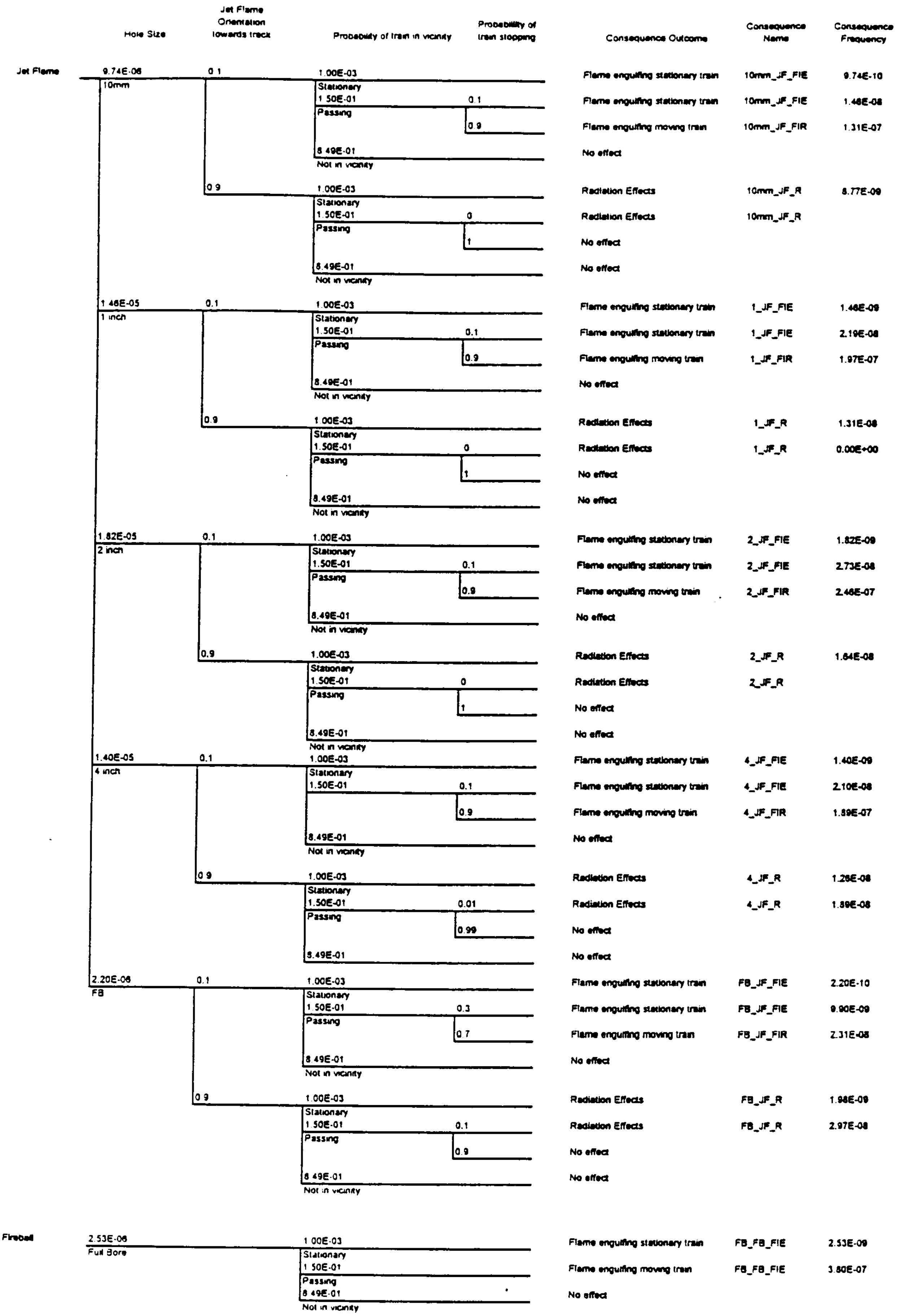
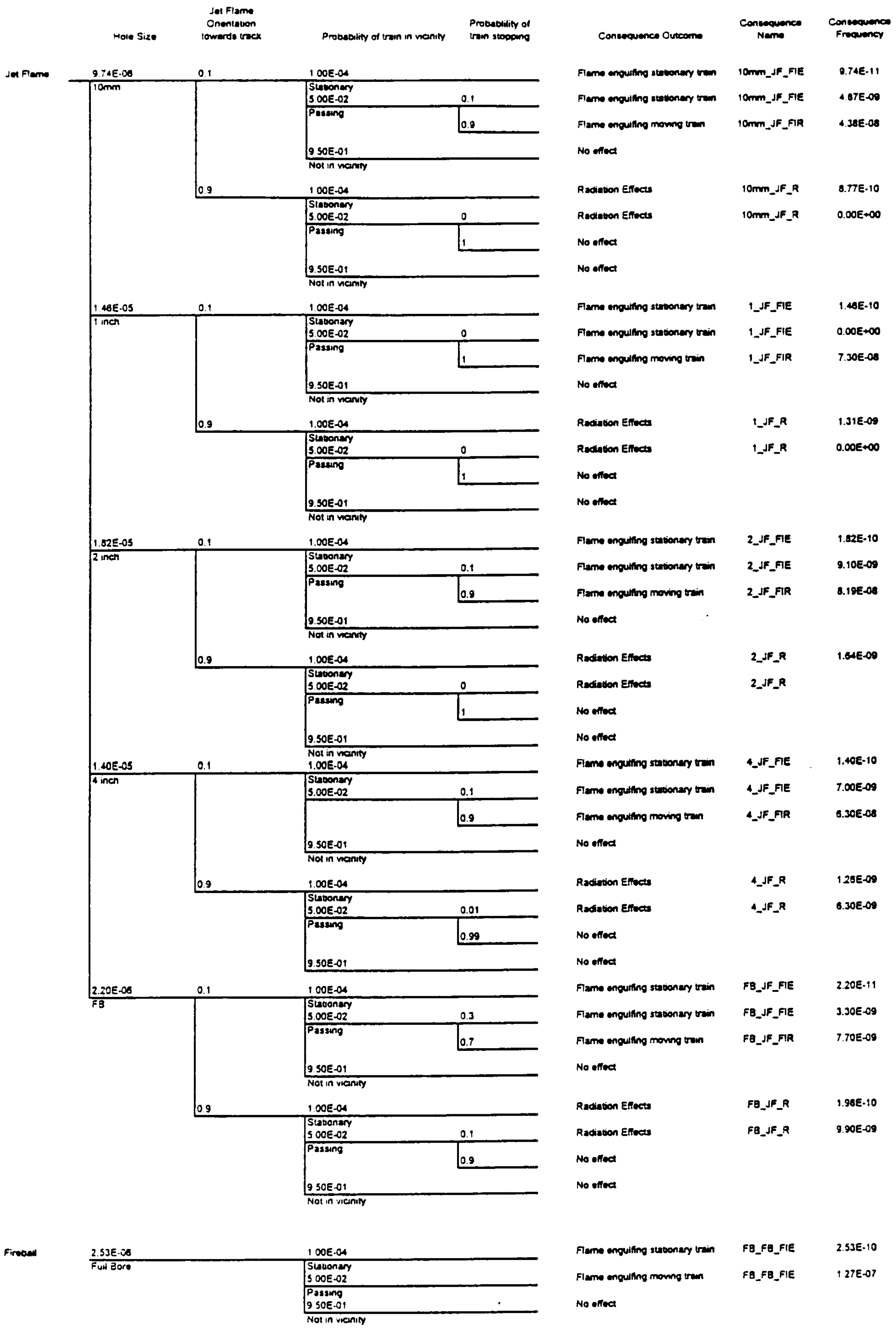


Figure 11.10c: Event Tree for Rail Passengers (off-peak)



Probability of Train Passing by the Scene of Incident

The probability of a passing train can be estimated from the frequency of service and the decision sight distance for the driver (which includes reaction time and braking distance). Assuming a deceleration rate of 1 m/s^2 at a speed of 60 km/hr, the braking distance is about 150 m (to this may be added the train length of 100m and the interaction length due to the hazard which may range between 10 to 150 m for 4" and full bore failure). Based on a frequency of 2 minutes during peak hours (ie 60 trains per hour in both directions), the probability of a passing train is estimated as {150 m/60 km/hr}x60 = 0.15 (the time period that a passing train is in the vicinity of the incident site is about 9 seconds). During off-peak hours, the frequency of service is 6 minutes and therefore the probability of a passing train is 0.05.

It is assumed that trains that are not within the decision sight distance will brake such that they stop away from the scene of incident. There is also the possibility of simultaneous train movement on both the tracks in the vicinity of the incident and both getting stopped due to common mode failure such as catenary damage. However, this is considered to be low and if it were to occur, the damage effects may not be increased in all the failure scenarios since the train nearest to the pipeline may shield the train on the track away from the pipeline.

Probability of Train being Stopped

This will depend on the orientation of the jet flame (with a higher probability if the jet flame is oriented towards the track) and the size of the release which together will determine the nature of damage that could be caused to stop the train.

Other Scenarios

The scenarios described above pertain to train passengers (between stations) affected by failure of the gas pipeline that runs parallel to the track. Other scenarios include:

- failure of the gas pipeline at the crossing underneath the viaduct;
- failure of the gas pipeline adjoining a station; or
- failure of the gas pipeline affecting the railway infrastructure.

Failure of Gas Pipeline at the Crossing Underneath the Viaduct

In the event of failure at the crossing and consequent ignition, the resulting jet fire is likely to engulf the viaduct structure. In this case, the probability of jet flame causing a passing train to stop will be high (for most events other than 10 mm and 1" hole. The jet flame lengths for the 10 mm and 1" releases are lower than the height of the viaduct, which is about 12 to 15 m).

The frequency of pipeline failure at the crossing is estimated as 1.7×10^{-6} per year considering 15 m section underneath the viaduct. Even if a higher probability is considered for train stopping, the resulting outcome frequency (with potential to cause fatality) is not found to be significantly higher than estimated for the rest of the section.

Failure of Gas Pipeline Adjoining Station

The effects of gas pipeline failure on passengers in the train station are modelled in the same way as effects on residential populations or other static receivers (it should be noted that train passengers between stations are modelled as mobile sources as explained in the paragraphs above). There will, however, be a continuous presence of passengers at the station (during the operating periods of the MOS Extension) although the number of passengers will vary between the peak and off-peak periods as given in *Table 11.2b.*

Failure of Gas Pipeline Affecting Railway Infrastructure Events associated with the failure of the gas pipeline have the potential to cause damage to the railway infrastructure, particularly the viaduct structure. Jet flame impingement on the viaduct (direct impingement at the location where the pipeline crosses underneath the viaduct or from an inclined jet in the event of a failure in the parallel section) could cause structural failure. As seen from *Table 11.10a*, release from a 50 mm hole could continue for about two hours unless there are intermediate manual valves which can be isolated. Even then, the residual inventory in the pipeline could last for about an hour. While this does not exacerbate the potential for fatalities since train movements would have stopped by then, structural damage could occur which may affect resumption of railway operations following an incident.

11.10.5 Fireball Effects

Immediate ignition of releases caused by a rupture in the pipeline may give rise to a fireball upon ignition. An account of the experimental work on jet fires from pipelines undertaken by Shell and British Gas as given by Hirst [18] suggests that the release results in an unignited jet which upon ignition results in a mushroom cloud followed by a jet flame. These tests were however, conducted using liquefied propane.

The potential for a fireball in the event of a gas release from a pipeline may be similar to the effects from vessel ruptures. Although the models developed for fireball analysis are mainly for BLEVE application, these are adopted here to model the fireball effects from gas pipeline ruptures. The following equations are adopted for estimation of fireball diameter and duration [19].

$D = 5.8M^{1/3}$
$t = 0.45M^{1/3}$

where D is final diameter of fireball (m),
t is fireball duration (seconds),
M is mass of fuel (kg).

Due to the transient nature of the release, the mass of fuel entering the fireball is difficult to estimate. Simplistically it can be assumed that the mass of fuel entering the fireball is equivalent to the mass released within about 10 to 30 seconds. A proposed method [20] is to calculate at each time step the quantity of fuel that can be consumed in a fireball with the same burning time as the time since the start of the release. The size of the fireball is determined by equating these two values. The fireball is limited to a maximum duration of 30s.

The fireball diameter and duration given in *Table 11.10b* are estimated based on a mass of 10te.

Table 11.10b Hazard Distances for Fireball

Parameter	Value
Mass of fuel	10te
Diameter of fireball	129m
Duration of fireball	9.34s

Persons caught in the open within the fireball diameter are assumed to be 100% fatally injured. No fatality is assumed outside the fireball diameter although thermal radiation effects could be significant. Secondary fires may also ensue.

Due to the presence of multistorey buildings, consideration of fireball rise is critical in estimating the potential for causing injury/fatality to persons at higher levels.

Lihou and Maund [19] suggest a simple relationship to calculate the height of rising methane fireballs:

$H = 10t$

where t is duration of fireball (seconds) and

H is the final height, m.

The final height is about 100 m and therefore all the floors in a multistorey building are likely to be engulfed by the rising fireball, if the building falls within the fireball diameter.

However, since the release associated with the rupture will be dominated by momentum effects, the initial height of the fireball is likely to be at some height above ground level thereby considerably mitigating the effects at /near ground level.

11.10.6 Dispersion of Obstructed Releases (continuous)

Since the gas is positively buoyant (ie its density is less than the density of air), Brigg's buoyant plume rise model [21] is adopted to estimate the initial plume rise followed by Gaussian dispersion to calculate the ground level concentration.

The plume rise model requires two inputs : discharge velocity and stack diameter. Since the release is assumed to be obstructed and therefore has low velocity, a minimum discharge velocity of 0.1 m/s is assumed. The modified diameter of the release is assumed as 0.5 m for 10 mm, 25 mm and 50 mm leak sizes and 1 m for 100 mm leak size.

The results show that the plume rise is not significant. The cloud lifts only about 0.5 m to 1 m. The plume rise may be much greater if the discharge velocity is higher than 0.1 m/s. The dispersion calculations given below may therefore be conservative as releases at higher elevation will have lower ground level concentration.

The effective release height calculated by the plume rise model is used as input for modelling the neutrally buoyant dispersion. The distance to LFL and also the distances to 1% fatality concentration for CO are presented in *Tables 11.10c & d.*

Table 11.10c Hazard Distances (LFL) for Continuous Releases

Release scenario	Weather state	Distance to LFL (m)	
		d	C
TG_10mm_0.4 kg/s	3D	15	1
	6D	9	1
	1.5F	46	2
TG_25mm_2.6 kg/s	3D	39	3
	6D	27	2
	1.5F	126	4
TG_50mm_10kg/s	3D	76	5
	6D	54	4
	1.5F	283	9
TG_100mm_38 kg/s	3D	140	9
	6D	96	6
	1.5F	569	16

Note : 'd' is downwind distance while 'C' refers to crosswind distance

Table 11.10d Hazard Distances (1% fatality concentration for CO) for Continuous Releases

Release scenario	Weather state	Distance to IDLH (m)	
		d	C
TG_10mm_0.4 kg/s	3D	13	1
	6D	8	1
	1.5F	42	1
TG_25mm_2.6 kg/s	3D	35	2
	6D	25	2
	1.5F	113	4
TG_50mm_10kg/s	3D	70	5

Release scenario	Weather state	Distance to IDLH (m)	
		d	C
	6D	49	3
	1.5F	253	8
TG_100mm_38 kg/s	3D	140	9
	6D	96	6
	1.5F	569	16

Note : 'd' is downwind distance while 'C' refers to crosswind distance

The fatality rate for flashfires is considered as 100% for persons within the cloud envelope. This applies to outdoor populations while the fatality rate for indoor populations may be considered as 10% of the outdoor fatality rate. Furthermore, a protection factor of 90% may be considered to account for the vertical distribution of populations in multi-storey buildings whereas flash fire effects will be limited to the width of the cloud envelope. Considering that 99% of people are indoors and 1% are outdoors during day time, an equivalent fatality rate of 1% is therefore assumed.

The average fatality rate due to toxic effects for the cloud envelope is estimated as the geometric mean of 100% fatality at the source and 1% fatality at the edges of the cloud envelope. The geometric mean is 10%. The equivalent fatality rate considering indoor/outdoor population distribution (99% indoors and 1% outdoors and indoor fatality rate is about 10% of outdoor fatality rate) is 1.1%. For road populations, fatality rates are derived based on ventilation rates. For this study, a value of 1.1% is assumed.

11.10.7 Vertical Releases - Momentum Jet Dispersion

In the event of a puncture on the pipeline from the top, the gas will be emitted vertically as a high velocity jet. The jet is likely to maintain its momentum unless an obstruction of significant dimension is encountered which can absorb the momentum of the jet. For most parts of the pipeline route this is not expected.

The vertical jet is modelled using the TNO correlation for jet dispersion [21]. It is observed that the jet remains vertical for a considerable height from the ground beyond which it gets deflected by wind and travels along the wind direction. No flashfire envelope is expected. Ignition of the jet can occur at the edges at LFL. The width of the jet is less than 4 m. *Table 11.10e* below summarises the hazard distances for vertical jet dispersion in relation to various release scenarios.

Table 11.10e Hazard Distances for Vertical Jet Dispersion

Release scenario	Jet length to LFL (m)	Jet maximum width (m)
TG_10mm_0.4kg/s	4	0.4
TG_25mm_2.6kg/s	9	1
TG_50mm_10kg/s	17	2
TG_100mm_38kg/s	33	4

It is also important to consider the dispersion of the cloud even after the jet velocity reaches wind speed when the dispersion will be governed by Gaussian dispersion. The cloud may reach buildings adjoining the pipeline route at heights above ground level and cause injury/fatality due to the presence of CO.

However the concentration of the gas corresponding to 1% fatality for 30 minutes exposure to CO is similar to the LFL concentration and therefore the effects of CO due to subsequent downwind cloud movement are not considered significant.

11.10.8 Vertical Releases - Momentum Jet Fire Effects

The dimensions of an ignited jet and the distances to 12.5 kW/m^2 and 4 kW/m^2 are estimated based on the Chamberlain model for jet fires [22]. The jet flame is modelled as a truncated frustum of a cone which emits radiation from its surface.

This model is validated for methane gas jet fires and therefore the jet fire effects are modelled assuming methane. The calorific value of methane (55.75 MJ/kg) is however. higher than the calorific value for town gas (28 MJ/kg) and therefore the results predicted may be slightly conservative.

The radiation level varies with elevation from the ground as the dimensions of the flame and the view factor for the receiver increases. Since the release occurs at below ground level at a depth of about 1m below ground, the receiver height of 2.5 m is considered which actually corresponds to 1.5 m above ground level.

Due to the presence of multistorey buildings, radiation from the jet fire along the vertical flame length is also important. However, for risk estimation, radiation at a receiver height of 1.5 m from ground level is considered.

Probits for Fatality due to Thermal Radiation

The probity equation given by Eisenberg [23] is used for the estimation of fatalities due to thermal radiation effects. The probity equation is given below:

Eisenberg : $Y = -14.9 + 2.56 \ln L$

where, L is the thermal load = $tI^{4/3}$
t is the exposure time, seconds
I is the thermal radiation intensity, kW/m^2

The effects of thermal radiation from jet fires are estimated based on the following assumption. Assuming an exposure time of 30 seconds (corresponding to the time taken to escape to a safe area), the radiation level corresponding to 1% fatality is estimated as 12.5 kW/m^2 based on Eisenberg probity.

The hazard distances for radiation from a jet flame following full bore rupture have been estimated assuming 366 kg/s (which is 1/4th the initial release rate). The dimensions of the flame from a full bore rupture will be so large (12 m at the base & 34 m wide at the top) that it may impinge on surrounding buildings or structures, if any are present, and potentially result in secondary fires.

Table 11.10f Hazard Distances for Radiation from Vertical Jet Flame (10mm to 100mm hole size)

Release scenario	Flame (frustum) Length (m)	Flame width at the tip (m)	Flame width at the base (m)	Distance (m) to radiation at 1.5m elevation from ground level	
				12.5 kW/m^2	4 kW/m^2
TG_10mm_0.4 kg/s	4.6	1.6	0.2	2.	5
TG_25mm_2.6 kg/s	11	3.6	0.7	5	14
TG_50mm_10 kg/s	20	7	1.6	10	30
TG_100mm_38 kg/s	36	12	3	21	57
TG_FBR_366 kg/s	102	34	12	65	178

11.11 Risk Summation & Evaluation

11.11.1 Approach

Risk summation combines the estimates of the consequences of an event with the event probabilities to give an estimate of the resulting frequency of varying levels of fatalities. The Consultants in-house software RISKPLOT™ has been used for risk summation.

The risks from pipelines are expressed as risk transects, Potential Loss of Life (PLL) and FN curve. Risk transects express the risk to a hypothetical individual who is assumed to be present all the time at a given distance.

Inputs for Risk Summation

Risks from the Towngas pipeline have been estimated for the following scenarios:

- considering only the existing population in residential developments and road traffic. This will form the base case results or the background risk;
- considering only the rail passengers travelling on trains and using Chevalier Garden station.

Base Case Risk

The event tree for the base case risk is shown in *Figure 11.10a.*

The frequency and consequence input files for the base case risk are given in *Tables 11.11a and 11.11b* in Annex H *of Volume 2 - Technical Annexes.*

Risks to Rail Passengers

The risk to rail passengers on trains and at the Chevalier Garden station are estimated based on the event trees shown in *Figures 11.10b and 11.10c,* for peak and off-peak scenarios respectively. The frequency and consequence input files for estimation of risk to train passengers are given in *Tables 11.11c & d* of Annex H in *Volume 2 - Technical Annexes.* The risk to station passengers is modelled similar to the base case.

11.11.2 Results

Potential Loss of Life (PLL)

The overall PLL considering all types of events is given separately for various cases in *Table 11.11e.*

Table 11.11e Potential Loss of Life (PLL) per year

Case	PLL value	% contribution
Base case - background population	1.3×10^{-4}	95.6%
Train passengers	2.1×10^{-6}	1.6%
Station passengers	3.7×10^{-6}	2.8%
Total	1.3×10^{-4}	

It is observed that the risks to the railway development are not significant as compared to the risks posed to the existing population adjoining the pipeline.

A breakdown of PLL by event types, ie flash fire, fireball, jet fire and toxic effects is also included in *Table 11.11f* in Annex H *of Volume 2 - Technical Annexes.* It is found that fireball events contribute the most to the overall PLL.

The results for fireball effects are however, conservative. It has been assumed that 100% fatality will be caused for persons within the fireball diameter. While this assumption is true for persons in the open, the indoor fatality rate is expected to be lower, ie 50%.

FN Curves

Societal risk can also be expressed in the form of an F-N curve which represents the cumulative frequency (F) of all outcomes leading to N or more fatalities. This is shown in *Figure 11.11a* in *Annex H of Volume 2 - Technical Annexes.* The FN pairs for each section are given in *Table 11.11g* in *Annex H of Volume 2 - Technical Annexes.*

Individual Risk

This represents the risk to a named individual at a specified location from the pipeline. As a simplistic measure, individual risk to a hypothetical individual who is assumed to be present 100% of the time at a specified location from the pipeline is estimated. The maximum individual risk is estimated as 3 x 10^{-7} per year. The risk transect is shown in *Figure 11.11b* in *Annex H of Volume 2 - Technical Annexes.*

The individual risk for a passenger on a train is lower than the value given above due to consideration of passing train probabilities etc.

Interpretation of Results

The results presented above are derived for the operational phase of the railway. Figure 11.11a shows that the total risk is largely dominated by the risk to the background population which would be present irrespective of the railway development. During the construction phase, the risk levels are assumed to be one order of magnitude higher than what has been derived above for the operational phase. While there will be no train passengers during this phase, construction workers will however, be exposed to the hazards in addition to the background population. Assuming an order of magnitude higher, the resultant PLL due to construction is about 1 x 10^{-5} /year (for the 15m section). The IR value would be less than 1 x 10^{-5} per year. As explained earlier in the frequency section, the pipeline failure frequency during the construction phase (for the relevant section and time) is about two orders of magnitude lower than the operational phase (approximately 1 x 10^{-6} vs 1 x 10^{-4}). Assuming that about 30 or less workers are present at any given time, the worst case scenario would be a fireball following a full bore rupture resulting in 100% fatality within the hazard range. The frequency of this event after subjecting it to ignition probability would be lower than the frequency for the same number of fatalities for the operational phase. The background risk would be the same and dominate the total risk in this case as well. Hence, the risks are acceptable provided adequate precautions are adopted. For our analysis it is assumed that the background population does not change from the construction phase to the operational phase even though some change is expected due to new developments as a result of the railway.

11.12 Risk Criteria

The individual risk criterion for a Potentially Hazardous Installation (PHI) specifies that the risk of fatality to an offsite individual should not exceed 1 x 10^{-5} per year. The individual risk is normally calculated in Hong Kong taking into account occupation or presence factors, protection factors etc.

It is generally accepted that the same individual risk criterion as specified for a PHI should be adopted for other dangerous activities including transport since it applies to people not involved directly with such activities.

The societal risk guidelines for Hong Kong are given in the Hong Kong Planning Standards and Guidelines, Chapter 11. However, these guidelines were developed for PHIs and not for the transport of hazardous chemicals including those by a pipeline.

In a recent study [13] by the Consultants on a Towngas pipeline, a discussion was included on the various approaches for risk criteria and the approach that was finally adopted was to consider a one mile (ie 1.6 km) segment and apply the PHI criteria (the inventory in a one mile (ie, 1.6 km) section of a 35 barg pressure pipeline is about 15 tonnes). This approach is also adopted in this study.

11.13 Discussion on Results

The risk transects provide individual risk values for a hypothetical individual at a specified location present 100% of the time. The maximum value of 3×10^{-7} per year is much lower than the individual risk criterion of 1×10^{-5} per year.

The individual risk to train passengers is still lower than 3×10^{-7} per year. Personal individual risk can be then calculated for rail users based on the number of train journeys undertaken by the most frequent rail user. Assuming 600 train journeys in both directions per year during peak hours, the proportion of an individual's journey to the total number of train operations during peak hours (which is 43,800 per year per direction) is 1.4%. The personal individual risk to a passenger is therefore very low.

The FN curves are shown in *Figure 11.11a* (in *Annex H of Volume 2 - Technical Annexes*) along with the criteria (not scaled to 2.3 km pipeline length but it is not significant). The results show that the FN curves for train and station passengers lie within the acceptable region while the FN curve for the existing population is in the lower ALARP region.

11.14 Conclusions and Recommendations

There are a number of gas pipelines (operating at various pressures, high, intermediate, medium) in proximity to the proposed MOS Extension and also crossing the railway alignment. This study has examined the interface between the HP gas pipeline and the railway alignment which poses the greatest hazard. The other lower pressure pipelines are considered to have acceptable risks with respect to the TM criteria. The hazards posed by the HP gas pipeline to the rail passengers and also the hazards posed by the construction and operation of the railway to the integrity of the pipeline have been examined.

It is recommended that the hazards due to proximity to other pipelines (intermediate, medium and low), particularly during construction be examined separately during the detailed design stage. Also, there are a number of crossings where pipelines may have to be relocated. KCRC will liaise closely with HKCG on issues of potential conflicts with the gas pipelines. Mitigation measures include diversion of the pipelines

which will be agreed with HKCG in due course. .About 2.3 km of the HP gas pipeline is in close proximity to the railway (mostly at a distance of 15 to 25 m) including a crossing of the railway alignment. At the pipeline crossing the railway will be on viaduct, however, for the rest of the section in close proximity to the gas pipeline, the railway will be at grade. The HP pipeline is also close to the Chevalier Garden station but no residential development is currently proposed at this station.

The analysis is based on the presumption that the HP gas pipeline at the crossing does not interfere with the viaduct foundations. If such interference is unavoidable, then the pipeline will have to be relocated It is expected that HKCG will adopt necessary safety measures for relocation.

The hazards posed by the presence of railway (during its operational phase) to the gas pipeline are not expected to be significant and meet the risk criteria of the EIAO TM as illustrated in Figure 11.11a. However, necessary engineering measures should be adopted to minimise stray current and vibration effects on the pipeline.

The hazards posed by the construction of the railway could threaten the integrity of the pipeline. Suitable procedural and safety management measures should be developed to minimise such hazards in accordance with the guidelines issued by EMSD and HKCG. KCRC should co-ordinate closely with HKCG during the detailed design and construction process. The construction safety plan to be developed by KCR's contractor in accordance with KCR's safety management system should include a detailed assessment of the hazards due to various tasks during construction with respect to the pipeline and also the required controls to reduce risks. Following the application of this plan and associated measures the construction risks will conform to the acceptability criteria of the EIAO TM.

The risk posed to the rail passengers due to the proximity of the gas pipeline is found to be low and is 'acceptable', although the overall risks considering existing populations adjoining the pipeline is found to be in the lower ALARP region. The low level of risks to train passengers is due to:

- the presence factor (the probability of a train being in the vicinity of an incident is 15% during peak and 5% during off-peak while trains approaching the scene of an incident are expected to brake at a distance away from the incident); and
- a proximity factor (the gas pipeline is 15 m to 25 m away).

In order to minimise the potential for approaching trains reaching the scene of the incident, it is recommended to devise a procedure whereby incidents of gas leakage/fire are immediately reported to the train control centre (by the Fire Services Department or HKCG) rather than relying solely on the driver to take appropriate action based on his visual observation of the scene of the incident. Table 11.14a contains the various recommendations and their implementation schedule.

Table 11.14a: Recommendations and Implementation Schedule

Recommendation	Implementation Schedule
Identify hazards due to intermediate, medium and low pressure pipelines	Detail Design
Adopt necessary engineering measures to reduce the effect of stray current corrosion	Operational
Devise procedure for communication of a gas leak/fire to train control centre	Operational
Develop a construction safety plan in accordance with KCR's Safety Management Plan	Construction
Carry out a Task Risk Assessment to identify hazards associated with the various construction activities and the controls required to reduce them	Construction

It can be seen from the study that the risks due to the high pressure pipeline are acceptable for the railway. The risks due the medium and low pressure pipelines are not expected to exceed this level and will also be well within the acceptable limits. Also, as stated earlier in Section 11.8.1 the IP, MP and LP pipelines are permitted to be laid in urban areas in accordance with international design codes and is also the practice worldwide. Therefore, the cumulative risk due to the high, medium and low pressure pipelines during the construction and the operational phases will meet the risk acceptability criteria of the EIAO TM.

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